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Energy requirements of children and adolescents

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Abstract

Total energy expenditure (TEE) was calculated at 1–18 years of age from measurements with doubly labelled water (DLW) in 483 boys and 646 girls, and heart rate monitoring (HRM) in 318 boys and 162 girls. Studies on obese, underweight and stunted groups were not included. TEE of populations with different lifestyles was estimated by factorial calculations in 42 studies on time allocation involving 1982 boys and 1969 girls in developed industrialised countries, and 1236 boys and 1116 girls in developing countries. Quadratic polynomial models were best to predict TEE in boys ($\text{TEE(MJ day}^{-1}) = 1.298 + 0.265\,\text{kg} - 0.0011\,\text{kg}^2$, $r = 0.982$, SEE $= 0.518$) and girls ($\text{TEE(MJ day}^{-1}) = 1.102 + 0.273\,\text{kg} - 0.0019\,\text{kg}^2$, $r = 0.955$, SEE $= 0.650$). TEE at 1–2 years was reduced by 7% based on DLW measurements and TEE estimates of infants. Energy requirements (ER) were calculated adding 8.6 kJ (2 kcal) for each gram of weight gained during growth. Compared with the 1985 FAO/WHO/UNU values[1], ER were 18–20% lower from 1 to 7 years of age, 12% lower for boys and 5% lower for girls at 7–10 years, and 12% higher for either gender from 12 years onwards. Differences between industrialised and developing countries, the variance in DLW and HRM studies, and the standard error of the estimate (SEE) of the quadratic predictive equations, suggested that ER should be adjusted after 5 years of age by ±15% in populations with more or less physical activity than an average lifestyle. Physical activity recommendations must accompany dietary recommendations in order to maintain optimal health and reduce the risk of diseases associated with sedentary lifestyles.

Keywords
Energy requirements
Energy expenditure
Dietary energy
Children
Adolescents
Lifestyle
Physical activity
Growth
Predictive equations

Background

FAO, WHO and UNU convened an Expert Consultation in 1981[1] to revise and update the recommendations on dietary energy and protein made 10 years earlier by a Joint FAO/WHO *Ad Hoc* expert committee[2]. Prior to that, other international expert groups had made recommendations in 1950 and 1957[3,4]. Energy requirements (ER) published in the 1985 Joint FAO/WHO/UNU Report[1] have been the basis for nutrition research, dietary guidelines and food policy around the world. That report also gave the following principles and guidelines:

- The energy requirement of an individual or group of persons is the amount of dietary energy needed to maintain health, growth, and an appropriate level of physical activity.
- ‘Appropriate’ physical activity includes those activities that an individual must perform to survive in his/her social environment (occupational activities), and to pursue his/her physical, intellectual and social desires and well-being (discretionary activities). For children, this should allow the exploration of the surroundings and the interaction with other children and adults.
- Energy needs are determined by energy expenditure. Therefore, estimates of ER should be based on measurements of energy expenditure and, for children, an additional allowance for growth.
- Daily ER and dietary recommendations can be expressed as energy units per kg of body weight. For adults, the preferred method of expression is as multiples of basal metabolic rate (BMR) or expressed as multiples of basal metabolic rate (METs).
- Total energy expenditure (TEE) of population groups can be estimated as a multiple of the group’s mean BMR. In the absence of direct measurements, BMR can be calculated with mathematical equations derived from published metabolic data.

Very little information was available in 1981 on TEE of children. In addition, the paucity of information on the time allocated to different activities by children <10 years of age, and on the energy cost of such activities, did not allow reliable estimates of TEE to calculate energy needs. Consequently, estimates of ER for 1–10 year olds were based on the reported energy intakes of healthy, well nourished children, assuming that those intakes

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maintained energy balance and allowed adequate growth. These estimates were derived from a review of published dietary intake data involving about 6500 children, mostly from the more developed, industrialised, countries[5].

An additional allowance of 5% was included in dietary recommendations to permit performance of a desirable level of physical activity, based on: (1) a perceived secular trend towards sedentary lifestyles in developed countries, and (2) the assumption that energy intake modulates the physical activity, and consequently the energy expenditure, of 1–10-year-old children.

From 10 to 18 years, daily energy expenditure was estimated using theoretical factorial assumptions of time allocation and energy expended in five categories of activities (Table 1). Energy costs were calculated as METs, using BMR estimated from body weight applied to age- and sex-specific equations. The times allocated each day to those activities, averaged over a 12-month period, and their energy costs were based on the activity pattern of children and adolescents in industrialised countries, who attend school through age 18. Additional energy for growth was estimated as 21 kJ (5 kcal) per gram of expected weight gain. Estimates of ER calculated in this manner exceeded dietary energy intakes reported for 10–18-year-olds. The low intakes were interpreted as indication of an undesirable low level of physical activity in affluent countries. It was concluded that the proposed requirements would be adequate if physical activity increased to appropriate levels in those countries, and that they provided a margin of safety in developing countries where children and adolescents are more active.

After 2 years of age, requirements were calculated at 2- or 3-year intervals. That led to the saltatory pattern of requirements illustrated in Fig. 1. The big jump from 6 to 7 years of age is an artifact due to the combination and averaging of requirements for a 3-year period at ages 7–9. The next big jump is another artifact probably due to the change in methods to estimate requirements, from energy intake to factorial calculations.

Initial revision of the recommendations

In the years that followed more was learned about the energy expenditure of children and adolescents. In 1989,

Table 1 Estimates made in 1981 of the time allocated and energy cost of activities performed daily by children 10–18 years old[a]

	Time allocated[b] h day^{-1}	Energy cost, in METs	
		Boys	Girls
Sleep	9–8	1	1
Going to school	4–6	1.6	1.5
Light activity	4–7	1.6	1.5
Moderate activity	6.5–2.5	2.5	2.2
High activity	0.5	6.0	6.0

[a] Adapted from FAO, WHO 1985[1,17].
[b] Averaged through the whole year. Daily time allocation varies with age.

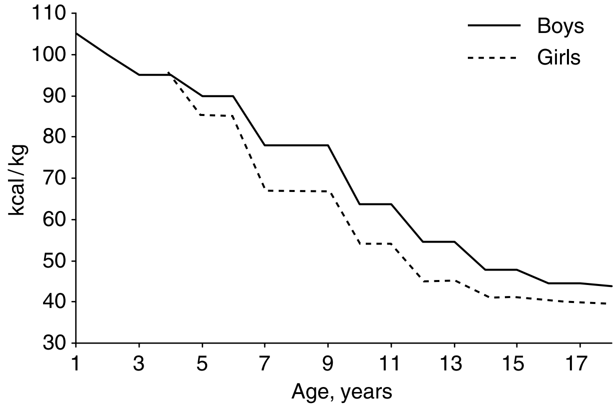

Fig. 1 Daily energy requirements, Joint FAO/WHO/UNU Expert Consultation, 1985[1]

the International Dietary Energy Consultancy Group (IDECG) organised a meeting to evaluate new data on activity and energy expenditure of infants and children, as a first attempt to base ER on measures of TEE[6]. The discussions included, among other issues, an analysis of TEE measured with the doubly labelled water (DLW) method in children[7], the estimation and validation of TEE measured by heart rate monitoring (HRM)[8], and the measurement and estimation of energy cost of activities in children[9].

The technology to measure energy expenditure in free-living individuals improved, and there was an increased awareness of the way that children and adolescents in different societies distribute their time to activities that demand different levels of energy expenditure. In 1994, IDECG organised a workshop to re-examine and update selected parts of the FAO/WHO/UNU 1985 report[1]. Among the 22 workshop participants, seven had been in the 1985 Expert Consultation. Four areas related to energy and three to proteins were identified as needing review: ER of infants; ER of children and adolescents; ER of pregnant and lactating women; ER of the elderly; protein requirements of infants and children; indispensable amino acid requirements of the adult; and protein requirements of the elderly. Scientists with expertise in those areas were asked to write position papers addressing them. The position papers were circulated among other experts in each particular area, and they were discussed at the workshop. The revised papers and the workshop conclusions and recommendations were published 14 months later[10].

Revision of requirements of children and adolescents

The position paper on ER of children and adolescents evaluated data on TEE using DLW, HRM, and time-motion or activity diary techniques, and on dietary energy intake of well-nourished boys and girls, 1–18-years-old[11]. Table 2 shows the total number of children involved and the countries where the studies were done. Estimates of

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Table 2 Data analysed in the position paper presented to IDECG on energy requirements of children 1–18 years old[a]

Studies on	No. of children	Age, years	Publication date
Total energy expenditure by doubly labelled water[b]	387	1–18	1988–1994
Total energy expenditure by heart rate monitoring[c]	316 (+74 stunted and 192 mildly underweight)	2–16	1981–1994
Total energy expenditure by time–motion/activity diary[d]	936 (+48 stunted)	1–18	1970–1991
Dietary energy intake[e]	37 123	1–18	1980–1994

[a] Torun *et al.*[11].
[b] The Netherlands, United Kingdom and the United States.
[c] Canada, Colombia, Guatemala, the Netherlands and the UK.
[d] Australia, Canada, the Gambia, Guatemala, the Philippines, Singapore and the UK.
[e] Studies in 16 industrialised and 10 developing countries.

requirements based on TEE and growth were compared with the energy intake data and the 1985 report.

The position paper included an analysis of the time allocated to energy-demanding activities by children and adolescents in urban and rural areas of developing countries, and how they differed from industrialised, more affluent societies. It also made some preliminary evaluations of the accuracy of the equations that had been recommended to calculate BMR[1,12], when applied to children and adolescents of different ethnic backgrounds.

Conclusions derived from those analyses included the following[11,13]:

- ER of children and adolescents should be estimated from measurements of energy expenditure and growth.
- Dietary intake data of population groups tend to overestimate ER of children under 8, and to underestimate requirements after 12 years of age.
- Differences in lifestyles related to socioeconomic and developmental characteristics supported making recommendations for dietary energy intake of children from 5 years onwards according to different levels of habitual physical activity, as was done for adults in 1985.
- Dietary energy recommendations for children must be accompanied by recommendations of physical activity compatible with the achievement and maintenance of health and the prevention of obesity.
- The DLW technique provided the best measurements of TEE of free-living individuals, and other methods should be validated more extensively in children against the DLW method.
- The database used by Schofield on BMR of children should be expanded, with the inclusion of data from children of different ethnic backgrounds.
- Recommendations for dietary energy intake should be consistent with the growth reference values being developed and endorsed by WHO.
- Dietary energy intake surveys are inappropriate to establish requirements, but can be used to estimate the adequacy of diets relative to requirements.

Forthcoming FAO/WHO/UNU Expert Consultation

In order to be acknowledged and accepted by governments and policy makers around the world, international dietary recommendations require approval and formal endorsement of the United Nations' agencies that have traditionally convened international bodies of experts and sanctioned their proposals, namely, FAO, WHO and, more recently, UNU. The discussions and conclusions of the IDECG workshop indicated that although more information might be needed in some specific areas, the time was ripe for a revision of the 1985 energy recommendations. Representatives of the three United Nations' agencies who participated in the discussions concurred that the outcome of the workshop would provide a good basis for a new joint consultation. This was approved 5 years later and it was decided to hold the new consultation in the year 2001.

Two major variants were introduced in comparison to the preceding joint expert consultation:

1. The metabolic interactions of energy and protein continue being recognised. However, there is now more knowledge about physiological functions, epidemiological characteristics and health consequences specifically associated with the intake of either dietary energy or proteins and amino acids. Consequently, two separate joint consultations on energy and proteins were organised.
2. Expert groups held preliminary meetings, where commissioned background papers were analysed critically. When necessary, the papers were modified or expanded prior to the definitive Expert Consultation.

Rationale for changes in the 1985 recommendations

The principle stated in 1981 and confirmed in 1994 that energy needs are determined by energy expenditure and growth has gone unchallenged for the past 20 years. Nevertheless, the 1981 Joint FAO/WHO/UNU Expert Consultation was unable to apply that principle to children under 10 years of age due to the paucity of information on energy expenditure. For the same reason, specific recommendations were not given for children and adolescents with different activity patterns. Since then, reliable information on TEE has become available, albeit mostly from affluent societies in North America and Western Europe. Knowledge about the energy demands

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imposed by lifestyle, permits making inferences on the needs of children and adolescents in other societies.

Studies on TEE published since the 1981 Consultation, consistently indicate that the energy needs of infants, preschoolers, young school-aged children and adolescents, differ from what was estimated twenty years ago. On the other hand, the rise in the incidence of childhood and adolescent obesity in parts of the world emphasises the importance of making recommendations from an early age for an appropriate balance between energy intake and expenditure. Thus, a re-evaluation of energy recommendations is timely, both from the intake and expenditure points of view.

Criteria to evaluate TEE and calculate ER

An extensive review was made of data published in the last three decades on energy expenditure, growth and activity patterns of free-living, healthy children and adolescents. Studies using DLW and HRM methods provided quantitative information on TEE. Studies using timed-motion observations and activity diaries (TM-AD) provided qualitative information about the activity patterns and habitual physical effort of children and adolescents in different countries and societies.

As many studies on TEE did not present results from individual children, the mean values given for boys or girls of a specific age or a reasonably narrow age range were used, and the variability within studies was evaluated. For analysis, data from different studies were pooled, weighting the results on the number of children in each study. The following criteria were applied for the selection and analysis of the studies included in this paper:

- Studies on children under 1 year of age were excluded, as these were the subject of a separate background paper[14].
- Energy recommendations for population groups are based on requirements of healthy individuals. This should include a reduced risk to present and future health. Consequently, studies on obese and undernourished children were excluded.
- By the same token, studies described as done with 'healthy, well-nourished children' were also excluded when the group's mean body weight was at or above +2 Z of the references endorsed by WHO for weight-for-age[15], or for age-adjusted body mass index[16,17]. Weight-for-age, rather than weight-for-height, was used as the exclusion criterion because many publications did not provide data on height.
- Stunted children with adequate weight-for-height represent a large segment of the population in the developing world. Studies on such children were analysed and presented separately.
- Although most studies did not describe the subjects' lifestyles, they were random or convenient samples recruited from the segment of society where the study was done. Studies on athletes were excluded from this analysis.
- Studies were excluded when it was not possible to separate data from boys and girls over 3 years of age. Results were maintained from studies in younger children because gender differences in energy expenditure and requirements are negligible among toddlers.
- Studies were excluded when they only presented the mean results of TEE for a broad age spectrum (e.g. 3–15 years).
- Care was taken to avoid including studies that presented TEE data from the same children more than once, albeit with different objectives (e.g. comparing in one paper TEE of different ethnic groups and in another paper comparing TEE with dietary energy intakes).
- Where the data permitted, energy expenditure was calculated for each year of age (1 to 1.9 + , 2 to 2.9 + , and so on). When only a mean age or a reasonably narrow age span was presented, energy expenditure was assumed to correspond to the mean age.
- Initially, TEE per unit of body weight was evaluated. When a paper did not express TEE in that manner, it was calculated from each child's TEE and weight. When individual data were not available, the group's mean values were used for calculations.
- Daily ER were calculated adding the energy content of tissue accretion during normal growth at each year of age, to the mean energy expenditure.
- For analysis and prediction of requirements, results from different studies were pooled, weighting the data on the number of children in each study.
- Body weight and age are the main determinants of energy expenditure of healthy individuals with a normal body composition. Since weight and age are highly correlated in childhood and adolescence, ER were calculated from regression analysis of TEE on weight, plus the corresponding allotment for growth. They were expressed as requirements per kg of body weight at each year of age, for healthy, well-nourished boys and girls.
- Experimental values of physical activity level (PAL) were calculated by the investigators or by the author of this paper, using experimental data of TEE, BMR and resting energy expenditure (REE). REE measured after an overnight fast was equated to BMR; otherwise, 11% was subtracted from the non-fasting REE to compensate for the thermogenic effect of food[18,19]. When a paper did not give individual data, the group's mean TEE, BMR and REE were used.
- Estimated values of PAL were calculated by the investigators or by the author of this paper, using the equations published by Schofield[12] to estimate BMR. When weights were not given for individual children, BMR was estimated from the mean group weight of the corresponding age and gender.

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Studies on TEE

Studies with DLW

The use of DLW ($^2H_2{}^{18}O$) to calculate total production of CO_2 over several days and, from it, TEE, was originally developed for use in small mammals[20], and its application was later validated in man[21–23]. Although questions have been raised about the appropriateness of the assumptions used for the calculation of energy expenditure[24], it is currently considered as the most accurate method for measuring TEE in free-living individuals. Results obtained with this technique were used as the starting point for revision of the 1985 energy requirements.

The studies included in this evaluation involved a total of 483 individual measurements on boys and 657 on girls (Tables 3 and 4). The data of 11 girls with a mean outlying value for TEE (see below) were excluded from analysis, and the number of individual measurements in girls was reduced to 646. One study was done in each of Brazil, Canada, Chile, Denmark, Guatemala, Mexico, the Netherlands and Sweden. The rest were done in the United Kingdom or the United States of America. Some of the latter studies involved Caucasian-American, African-American and native-American children.

Correlation of energy expenditure and age

Initially, the association of TEE kg^{-1} per day and age was explored, and a good linear correlation was found (Fig. 2). One outlying result with a residual value of −3.02 standard deviations was identified among those shown in Table 4, corresponding to a group of 11 girls, 9.5 years old,

Table 3 Boys – Total daily energy expenditure estimated by doubly labelled water method (does not include energy retained for growth)

Age (years)					Total energy expenditure								PAL			
			Weight		MJ day^{-1}		kcal day^{-1}		kJ kg^{-1} per day		kcal kg^{-1} per day		BMR	Math		
Mean or Range	SD	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	Mean	Country	Reference
1–1.9		8[a]	11.2		3.889		929		347	38	83.0	9.0		1.48	UK	Prentice *et al.*[64]
1.5–2		26	11.9	1.2	3.995	0.540	955	129	335	40	80.1	10.0	1.38	1.41	USA	Butte *et al.*[38]
1.5–2.4		11	12.7	1.4	4.497	1.276	1075	305	359	108	85.8	26.0		1.49	UK	Davies *et al.*[65]
2–2.9		6[a]	13.3		4.506		1077		339	42	81.0	10.0		1.43	UK	Prentice *et al.*[64]
3		13	15.5		5.410	0.660	1293	158	351	48	83.9	11.5		1.52	UK	Davies *et al.*[66]
2.5–3.4		15	15.0	1.7	5.050	0.757	1207	181	341	63	81.5	15.2		1.43	UK	Davies *et al.*[65]
3.5–4.4		16	16.9	2.3	5.443	0.882	1301	211	327	61	78.2	14.5		1.47	UK	Davies *et al.*[65]
4.2	0.9	14	17.6	1.3	6.190	0.820	1479	196	352	40	84.0	9.6		1.63	Chile	Salazar *et al.*[67]
4.2–6.9		22	19.5	4.1	5.840	1.140	1396	272	299		71.6			1.47	USA	Kaskoun *et al.*[68]
5		12	18.9		6.880	0.750	1644	179	366	42	87.5	10.0		1.76	UK	Davies *et al.*[66]
5.1	0.8	8	19.1	3.4	5.795	0.920	1385	220	308	52	73.6	12.4	1.41	1.48	Guate	Wren *et al.*[62,b]
5.3	0.9	11	21.3	4.7	6.590	1.268	1575	303	309		73.9		1.34	1.59	USA	Goran *et al.*[25]
5.3	0.8	25	20.1	3.8	5.782	1.067	1382	255	288		68.8		1.27	1.44	US–Can	Goran *et al.*[69]
5.4	0.3	15	21.1	3.9	5.920	1.054	1415	252	281		67.1		1.36	1.44	USA	Fontvieille *et al.*[70]
5.5	0.7	10	21.3	3.9	6.297	0.523	1505	125	296		70.7		1.37	1.52	US–Can	Goran *et al.*[69]
6.4	0.9	11	25.2	6.6	7.548	2.569	1804	614	300		71.6		1.42	1.68	USA	Goran *et al.*[25]
7		6	25.4	6.6	7.977	1.866	1907	446	314		75.1		1.69	1.76	UK	Livingstone *et al.*[32]
7		10	24.6		8.150	1.640	1948	392	333	38	79.6	9.1		1.82	UK	Davies *et al.*[66]
7.7	2.4	12	28.5	7.5	7.828	1.087	1871	260	275		65.6		1.44	1.62	USA	Trowbridge *et al.*[71]
6–10		10	26.9	7.5	6.600	1.500	1577	359	245		58.6		1.38	1.41	Mexico	Valencia *et al.*[72]
6–10		10	27.2	7.6	7.490	1.550	1790	370	275		65.8		1.54	1.60	Mexico	Valencia *et al.*[72]
8.3	1.6	21	29.3	7.2	7.130	1.381	1704	330	243		58.2		1.37	1.46	USA	Sun *et al.*[73]
9		14	29.5		8.950	1.210	2139	289	309	51	73.9	12.2		1.84	UK	Davies *et al.*[66]
9		5	30.2	9.4	9.766	1.098	2334	262	323		77.3		2.05	1.96	UK	Livingstone *et al.*[32]
9.1	0.3	15	33.0	5.7	8.878	1.151	2122	275	273	38	65.3	9.1	1.71	1.70	Denmark	Ekelund *et al.*[74]
9.3	1	11	37.8	12.0	8.678	1.770	2074	423	230		54.9		1.65	1.52	USA	Goran *et al.*[25]
9.3	1.4	9	30.9	4.3	9.000		2151		291		69.6		1.77	1.78	Holland	Saris *et al.*[75]
10.1	1.6	14	32.0	5.2	9.029	1.377	2158	329	282		67.4		1.73	1.75	Brazil	Hoffman *et al.*[63]
10.3	0.7	15	36.8		10.661		2548		290		69.2			1.95	USA	Champagne *et al.*[76]
10.6	0.3	18	35.3	8.5	8.912	2.432	2130	581	252		60.3		1.69	1.66	USA	Roemmich *et al.*[77]
12		5	43.8	7.3	10.692	0.811	2555	194	244		58.3		1.70	1.78	UK	Livingstone *et al.*[32]
12		8	39.7		10.480	1.470	2505	351	246	41	58.8	9.8		1.76	UK	Davies *et al.*[66]
14.5	1.5	14	56.4	10.2	13.008	2.117	3109	506	231		55.1		1.78	1.88	USA	Bandini *et al.*[78]
14.6	0.4	11	54.5	8.6	11.284	2.817	2697	673	207		49.5		1.66	1.66	USA	Roemmich *et al.*[77]
15		25	61.3	8.5	14.070	2.330	3363	557	230		54.9		1.92	1.93	Sweden	Bratteby *et al.*[58]
15		3	50.7	6.4	10.973	0.759	2623	181	216		51.7		1.62	1.69	UK	Livingstone *et al.*[32]
15		12	60.1		13.470	3.030	3219	724	225	32	53.8	7.6		1.85	UK	Davies *et al.*[66]
18		12	71.6		15.050	2.880	3597	688	201	18	48.0	4.3		2.01	UK	Davies *et al.*[66]

Transcribed or calculated from publications in the 'Reference' column.
PAL BMR: physical activity level calculated using BMR, fasting or adjusted non-fasting resting energy expenditure (see text).
PAL math: physical activity level calculated with Schofield *et al.*'s equations for sex, age and weight[12].
[a] Assuming that half the children studied were boys.
[b] Original data provided by Wren *et al.*[62].

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Table 4 Girls – Total daily energy expenditure estimated by doubly labelled water method (does not include energy retained for growth)

Age (years)					Total energy expenditure								PAL			
			Weight		MJ day^{-1}		kcal day^{-1}		kJ kg^{-1} per day		kcal kg^{-1} per day		BMR	Math		
Mean or Range	SD	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	Mean	Country	Reference
1–1.9		8[a]	11.2		3.889		929		347	38	83.0	9.0		1.48	UK	Prentice *et al.*[64]
1.5–2		41	11.5	1.2	3.780	0.690	903	165	330	50	78.9	12.0	1.35	1.41	USA	Butte *et al.*[38]
1.5–2.4		12	13.0	1.9	4.443	0.887	1062	212	347	81	83.0	19.5		1.46	UK	Davies *et al.*[65]
2–2.9		6[a]	13.3		4.506		1077		339	42	81.0	10.0		1.43	UK	Prentice *et al.*[64]
3		18	14.8		4.760	0.570	1138	136	325	43	77.7	10.3		1.44	UK	Davies *et al.*[66]
2.5–3.4		16	14.9	1.1	4.707	0.882	1125	211	317	63	75.8	15.0		1.43	UK	Davies *et al.*[65]
3.5–4.4		11	17.1	1.9	5.288	0.996	1264	238	310	46	74.2	11.0		1.52	UK	Davies *et al.*[65]
4.6	0.9	14	17.6	1.8	5.734	0.536	1370	128	328	33	78.4	7.8		1.63	Chile	Salazar *et al.*[67]
4.2–6.9		23	20.7	4.1	5.630	1.240	1346	296	272		65.0			1.48	USA	Kaskoun *et al.*[68]
5		16	18.5		6.180	1.033	1477	247	333	44	79.6	10.5		1.73	UK	Davies *et al.*[66]
5.1	0.9	26	20.1	3.5	5.247	1.138	1254	272	261		62.4		1.47	1.40	US–Can	Goran *et al.*[69]
5.4	0.8	17	19.8	3.2	5.786	0.866	1383	207	292		69.8		1.56	1.56	US–Can	Goran *et al.*[69]
5.4	0.6	8	18.5	1.4	5.217	1.096	1247	262	282	54	67.4	12.9	1.33	1.45	Guatema	Wren *et al.*[62,b]
5.5	0.9	11	21.5	5.3	5.711	1.381	1365	330	266		63.5		1.40	1.48	USA	Goran *et al.*[25]
5.5	0.4	13	18.9	2.5	5.636	0.770	1347	184	298		71.3		1.40	1.55	USA	Fontvieille *et al.*[70]
6.6	0.9	11	24.8	6.7	7.594	1.640	1815	392	306		73.2		1.58	1.62	USA	Goran *et al.*[25]
7		5	23.5	2.5	7.144	0.631	1707	151	304		72.7		1.64	1.77	UK	Livingstone *et al.*[32]
7		15	26.0		8.170	1.470	1953	351	320	74	76.5	17.7		1.92	UK	Davies *et al.*[66]
8.1	1.3	10	28.2	2.6	8.058		1926		286		68.3		1.69	1.82	Holland	Saris *et al.*[75]
8.2	1	12	28.5	3.5	6.586	0.912	1574	218	231		55.2		1.46	1.48	USA	Treuth *et al.*[79]
8–9		29	27.2	3.6	7.138	1.159	1706	277	262		62.7		1.59	1.64	USA	Treuth *et al.*[80]
8–9		43	28.0	4.6	7.376	1.280	1763	306	263		63.0		1.63	1.67	USA	Treuth *et al.*[80]
8–9		25	29.6	4.6	7.519	1.310	1797	313	254		60.7		1.61	1.65	USA	Treuth *et al.*[80]
9		4	33.4	3.8	8.135	0.760	1944	182	244		58.2		1.84	1.67	UK	Livingstone *et al.*[32]
9		15	29.1		7.569	1.270	1809	304	261	44	62.4	10.5		1.65	UK	Davies *et al.*[66]
9.1	0.3	11	37.0	5.0	8.255	0.828	1973	198	227	34	54.2	8.2	1.61	1.61	Denmark	Ekelund *et al.*[74]
9.5	0.9	11	38.0	11.4	6.728*	1.188	1608*	284	177*		42.3*		1.57	1.44*	USA	Goran *et al.*[25]
10.0	1.3	14	30.9	6.2	8.079	1.500	1931	359	261		62.5		1.73	1.73	Brazil	Hoffman *et al.*[63]
10.3	0.7	15	28.9		8.276		1978		286		68.4			1.84	USA	Champagne *et al.*[76]
10.6	0.4	12	36.6	8.7	8.071	2.696	1929	644	221		52.7		1.58	1.57	USA	Roemmich *et al.*[77]
12		5	45.1	4.7	9.888	1.062	2363	254	219		52.4		1.69	1.82	UK	Livingstone *et al.*[32]
12		10	49.3		10.530	1.890	2517	452	218	33	52.1	7.9		1.75	UK	Davies *et al.*[66]
13.2	1.8	9	43.3	8.9	9.711	1.176	2321	281	224		53.6			1.82	USA	Wong[81]
13.4	1.7	41	57.5	13.9	10.075	3.021	2408	722	175		41.9			1.65	USA	Wong *et al.*[82]
13.6	1.7	40	53.2	10.6	11.791	3.017	2818	721	222		53.0			2.01	USA	Wong *et al.*[82]
13.7	0.3	18	51.8	8.5	9.665	2.237	2310	535	187		44.6		1.67	1.67	USA	Roemmich *et al.*[77]
14.3	1	12	55.7	9.4	9.979	1.866	2385	446	179		42.8		1.66	1.66	USA	Bandini *et al.*[78]
15		25	58.4	7.8	10.660	1.640	2548	392	183		43.6		1.79	1.73	Sweden	Bratteby *et al.*[58]
15		3	55.4	13.2	9.573	2.816	2288	673	173		41.3		1.86	1.60	UK	Livingstone *et al.*[32]
15		11	58.0		10.120	1.650	2419	394	177	25	42.3	6.0		1.68	UK	Davies *et al.*[66]
18		11	62.4		11.090	1.870	2651	447	170	32	40.6	7.6		1.88	UK	Davies *et al.*[66]

Transcribed or calculated from publications in the 'Reference' column.
PAL BMR: physical activity level calculated using BMR, fasting or adjusted non–fasting resting energy expenditure.
PAL math: physical activity level calculated with Schofield *et al.*'s equations for sex, age and weight[12].
[a] Assuming that half the children studied were boys.
[b] Original data provided by Wren *et al.*[62].
*Outlying values.

with a mean TEE of 177 kJ (42.3 kcal)kg^{-1} per day[25]. Excluding the outlier and weighting the mean data points on the number of children in each study, the regression equations of TEE kg^{-1} on age were:

$$\text{Boys: TEE (kJ kg}^{-1}\text{ per day)} = 360 - 9.23\text{ years}$$

$$n_{\text{weighted}} = 483,\ r = 0.873,\ r^2 = 0.762$$

$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 86.0 - 2.21\text{ years}$$

$$\text{SEE} = 22\text{ kJ (5.2 kcal)kg}^{-1}\text{ per day}$$

$$\text{Girls: TEE (kJ kg}^{-1}\text{ per day)} = 356 - 11.41\text{ years}$$

$$n_{\text{weighted}} = 646,\ r = 0.925,\ r^2 = 0.855$$

$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 85.2 - 2.73\text{ years}$$

$$\text{SEE} = 20\text{ kJ (4.8 kcal)kg}^{-1}\text{ per day}$$

Variability within studies and age groups

The coefficients of variation (CV) within studies were calculated from the mean and standard deviations of studies with 10 or more children of a given age and

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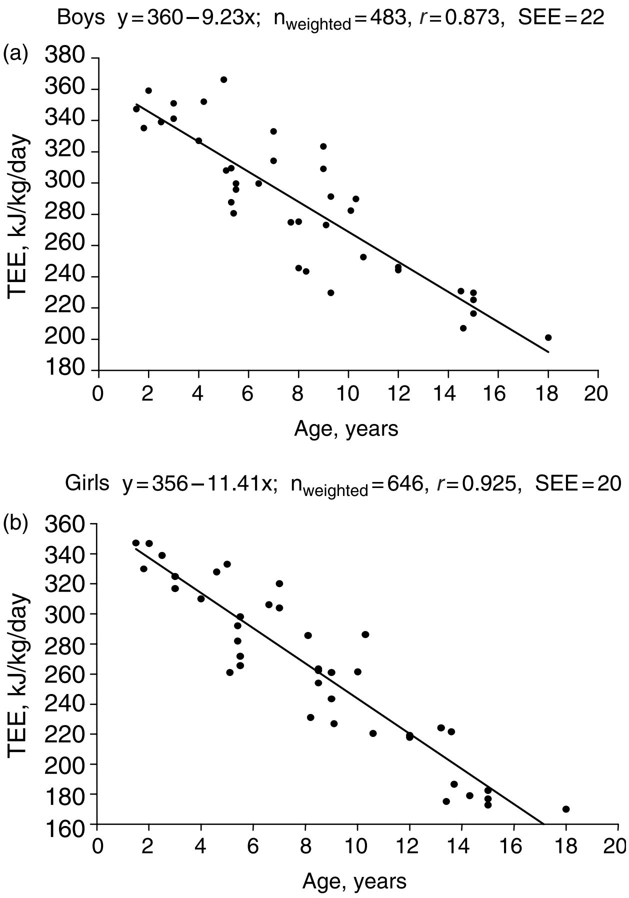

Fig. 2 Total energy expenditure per unit of body weight, measured with doubly labelled water

gender (Tables 3 and 4). The CVs of 59 mean values of total daily energy expenditure (i.e. TEE day^{-1}) ranged from 9.3 to 34.0%, with an approximate average of 19.1% (calculated as the square root of the sum of CV^2/n). The CVs of 28 mean values of energy expenditure per unit of body weight (i.e. TEE kg^{-1} per day) ranged from 9.0 to 23.3%, with an approximate average of 15.1%. There was no association between the magnitude of the CV and the children's age or gender.

Studies with HRM

The HRM method is based on the relationship that exists between heart rate and oxygen consumption[26]. In addition to monitoring the heart rate throughout the day, two other elements are necessary to calculate TEE: the individual calibration of each person's heart rate-oxygen consumption relationship, and the measurement or reliable estimate of energy expenditure under basal or sleeping conditions. The method has been applied to measure total daily energy expenditure in children and adults since the early 1970s[27,28], and the development of small instruments that record minute-by-minute heart rates for long periods of time has improved its applicability. The accuracy of HRM to measure TEE has been validated with whole body calorimetry and DLW. Comparisons varied on an individual basis, but the mean values for TEE at group level were similar to those obtained with the other methods[29–37].

Correlation of energy expenditure and age

The studies with HRM listed in Table 5 involved a total of 323 individual measurements on boys and 167 on girls from Canada, Colombia, Guatemala, Italy, the Netherlands, Sweden and the UK. They showed a good linear correlation between TEE kg^{-1} per day and age. One study on five boys and five girls, 8.4 years old[33], had studentised residual values of +4.96 (boys) and +4.32 (girls). They were excluded from further analysis, reducing the number of individual measurements to 318 boys and 162 girls. The linear regression equations with the remaining data points weighted on the number of children in each study were:

$$\text{Boys: TEE (kJ kg}^{-1}\text{ per day)} = 362 - 9.47\text{ years}$$
$$n_{weighted} = 318,\ r = 0.888,\ r^2 = 0.789$$
$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 86.5 - 2.25\text{ years}$$
$$\text{SEE} = 13\text{ kJ (3.1 kcal)kg}^{-1}\text{ per day}$$

$$\text{Girls: TEE (kJ kg}^{-1}\text{ per day)} = 337 - 10.94\text{ years}$$
$$n_{weighted} = 162,\ r = 0.962,\ r^2 = 0.925$$
$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 80.3 - 2.59\text{ years}$$
$$\text{SEE} = 10\text{ kJ (2.3 kcal)kg}^{-1}\text{ per day}$$

The standard error of the estimate (SEE) was lower than with studies using DLW. This may be due to the smaller age span (6.6–15.6 years) covered by the studies with HRM.

Variability within studies and age groups

The CV within studies were calculated as described for the DLW method. The CVs of 19 mean values of TEE day^{-1} in Table 5 ranged from 9.2 to 26.8%, with an average of 19.6%. The CVs of 14 mean values of TEE kg^{-1} per day ranged from 11.9 to 25.3%, with an average of 20.5%.

Combination of studies with DLW and HRM

Figure 3 illustrates the consistency in the association of age and TEE kg^{-1} per day, whether measured with DLW or HRM. The linear regression equations using the data

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Table 5 Total daily energy expenditure estimated by heart rate monitoring (does not include energy retained for growth)

Age (years)					Total energy expenditure								PAL			
			Weight		MJ day^{-1}		kcal day^{-1}		kJ kg^{-1} per day		kcal kg^{-1} per day		BMR	Math		
Mean or Range	SD	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	Mean	Country	Reference
Boys																
6.8	0.5	24	21.9	1.6	6.615	1.565	1581	374	303	70	72.3	16.8	1.60	1.58	Colombia	Spurr & Reina[61]
7	0.5	12	21.8	1.4	6.448	1.067	1541	255	294	35	70.2	8.4		1.54	Colombia	Spurr, *et al.*[83]
7.5	0.3	6	25.4	6.6	7.772	1.620	1858	387	306		73.1		1.65	1.72	UK	Livingstone *et al.*[32]
8.4		5	27.8		10.100*	1.648	2414*	394	363*	59	86.8*	14.2		2.13*	Holland	Emons *et al.*[33]
9.3	0.2	5	30.2	9.4	8.858	0.762	2117	182	293		70.1		1.86	1.78	UK	Livingstone *et al.*[32]
9.4	0.5	6	30.4	4.8	8.710	1.220	2082	292	287		68.5			1.74	Italy	Maffeis *et al.*[84]
9.4	1	11	32.1	4.4	9.054	0.833	2164	199	278	41	66.4	9.8	1.86	1.75	Canada	Spady[85]
9.7	0.3	70	34.9		9.047	0.920	2162	220	259		61.9		1.71	1.67	UK	Brown *et al.*[86]
10.8	0.5	34	33.3	2.8	8.581	1.674	2051	400	258	54	61.7	13.0	1.75	1.64	Guatemala	Ramirez & Torun[87]
11	0.6	20	32.4	3.3	9.242	1.753	2209	419	285	53	68.1	12.7		1.79	Colombia	Spurr, *et al.*[83]
11.1	0.6	14	33.1	2.3	8.406	1.761	2009	421	254	53	60.7	12.7	1.67	1.62	Colombia	Spurr & Reina[88]
11.2	0.5	18	33.3	2.5	8.452	2.268	2020	542	253	64	60.5	15.2	1.74	1.62	Colombia	Spurr & Reina[61]
12.7	0.3	5	43.8	7.3	10.970	1.316	2622	315	250		59.9		1.74	1.83	UK	Livingstone *et al.*[32]
14.7	0.5	12	46.7	3.5	11.556	2.008	2762	480	244	38	58.4	9.0	1.84	1.86	Colombia	Spurr, *et al.*[83]
14.8	0.3	42	61.6	13.1	12.800	2.600	3059	621	208		49.7			1.74	Sweden	Ekelund *et al.*[37]
14.8	0.6	20	49.9	3.2	12.117	2.720	2896	650	244	60	58.4	14.4	1.94	1.88	Colombia	Spurr & Reina[61]
15	1	16	59.2	10.0	12.490	2.340	2985	559	213		50.9		1.61	1.75	Sweden	Ekelund *et al.*[59]
15.4	0.4	3	50.7	6.4	11.473	0.137	2742	33	226		54.1		1.69	1.76	UK	Livingstone *et al.*[32]
Girls																
6.6	0.5	21	21.4	1.1	5.799	1.272	1386	304	264	48	63.0	11.5	1.53	1.51	Colombia	Spurr & Reina[61]
7.8	0.3	5	23.5	2.5	6.724	1.085	1607	259	286		68.4		1.54	1.67	UK	Livingstone *et al.*[32]
8.4		5	28.3		8.699*	0.799	2079*	191	308*	28	73.5*	6.8		1.96*	Holland	Emons *et al.*[33]
9.1	0.3	6	29.7	2.8	7.560	1.400	1807	335	255		60.8			1.66	Italy	Maffeis *et al.*[84]
9.4	0.5	4	33.4	3.8	7.228	0.729	1727	174	216		51.7		1.63	1.48	UK	Livingstone *et al.*[32]
9.4	1.2	24	28.3	3.4	6.431	1.423	1537	340	231	57	55.2	13.6	1.43	1.45	Colombia	Spurr & Reina[89]
9.5	0.8	10	31.6	3.7	7.180	1.017	1716	243	231	49	55.1	11.6		1.52	Canada	Spady[85]
10.9	0.7	11	34.2	3.7	6.740	1.335	1611	319	196	37	46.8	8.9	1.45	1.40	Colombia	Spurr & Reina[61]
12.5	0.4	5	45.1	4.7	9.332	0.979	2230	234	207		49.5		1.59	1.72	UK	Livingstone *et al.*[32]
14.7	0.3	40	55.9	8.6	10.000	1.900	2390	454	179		42.8			1.67	Sweden	Ekelund *et al.*[37]
14.9	0.6	19	49.3	2.7	8.293	1.891	1982	452	174	40	41.7	9.6	1.61	1.47	Colombia	Spurr & Reina[61]
15	1	14	55.7	10.0	9.130	1.730	2182	413	168		40.2		1.58	1.53	Sweden	Ekelund *et al.*[59]
15.6	0.4	3	55.4	13.2	9.887	3.391	2363	810	178		42.7		1.92	1.65	UK	Livingstone *et al.*[32]

Transcribed or calculated from publication in the 'Reference' column.
PAL BMR: physical activity level calculated using BMR, fasting or adjusted non–fasting resting energy expenditure (see text).
PAL math: physical activity level calculated with Schofield *et al.*'s equations for sex, age and weight[12].
*Outlying values (see text).

obtained with either method were:

$$\text{Boys: TEE (kJ kg}^{-1}\text{ per day)} = 360 - 9.27\text{ years}$$

$$n_{\text{weighted}} = 801,\ r = 0.894,\ r^2 = 0.799$$

$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 86.0 - 2.21\text{ years}$$

$$\text{SEE} = 19\text{ kJ (4.5 kcal)kg}^{-1}\text{ per day}$$

$$\text{Girls: TEE (kJ kg}^{-1}\text{ per day)} = 357 - 11.77\text{ years}$$

$$n_{\text{weighted}} = 808,\ r = 0.934,\ r^2 = 0.872$$

$$\text{TEE (kcal kg}^{-1}\text{ per day)} = 85.3 - 2.81\text{ years}$$

$$\text{SEE} = 19\text{ kJ (4.6 kcal)kg}^{-1}\text{ per day}$$

These equations resembled closely those derived from DLW alone, with a slight improvement in regression coefficients and SEEs. The average CVs when energy expenditure was measured with either DLW or HRM on 10 or more children were 19.2% and 17.1% for TEE day^{-1} and TEE kg^{-1} per day, respectively.

Prediction of TEE

The validation of TEE measurements with HRM against DLW and whole body calorimetry, the similarities in the linear regression equations and inter-individual CVs, and the consistency of the association between TEE kg^{-1} per day and age, supported combining the studies listed in Tables 3–5 to predict total daily energy expenditure (TEE day^{-1}) and to calculate ER. Addition of the HRM data expanded the DLW database to encompass more studies in developing countries and in age groups where few studies existed with DLW.

Linear regression models

Simple and multiple regression models explored to predict total daily energy expenditure from weight and age gave the following linear equations:

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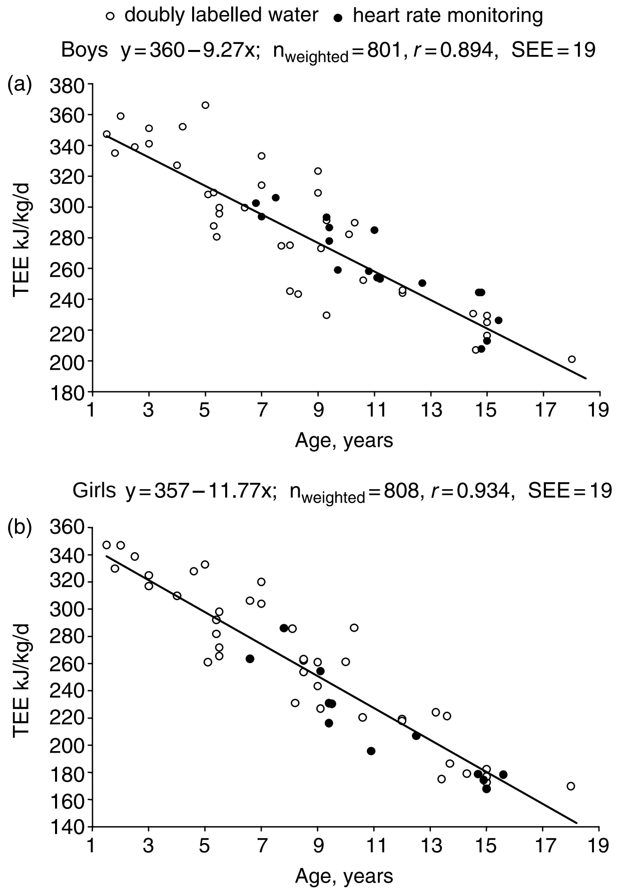

Fig. 3 Total energy expenditure per unit of body weight, measured with doubly labelled water or heart rate monitoring

Boys: ($n_{weighted} = 801$)

$$\text{TEE on weight MJ day}^{-1} = 2.710 + 0.178\,\text{kg}$$
$$r = 0.977,\ r^2 = 0.954,\ \text{SEE} = 0.584$$
$$\text{TEE on age MJ day}^{-1} = 2.667 + 0.652\,\text{years}$$
$$r = 0.965,\ r^2 = 0.931,\ \text{SEE} = 0.719$$
$$\text{TEE on weight and age MJ day}^{-1} = 2.585 + 0.118\,\text{kg} + 0.232\,\text{years},\ r = 0.982,\ r^2 = 0.964,\ \text{SEE} = 0.522$$

Girls: ($n_{weighted} = 808$)

$$\text{TEE on weight MJ day}^{-1} = 3.215 + 0.130\,\text{kg}$$
$$r = 0.941,\ r^2 = 0.885,\ \text{SEE} = 0.744$$
$$\text{TEE on age MJ day}^{-1} = 3.239 + 0.479\,\text{years}$$
$$r = 0.932,\ r^2 = 0.869,\ \text{SEE} = 0.794$$
$$\text{TEE on weight and age MJ day}^{-1} = 3.161 + 0.085\,\text{kg} + 0.173\,\text{years}\quad r = 0.945,\ r^2 = 0.892,\ \text{SEE} = 0.722$$

Multiple regression analysis showed that weight played a greater role than age in predicting TEE: the standardised regression coefficients for weight were 0.640 and 0.601 among boys and girls, respectively, whereas for age they were 0.352 and 0.348. Although the multiple regressions on weight and age resulted in the lowest SEE, the two independent variables were highly correlated with a tolerance of 0.078 among boys and 0.061 among girls.

When TEE was regressed on weight alone, the SEE was reduced by 23% among boys and 7% among girls, compared with regressions on age. However, there was a bias at the lower end of the weight range (Fig. 4), which resulted in an overestimation of TEE among the lighter, and therefore younger, children.

Quadratic regression model

When a quadratic polynomial model was used, the regression of TEE on weight did not show the bias observed with the linear models, and the SEE was reduced further by 13–14% among both boys and girls (Fig. 5). In addition, predictions of TEE with the quadratic equations resulted in a more coherent transition of ER between infancy and early childhood, and between late adolescence and adulthood[38,39].

The quadratic regression equations to predict TEE day^{-1} from body weight at ages 1–18 years were:

$$\text{Boys: TEE (MJ day}^{-1}) = 1.298 + 0.265\,\text{kg} - 0.0011\,\text{kg}^2;$$
$$n_w = 801,\ r = 0.982,\ r^2 = 0.964,\ \text{SEE} = 0.518$$
$$\text{TEE (kcal day}^{-1}) = 310.2 + 63.3\,\text{kg} - 0.263\,\text{kg}^2$$

$$\text{Girls: TEE (MJ day}^{-1}) = 1.102 + 0.273\,\text{kg} - 0.0019\,\text{kg}^2;$$
$$n_w = 808,\ r = 0.955,\ r^2 = 0.913,\ \text{SEE} = 0.650$$
$$\text{TEE (kcal day}^{-1}) = 263.4 + 65.3\,\text{kg} - 0.454\,\text{kg}^2$$

Internal validation of predictive quadratic equations

To validate the predictive equations and estimate the error of prediction of TEE, the studies in Tables 3–5 were randomly divided into model-building and validation sub-samples. In addition to the outliers, the study on twelve 18-year-old men was excluded, as their mean TEE (15.050 MJ day^{-1}, 3597 kcal day^{-1}) and PAL (2.01) were very high, and they were 10 kg heavier (mean weight: 71.6 kg) than any of the other study groups. Consequently, this single study at the upper end of the distribution might weigh too heavily on the predictive regression equations.

Model-building and validation sub-samples

Twenty-five percent of the 54 studies on boys and of the 52 studies on girls were randomly selected, stratifying them on body weight, method to measure TEE (DLW or HRM), and type of country (industrialised or developing). These 14 studies on boys and 13 on girls were designated as the 'validation sub-samples' to test the predictive

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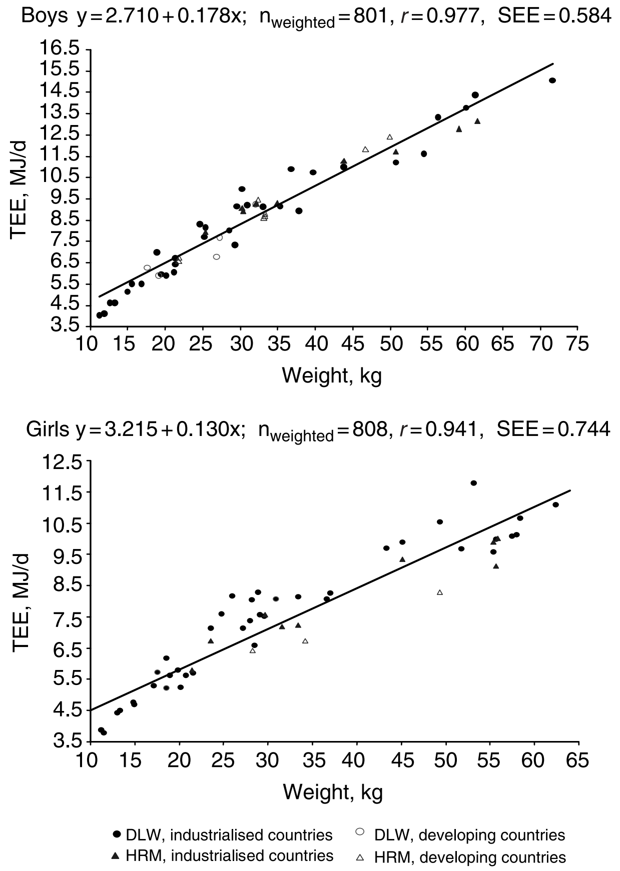

Fig. 4 Linear regression of total energy expenditure on body weight, weighting each data point by the number of children in each study

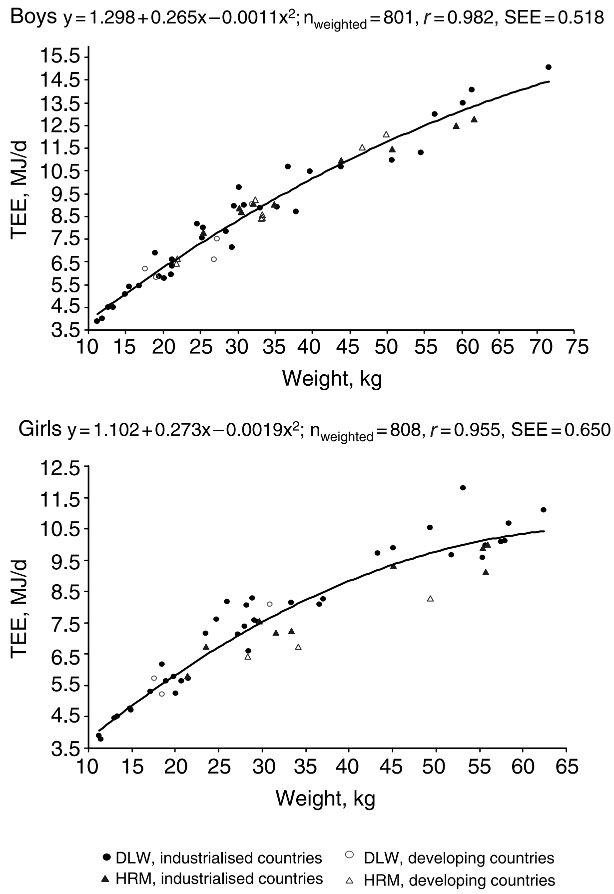

Fig. 5 Quadratic polynomial regression of total energy expenditure on body weight, weighting each data point by the number of children in each study

equations derived from the remaining 40 or 39 studies for each gender ('model-building sub-samples').

The procedure followed for stratification of the validation sub-samples:

Within each gender, the studies on children < 3 years old – all of which had been done with DLW in industrialised countries – were placed in a category, and the remaining 50 studies were divided in quartiles of body weight. The latter were further stratified according to the method used to measure TEE and the type of country where the study was done. One or two studies were selected randomly in each stratum, as shown in Table 6. The random selection of the validation and model-building sub-samples was repeated twice, in order to repeat the procedure and assess twice the validity of the regression equations when a smaller number of studies ($n = 39$ or 40) than in the original analysis was used to calculate such equations. Tables 7 and 8 show the studies in the validation sub-samples for the 'First' and 'Second' validation trials.

Analysis

Data from the studies in the model-building sub-samples were weighted on the number of children in each study, and TEE day^{-1} was regressed on weight. As in the original analysis, the best predictive models based on high

Table 6 Random selection of validation samples, stratified on body weight, method to measure TEE and type of country

Gender	Weight, kg	Method	Country	Studies selected
Boys	11.2–13.3 (< 3 years)	DLW	Industrialised	1 of 4
	15.0–21.9	DLW	Industrialised	1 of 9
		DLW	Developing	1 of 2
		HRM	Developing	1 of 2
	24.6–30.4	DLW	Industrialised	1 of 7
		DLW	Developing	1 of 2
		HRM	Industrialised	1 of 3
	30.9–37.8	DLW	Industrialised	1 of 5
		HRM	Industrialised	1 of 2
		HRM	Developing	1 of 4
	39.7–61.6	DLW	Industrialised	2 of 7
		HRM	Industrialised	1 of 4
		HRM	Developing	1 of 2
Girls	11.2–13.3 (< 3 years)	DLW	Industrialised	1 of 4
	14.8–21.5	DLW	Industrialised	2 of 9
		DLW	Developing	1 of 2
	23.5–29.1	DLW	Industrialised	2 of 9
		HRM	Industrialised	1 of 2
		HRM	Developing	1 of 1
	29.6–45.1	DLW	Industrialised	1 of 6
		HRM	Industrialised	1 of 4
	49.3–62.4	DLW	Industrialised	2 of 9
		HRM	Industrialised	1 of 3

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correlation coefficients and the smallest SEE, were quadratic polynomial equations. The equations derived from the model-building sub-sample used in each validation trial were:

Boys (first validation trial): weighted $n = 549$

$$\text{MJ day}^{-1} = 0.627 + 0.308\,\text{kg} - 0.0017\,\text{kg}^2$$

$$r = 0.982,\ r^2 = 0.964,\ \text{SEE} = 0.504$$

Boys (second validation trial): weighted $n = 618$

$$\text{MJ day}^{-1} = 1.125 + 0.274\,\text{kg} - 0.0012\,\text{kg}^2$$

$$r = 0.981,\ r^2 = 0.962,\ \text{SEE} = 0.509$$

Girls (first validation trial): weighted $n = 617$

$$\text{MJ day}^{-1} = 0.874 + 0.284\,\text{kg} - 0.0020\,\text{kg}^2$$

$$r = 0.959,\ r^2 = 0.920,\ \text{SEE} = 0.651$$

Girls (second validation trial): weighted $n = 607$

$$\text{MJ day}^{-1} = 0.981 + 0.287\,\text{kg} - 0.0023\,\text{kg}^2$$

$$r = 0.967,\ r^2 = 0.936,\ \text{SEE} = 0.537$$

The mean differences between predicted and measured TEE in the validation sub-samples were $<1\%$ among boys, and within $\pm 3\%$ among girls. The standard deviation of the differences was about 6% among boys, and 9–10% among girls (Tables 7 and 8). This variability is within acceptable limits, and it could be due to differences in the habitual physical activity of the children involved in the various studies, and not necessarily to errors of prediction.

This internal validation reinforced the application of quadratic regression equations to predict TEE from body weight in 1–18-year-old boys and girls. The TEE was calculated from several papers published after the quadratic equations were derived. The predicted values coincided within 6%, with a mean TEE measured with DLW.

Energy needs for growth of children and adolescents

ER of children and adolescents are determined by their energy expenditure and the energy needs for growth. The latter consist of two components: (1) the energy deposited

Table 7 Boys – TEE measured in validation sub-samples and TEE predicted using quadratic regression equations of TEE on weight

Method	Country	*n*	Age Years	Weight kg	TEE measured MJ day^{-1}	TEE predicted MJ day^{-1}	Difference predicted – measured: MJ day^{-1}	Difference predicted – measured: % *
Boys – first validation trial								
DLW	Industrialised	6	2.5	13.3	4.506	4.423	−0.083	−1.8
DLW	Developing	14	4.2	17.6	6.180	5.521	−0.659	−10.7
DLW	Industrialised	12	5.0	18.9	6.880	5.841	−1.039	−15.1
HRM	Developing	12	7.0	21.8	6.448	6.533	0.085	1.3
DLW	Industrialised	10	7.0	24.6	8.150	7.175	−0.975	−12.0
HRM	Industrialised	6	7.5	25.4	7.772	7.353	−0.419	−5.4
DLW	Developing	10	8.0	27.2	7.490	7.747	0.257	3.4
HRM	Industrialised	70	9.7	34.9	9.047	9.306	0.259	2.9
DLW	Industrialised	18	10.6	35.3	8.912	9.381	0.469	5.3
HRM	Developing	18	11.2	33.3	8.452	8.998	0.546	6.5
HRM	Developing	20	14.8	49.9	12.117	11.763	−0.354	−2.9
DLW	Industrialised	3	15.0	50.7	10.973	11.873	0.900	8.2
HRM	Industrialised	16	15.0	59.2	12.490	12.903	0.413	3.3
DLW	Industrialised	25	15.0	61.3	14.070	13.119	−0.951	−6.8
				mean (weighted on n):	*9.372*	*9.305*	*−0.067*	*−0.8*
				SD (weighted on n):	*2.437*	*2.408*	*0.555*	*6.3*
Boys – second validation trial								
DLW	Industrialised	11	2.0	12.7	4.497	4.411	−0.086	−1.9
DLW	Industrialised	13	3.0	15.5	5.410	5.084	−0.326	−6.0
DLW	Developing	8	5.1	19.1	5.795	5.921	0.126	2.2
HRM	Developing	24	6.8	21.9	6.615	6.550	−0.065	−1.0
HRM	Industrialised	6	7.5	25.4	7.772	7.310	−0.462	−5.9
DLW	Developing	10	8.0	26.9	6.600	7.627	1.027	15.6
DLW	Industrialised	14	9.0	29.5	8.950	8.164	−0.786	−8.8
DLW	Industrialised	9	9.3	30.9	9.000	8.446	−0.554	−6.2
HRM	Industrialised	11	9.4	32.1	9.054	8.684	−0.370	−4.1
HRM	Developing	14	11.1	33.1	8.406	8.880	0.474	5.6
DLW	Industrialised	11	14.6	54.5	11.284	12.494	1.210	10.7
HRM	Developing	12	14.7	46.7	11.556	11.304	−0.252	−2.2
DLW	Industrialised	12	15.0	60.1	13.470	13.258	−0.212	−1.6
HRM	Industrialised	16	15.0	59.2	12.490	13.140	0.650	5.2
				mean (weighted on n):	*8.687*	*8.724*	*0.038*	*0.2*
				SD (weighted on n):	*2.695*	*2.847*	*0.561*	*6.4*

*((TEE predicted − TEE measured)/TEE measured) × 100.

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Table 8 Girls – TEE measured in validation sub-samples and TEE predicted using quadratic regression equations of TEE on weight

Method	Country	*n*	Age years	Weight kg	TEE measured MJ day^{-1}	TEE predicted MJ day^{-1}	Difference predicted – measured MJ day^{-1}	Difference predicted – measured % *
Girls – first validation trial								
DLW	Industrialised	6	2.5	13.3	4.506	4.297	−0.209	−4.6
DLW	Developing	14	4.6	17.6	5.770	5.253	−0.517	−9.0
DLW	Industrialised	16	5.0	18.5	6.180	5.444	−0.737	−11.9
DLW	Industrialised	17	5.4	19.8	5.786	5.713	−0.073	−1.3
DLW	Industrialised	11	6.6	24.8	7.594	6.687	−0.907	−11.9
HRM	Industrialised	5	7.8	23.5	6.724	6.444	−0.281	−4.2
DLW	Industrialised	12	8.2	28.5	6.586	7.344	0.757	11.5
HRM	Industrialised	4	9.4	33.4	7.228	8.128	0.900	12.5
HRM	Developing	24	9.4	28.3	6.431	7.309	0.878	13.7
DLW	Industrialised	9	13.2	43.3	9.711	9.421	−0.290	−3.0
DLW	Industrialised	41	13.4	57.5	10.075	10.592	0.516	5.1
DLW	Industrialised	18	13.7	51.8	9.665	10.219	0.554	5.7
HRM	Industrialised	14	15.0	55.7	9.130	10.488	1.358	14.9
				mean (weighted on n):	*7.784*	*8.038*	*0.253*	*2.6*
				SD (weighted on n):	*1.830*	*2.174*	*0.655*	*9.0*
Girls – second validation trial								
DLW	Industrialised	12	2.0	13.0	4.443	4.323	−0.120	−2.7
DLW	Developing	8	5.4	18.5	5.217	5.503	0.286	5.5
DLW	Industrialised	13	5.5	18.9	5.636	5.584	−0.052	−0.9
DLW	Industrialised	23	5.5	20.7	5.630	5.936	0.306	5.4
DLW	Industrialised	29	8.5	27.2	7.138	7.086	−0.052	−0.7
DLW	Industrialised	25	8.5	29.6	7.519	7.461	−0.058	−0.8
HRM	Industrialised	6	9.1	29.7	7.560	7.476	−0.084	−1.1
HRM	Industrialised	10	9.5	31.6	7.180	7.754	0.574	8.0
DLW	Industrialised	15	10.3	28.9	8.276	7.354	−0.922	−11.1
HRM	Developing	11	10.9	34.2	6.740	8.106	1.366	20.3
DLW	Industrialised	40	13.6	53.2	11.791	9.740	−2.051	−17.4
HRM	Industrialised	3	15.6	55.4	9.887	9.822	−0.065	−0.7
DLW	Industrialised	11	18.0	62.4	11.090	9.934	−1.156	−10.4
				mean (weighted on n):	*7.920*	*7.511*	*−0.409*	*−2.9*
				SD (weighted on n):	*2.377*	*1.637*	*0.958*	*9.8*

*((TEE predicted − TEE measured)/TEE measured) × 100.

in growing tissues, basically as fat and protein, since carbohydrate content is insignificant; and, (2) the energy expended to synthesize those tissues. In the 1985 factorial calculations, 21 kJ (5 kcal) per gram of weight gain was used as the energy cost of growth (synthesis + energy in tissues)[1]. That value was derived from studies on weight gain and energy intake or energy balance of infants recovering from malnutrition[40–44]. Other studies on recovering malnourished toddlers with mean ages ranging from 13 to 16 months gave slightly higher values, from about 21 to 28 kJ (5.1–6.6 kcal) per gram[45–47]. Several authors[48,49] have reviewed those studies. In general, the CV for the energy cost of growth ranged from 35 to 59%.

Table 9 shows the mean weight gains at each year of age, calculated from the WHO references of weight for age (WHO, 1983). TEE measured with DLW or HRM includes the energy cost of tissue synthesis. Therefore, only the energy deposited in growing tissues must be added to calculate ER. In a longitudinal study on well-nourished, healthy infants (26 boys, 41 girls), Butte and co-workers determined TEE, body composition and rate of weight gain at 3, 6, 9, 12, 18 and 24 months of age[38,50]. TEE was measured with DLW, and body composition was estimated from assessments of total body water, total body potassium and bone mineral content. Energy deposited in growing tissues was about 20% of total requirements in the first three months of age, and fell rapidly to < 2% in the second year[14,38,50]. On average, it was 10 kJ (2.4 kcal) per gram of weight gain from 3 to 24 months of age, with CV around 75% at 18 and 24 months. Adding 17 and 138% as the metabolic cost to synthesize fat and protein, respectively[51], the overall energy cost of growth at 1 and 2 years of age would be about 17 kJ (4.0 kcal) per gram of weight gain.

The composition of normal weight gain does not change much between the end of infancy and the onset of puberty. In early adolescence fat deposition increases among girls, and protein accretion increases among boys. However, since energy deposition during childhood and adolescence only represents about 1% of total energy requirements, it can be assumed that the composition of body mass gained during this time is relatively constant, consisting of about 10% fat with an energy content of 38.7 kJ (9.25 kcal) per gram, 20% protein with 23.6 kJ (5.65 kcal) per gram, and 70% water and minerals with negligible amounts of energy. Energy deposited in growing tissues would then be around 8.6 kJ (2 kcal) per gram of weight gain. Even if this amount were 50% higher

Table 9 Mean weight gain of boys and girls, 1–17 years old[a]

Age years	Weight gain, boys		Weight gain, girls	
	$kg\ year^{-1}$	$g\ day^{-1}$	$kg\ year^{-1}$	$g\ day^{-1}$
1–1.9	2.4	6.6	2.4	6.6
2–2.9	2.0	5.5	2.2	6.0
3–3.9	2.1	5.8	1.9	5.2
4–4.9	2.0	5.5	1.7	4.7
5–5.9	2.0	5.5	1.8	4.9
6–6.9	2.2	6.0	2.3	6.3
7–7.9	2.4	6.6	3.0	8.2
8–8.9	2.8	7.7	3.7	10.1
9–9.9	3.3	9.0	4.0	11.0
10–10.9	3.9	10.7	4.5	12.3
11–11.9	4.5	12.3	4.5	12.3
12–12.9	5.2	14.2	4.6	12.6
13–13.9	5.8	15.9	4.2	11.5
14–14.9	5.9	16.2	3.4	9.3
15–15.9	5.4	14.8	2.2	6.0
16–16.9	4.2	11.5	0.8	2.2
17–17 9	2.6	7.1	0	0

[a] Calculated from WHO references of weight by age[15].

or lower, the quantitative implications for assessment of total ER and recommended dietary intakes would be negligible.

Proposal for new daily ER

Table 10 shows the mean daily requirements (ER) of healthy, well-nourished children and adolescents with an 'average' or 'moderate' level of habitual physical activity. Calculations were based on TEE predicted with the quadratic equations from the median body weight at the midpoint of each year of age (i.e. at 1.5, 2.5,. . .17.5 years[15]). Energy deposition in growing tissues (E_g) was calculated as 8.6 kJ (2 kcal) per gram of daily weight gain[15], and added to TEE. The results were then divided by the median weight-for-age, in order to express ER per unit of body weight.

Requirements calculated in this manner for boys and girls 1–1.9 years old were, respectively, 370 and 360 $kJ\ kg^{-1}$ per day (88.4 and 86.0 $kcal\ kg^{-1}$ per day). These values were significantly higher than Butte's estimates for 12-month-old infants (338 and 332 $kJ\ kg^{-1}$ per day for boys and girls, respectively[14]). A closer look at the quadratic polynomial regressions (Fig. 5) showed a tendency to overestimate energy expenditure at the lower end of the weight distribution, which corresponded to infants between one and two years of age. The overestimation was, on average, about 7% compared with actual measurements of TEE (Tables 3 and 4). Therefore, the estimated requirements for 1–1.9 years were adjusted by that percentage, as shown in Table 10. This adjustment allowed avoiding a 'jump' in requirements between infancy and childhood.

BMR was estimated with Schofield's[12] equations, using the median weight for each year of age. Mean PAL was calculated dividing TEE by the estimated BMR. Daily requirements were also calculated as multiples of BMR (MET), dividing ER (i.e. TEE + E_g) by the estimated BMR.

It should be noted that when requirements are expressed as energy units per day or per kg body weight, they are higher for boys than girls at every year of age; but when expressed as multiples of BMR, they are similar for both genders up to 12.9 years. The relatively high mean PAL of boys 12 years and older are not mathematical artefacts of the predictive equations, but a reflection of the high activity level at those ages in most studies with DLW or HRM (Tables 3 and 5).

The new requirements are compared in Table 11 and Fig. 6 with those in the 1985 Joint FAO/WHO/UNU Report. The cross-over of the curves at about 10–11 years is most probably an artefact due to the different methods used in the 1981 Consultation to calculate requirements of children under and over 10 years old. At ages 1–6.9, requirements proposed in this paper are, on average, 18 and 20% lower for boys and girls, respectively. They are also 12% lower for boys and 5% lower for girls 7–9.9 years old. From age 12 onwards, the proposed requirements are 12% higher for both boys and girls. However, although the predictive quadratic polynomial equations tend to overestimate TEE at both ends of the body weight distribution, no corrections were made in the values calculated for older adolescents. Therefore, the energy requirements for 16–18 year olds shown in Tables 10 and 11 may differ by less than 12% from those in the 1985 report.

Adjustments for lifestyles with different levels of physical activity

There are marked differences in the habitual physical activity of children and adolescents who live in societies with different cultural and social characteristics. For example, while most children in industrialised societies and in affluent groups of developing countries go to school several hours each day, and do not have work obligations, many children in rural traditional societies of developing countries partake in domestic chores and in their community's labour force from an early age[52–54]. The 1985 FAO/WHO/UNU Expert Consultation proposed ER and dietary allowances for adults with three levels of occupational physical activity. Present knowledge of TEE, time allocated to activities in different societies, and the energy cost of such activities in different terrains and with different means of transportation allows suggesting a similar approach for children and adolescents.

Calculations of ER in the preceding sections were based on studies in industrialised countries and cities of developing countries. Subjects were random or convenient samples recruited from segments of society where the study was done, and groups of athletes were excluded from this analysis. In each study, there were individual children who were more or less active than others, and within-group coefficients of variability for TEE were as large as ±34%. Consequently, the proposed mean requirements are for children and adolescents with

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Table 10 Energy requirements calculated by quadratic regression analysis of total energy expenditure (TEE) on weight, plus allowance for energy deposition in tissues during growth (E_g)*

Age	Weight	TEE[a,b]		E_g[c]		BMR_{sc}[d]		PAL_{sc}[e]	Daily energy requirement				
years	kg	MJ day^{-1}	(kcal day^{-1})	MJ day^{-1}	(kcal day^{-1})	MJ day^{-1}	(kcal day^{-1})		MJ day^{-1}	(kcal day^{-1})	kJ kg^{-1}day^{-1}	(kcal kg^{-1}day^{-1})	MET_{sc}[f]
Boys													
1–1.9	11.5	3.906	(934)	0.057	(14)	2.737	(654)	1.43	3.963	(948)	345	(82.4)	1.45
2–2.9	13.5	4.675	(1117)	0.047	(11)	3.235	(773)	1.45	4.722	(1129)	350	(83.6)	1.46
3–3.9	15.7	5.187	(1240)	0.049	(12)	3.602	(861)	1.44	5.236	(1252)	334	(79.7)	1.45
4–4.9	17.7	5.644	(1349)	0.047	(11)	3.792	(906)	1.49	5.691	(1360)	322	(76.8)	1.50
5–5.9	19.7	6.092	(1456)	0.047	(11)	3.982	(952)	1.53	6.139	(1467)	312	(74.5)	1.54
6–6.9	21.7	6.531	(1561)	0.052	(12)	4.172	(997)	1.57	6.583	(1573)	303	(72.5)	1.58
7–7.9	24.0	7.024	(1679)	0.057	(14)	4.390	(1049)	1.60	7.081	(1692)	295	(70.5)	1.61
8–8.9	26.7	7.589	(1814)	0.066	(16)	4.647	(1111)	1.63	7.655	(1830)	287	(68.5)	1.65
9–9.9	29.7	8.198	(1959)	0.078	(19)	4.932	(1179)	1.66	8.276	(1978)	279	(66.6)	1.68
10–10.9	33.3	8.903	(2128)	0.092	(22)	5.218	(1247)	1.71	8.995	(2150)	270	(64.6)	1.72
11–11.9	37.5	9.689	(2316)	0.106	(25)	5.529	(1321)	1.75	9.795	(2341)	261	(62.4)	1.77
12–12.9	42.3	10.539	(2519)	0.123	(29)	5.884	(1406)	1.79	10.662	(2548)	252	(60.2)	1.81
13–13.9	47.8	11.452	(2737)	0.137	(33)	6.291	(1504)	1.82	11.588	(2770)	242	(57.9)	1.84
14–14.9	53.8	12.371	(2957)	0.139	(33)	6.735	(1610)	1.84	12.510	(2990)	233	(55.6)	1.86
15–15.9	59.5	13.171	(3148)	0.127	(30)	7.157	(1711)	1.84	13.298	(3178)	224	(53.4)	1.86
16–16.9	64.4	13.802	(3299)	0.099	(24)	7.520	(1797)	1.84	13.901	(3322)	216	(51.6)	1.85
17–17.9	67.8	14.208	(3396)	0.061	(15)	7.771	(1857)	1.83	14.270	(3410)	210	(50.3)	1.84
Girls													
1–1.9	10.8	3.561	(851)	0.057	(14)	2.505	(599)	1.42	3.618	(865)	335	(80.1)	1.44
2–2.9	13.0	4.330	(1035)	0.052	(12)	3.042	(727)	1.42	4.382	(1047)	337	(80.6)	1.44
3–3.9	15.1	4.791	(1145)	0.045	(11)	3.317	(793)	1.44	4.836	(1156)	320	(76.5)	1.46
4–4.9	16.8	5.152	(1231)	0.040	(10)	3.461	(827)	1.49	5.192	(1241)	309	(73.9)	1.50
5–5.9	18.6	5.522	(1320)	0.042	(10)	3.614	(864)	1.53	5.564	(1330)	299	(71.5)	1.54
6–6.9	20.6	5.920	(1415)	0.054	(13)	3.784	(904)	1.56	5.974	(1428)	290	(69.3)	1.58
7–7.9	23.3	6.431	(1537)	0.071	(17)	4.014	(959)	1.60	6.502	(1554)	279	(66.7)	1.62
8–8.9	26.6	7.019	(1678)	0.087	(21)	4.294	(1026)	1.63	7.106	(1698)	267	(63.8)	1.65
9–9.9	30.5	7.661	(1831)	0.094	(23)	4.626	(1105)	1.66	7.755	(1854)	254	(60.8)	1.68
10–10.9	34.7	8.287	(1981)	0.106	(25)	4.841	(1157)	1.71	8.393	(2006)	242	(57.8)	1.73
11–11.9	39.2	8.884	(2123)	0.106	(25)	5.093	(1217)	1.74	8.990	(2149)	229	(54.8)	1.77
12–12.9	43.8	9.414	(2250)	0.108	(26)	5.351	(1279)	1.76	9.523	(2276)	217	(52.0)	1.78
13–13.9	48.3	9.855	(2355)	0.099	(24)	5.603	(1339)	1.76	9.954	(2379)	206	(49.3)	1.78
14–14.9	52.1	10.168	(2430)	0.080	(19)	5.816	(1390)	1.75	10.248	(2449)	197	(47.0)	1.76
15–15.9	55.0	10.370	(2478)	0.052	(12)	5.978	(1429)	1.73	10.421	(2491)	189	(45.3)	1.74
16–16.9	56.4	10.455	(2499)	0.019	(5)	6.056	(1447)	1.73	10.474	(2503)	186	(44.4)	1.73
17–17.9	56.7	10.473	(2503)	0.000	(0)	6.073	(1451)	1.72	10.473	(2503)	185	(44.1)	1.72

*Requirements for 1–1.9 years were reduced by 7% to fit with requirements of infants (see text).
[a] Boys – TEE(MJ day^{-1}) = 1.298 + 0.265 kg − 0.0011 kg^2.
[b] Girls – TEE(MJ day^{-1}) = 1.102 + 0.273 kg − 0.0019 kg^2.
[c] 8.6 kJ or 2 kcal g^{-1} weight gain.
[d] BMR_{sc}: basal metabolic rate estimated with predictive equations on body weight[12].
[e] PAL_{sc}: physical activity level = TEE/BMR_{sc}.
[f] *MET_{sc}: multiples of BMR_{sc} = daily req/BMR_{sc}.

'average' (or 'moderate') physical activity. Population groups with lifestyles involving lower or higher levels of habitual activity than the 'average' children have different ER. The quantitative differences and corresponding adjustments in dietary intake to maintain energy balance and sustain adequate growth and function can be assessed from the examination of the mean variability of TEE within studies, the standard error of the predicted TEE, and the comparison of estimated TEE among populations with different patterns of activity.

Timed observations and activity diaries (TM-AD)

TM-AD have been used to estimate TEE for nearly 40 years in conjunction with the measurement or estimation of the energy cost of activities[55]. The advantages and limitations of these techniques to assess TEE of free-living children have been reviewed[56]. Appropriate age-related corrections must be done when the energy cost of activities measured in adults is used for calculations in children under 15 years of age[9,57].

Some experimental comparisons of TM-AD with DLW and HRM showed good agreement between methods[58,59], whereas others suggested that TM-AD underestimated TEE[60]. This is illustrated in Table 12, which compares TEE estimates of several studies in children and adolescents of developed and developing countries, with predicted values derived from DLW and HRM. Regardless of the discrepancies, TM-AD provides information on time allocation, activity patterns and relative differences in energy expenditure of groups with different lifestyles.

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Table 11 Comparison of new proposals for daily energy requirements with the 1985 FAO/WHO/UNU Report[1]

	Boys				Girls			
	New values		FAO/WHO/UNU, 1985		New values		FAO/WHO/UNU, 1985	
Age	$kJ\,kg^{-1}$ per day	$kcal\,kg^{-1}$ per day	$kJ\,kg^{-1}$ per day	% diff[a]	$kJ\,kg^{-1}$ per day	$kcal\,kg^{-1}$ per day	$kJ\,kg^{-1}$ per day	% diff[a]
1	345	82.4	439	−21.4	335	80.1	439	−23.7
2	350	83.6	418	−16.3	337	80.6	418	−19.4
3	334	79.7	397	−15.9	320	76.5	397	−19.4
4	322	76.8	397	−18.9	309	73.9	397	−22.2
5	312	74.5	377	−17.2	299	71.5	356	−16.0
6	303	72.5	377	−19.6	290	69.3	356	−18.5
7	295	70.5	326	−9.5	279	66.7	280	−0.4
8	287	68.5	326	−12.0	267	63.8	280	−4.6
9	279	66.6	326	−14.4	254	60.8	280	−9.3
10	270	64.6	267	1.1	242	57.8	227	6.6
11	261	62.4	267	−2.2	229	54.8	227	0.9
12	252	60.2	228	10.5	217	52.0	189	14.8
13	242	57.9	228	6.1	206	49.3	189	9.0
14	233	55.7	200	16.5	197	47.0	173	13.9
15	224	53.4	200	12.0	189	45.3	173	9.2
16	216	51.6	186	16.1	186	44.4	167	11.4
17	210	50.3	186	12.9	185	44.1	167	10.8

[a] % difference = (New value/FAOWHOUNU × 100) − 100.

Allocation of time to activities with different levels of physical effort

Specialists in nutrition, physiology, anthropology, economics and behavioural sciences have published studies with information on time allocation of children. Methods included continuous and spot observations, recall interviews with children and caretakers, subject and observer diaries, and analysis of heart rate patterns. Results were examined and presented as specific activities (Table 13), or as groups of tasks and actions classified according to their nature (Table 14) or the level of physical effort (Table 15).

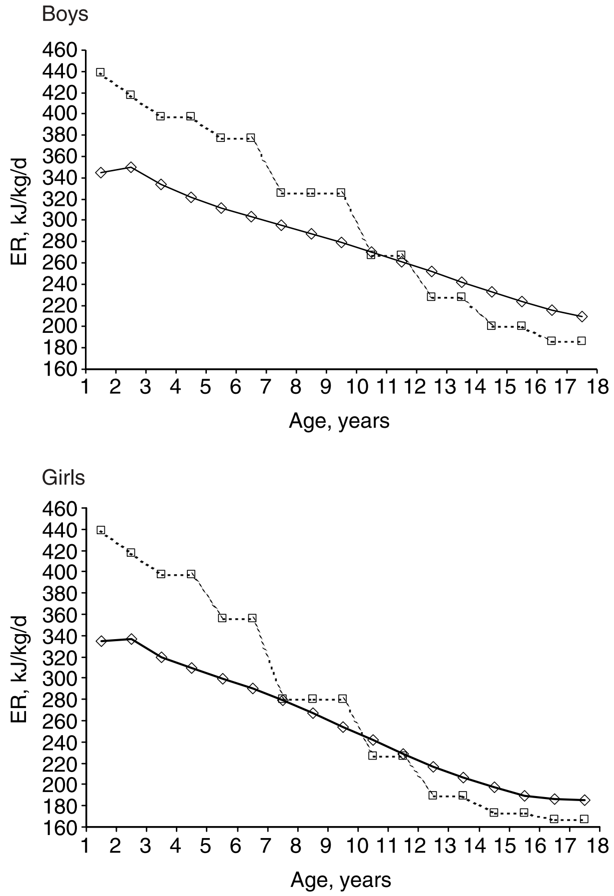

Fig. 6 Comparison of proposed energy requirements (continuous line) with FAO/WHO/UNU 1985 requirements (interrupted line)

Only about one half of the studies that were reviewed had sufficient information to evaluate the time allocated by children to different activities throughout the day, and the effort associated with their performance (Table 16). Specific activities were classified according to their nature or purpose as:

1. Sleeping
2. *At school:* classroom work, recess and other activities in school
3. *Domestic chores:* sibling and child care, house chores, sweeping and cleaning, washing dishes or laundry, preparing food, gardening, fetching water or other items, non-commercial crafts, etc.
4. *Productive activities, with or without wages:* agricultural chores, manufacture of goods for sale, trading and selling, hunting and gathering, working for wages, etc.
5. *Non-work activities:* eating, personal care, resting, walking and travelling, play and leisure, social and religious activities, school homework, watching television, etc.
6. *Non-sedentary recreational activities*: active play, running, sports.

Except for sleep, all categories involved a variety of tasks and actions with different energy demands, and they were performed at different rhythms, velocities and intensities.

Table 12 Total energy expenditure (TEE) estimated from time-motion observations or activity diaries (TM-AD), compared with predictions derived from doubly labelled water and heart rate monitoring studies

Age years	*n*	Weight kg	Country, subjects	Method for TEE with TM-AD[a]	TEE, kJ kg^{-1} per day			Reference for TM-AD
					TM-AD	pred[b]	% diff	
Boys								
1.5	12[c]	9.3	Gambia, mild malnutrition[d]	O-Estimated EC	328	394	−16.8	Lawrence *et al.*[90]
2–6	26	12.7	Guatemala, stunted	O-Estimated EC	339	353	−4.0	Torun[91]
4–6	25	17	Philippines	O-Estimated EC	278	323	−13.8	Guzman *et al.*[92]
7–9	26	24	Philippines	O-Estimated EC	262	293	−10.5	Guzman *et al.*[92]
9–12	128	33.3	Canada	D-Estimated EC	197	267	−26.3	Katzmarzyk *et al.*[93,94]
10–12	25	32	Philippines	O-Estimated EC	258	270	−4.6	Guzman *et al.*[92]
12–14	16	31.3	Singapore	D-Measured EC	243	272	−10.7	Banerjee and Saha[95]
13–15	118	50.8	Canada	D-Estimated EC	190	235	−19.0	Katzmarzyk *et al.*[93,94]
13–15	24	47	Philippines	O-Estimated EC	182	241	−24.5	Guzman *et al.*[92]
15 ± 0.05	171	61.1	Sweden	D-Estimated EC	232	219	5.9	Bratteby *et al.*[58]
15 ± 1.0	16	59.2	Sweden	D-Estimated EC	214	222	−3.5	Ekelund *et al.*[59]
16–17	65	69.4	Australia, students	D-Adult EC	167	207	−19.5	McNaughton *et al.*[96,97]
16–17	9	65	Australia, workers	D-Adult EC	186	213	−12.9	McNaughton *et al.*[96]
16–18	96	66.3	Canada	D-Estimated EC	197	212	−6.9	Katzmarzyk *et al.*[93,94]
16–19	32	56	Philippines	O-Estimated EC	204	227	−10.0	Guzman *et al.*[92]
18–19	12	72.3	Australia, students	D-Adult EC	156	203	−23.3	McNaughton *et al.*[96]
18–19	9	68.4	Australia, workers	D-Adult EC	168	209	−19.5	McNaughton *et al.*[96]
Girls								
1.5	12[c]	9.3	Gambia, mild malnutrition[d]	O-Estimated EC	328	374	−12.3	Lawrence *et al.*[90]
2–6	22	12.7	Guatemala, stunted	O-Estimated EC	339	336	1.0	Torun[91]
4–6	27	17	Philippines	O-Estimated EC	260	306	−14.9	Guzman *et al.*[92]
7–9	24	24	Philippines	O-Estimated EC	267	273	−2.3	Guzman *et al.*[92]
9–12	88	34.7	Canada	D-Estimated EC	183	239	−23.4	Katzmarzyk *et al.*[93,94]
13.3 ± 0.5	40	34.3	Senegal, very lean[d]	O-Estimated EC	245	240	2.1	Benefice *et al.*[98]
13–15	98	50.3	Canada	D-Estimated EC	176	199	−11.7	Katzmarzyk *et al.*[93,94]
13–15	24	46	Philippines	O-Estimated EC	159	210	−24.1	Guzman *et al.*[92]
15 ± 0.05	203	56.6	Sweden	D-Estimated EC	193	185	4.4	Bratteby *et al.*[58]
15 ± 1.0	14	55.7	Sweden	D-Estimated EC	183	187	−2.1	Ekelund *et al.*[59]
16–17	6	50.9	USA	D-Estimated EC	156	198	−21.2	Bradfield *et al.*[99]
16–17	113	58.3	Australia, students	D-Adult EC	145	181	−19.9	McNaughton *et al.*[96]
16–17	32	54.8	Australia, workers	D-Adult EC	164	189	−13.2	McNaughton *et al.*[96]
16–18	82	56.7	Canada	D-Estimated EC	182	185	−1.5	Katzmarzyk *et al.*[93,94]
16–19	32	50	Philippines	O-Estimated EC	161	200	−19.5	Guzman *et al.*[92]
18–19	21	58.7	Australia, students	D-Adult EC	139	180	−22.9	McNaughton *et al.*[96,97]
18–19	24	54.3	Australia, workers	D-Adult EC	160	190	−15.8	McNaughton *et al.*[96,97]

[a] O – observations during daytime and diary or recall interview at night; D – activity diary; EC – energy cost of activities.
[b] Predicted TEE, kJ kg^{-1} per day: Boys = $(1.298 + 0.265\,kg - 0.0011\,kg^2)kg^{-1} \times 1000$, Girls = $(1.102 + 0.273\,kg - 0.0019\,kg^2)kg^{-1} \times 1000$.
[c] Assuming 50% were boys and 50% girls.
[d] Mean of wet and dry seasons.

Based on the descriptions of the investigators and on assumptions about differences in the effort to perform domestic and productive tasks in developed and developing countries, an empirical estimation was made of the proportions of time spent within each category at sedentary, light, moderate and heavy levels of effort (Table 17). Energy demands at each level of effort were estimated as multiples of BMR (Table 18), based on the descriptions in the studies, and the energy cost of a variety of activities corrected for the children's age[9].

Factorial calculations of relative energy expenditure

Boys and girls were divided in three age groups (5–9, 10–14 and 15–19 years), according to the age breakdown allowed by most studies reviewed. Time distributions were calculated as weighted means, weighting them on the number of children in the studies listed in Table 16, and rounding the time to the nearest half-hour. When the sample size of a single study greatly outnumbered all others in the same age and sex category, the number of children was halved to calculate the weighted mean in order to reduce the magnitude of a bias that such study might introduce. For example, nine of 10 studies on boys 10–14 years old in industrialised countries involved between 11 and 171 children, whereas the tenth study involved 360; a weight of 180 was given to that study. In studies where only the number of households was presented, it was assumed that children were studied in 50% of those households. When there was no distinction in gender, it was assumed that half the children were boys and half were girls.

Table 19 shows the weighted mean time allocated by children to different types of activities in urban, rural, industrialised and developing settings, and a factorial estimate of the associated energy expenditure. Compared with children in industrialised societies, children in

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Table 13 Time allocated to specific activities by 2–21-year-old males in the Guatemalan village of San Juan Atitlan

	Time allocation (min day^{-1}) at different ages				
Activity	2–5 years	6–8 years	9–11 years	12–14 years	15–21 years
Productive work					
Gathering	6	6	18	72	0
Preparing fodder	6	30	60	66	48
In corn fields	0	12	12	36	54
Cash crops	12	84	132	144	228
Wage work	6	6	18	12	42
Selling goods	0	18	6	12	0
Crafts for sale	0	0	0	0	0
Total	30	156	246	342	372
Domestic work					
Errands	48	18	18	30	0
Child-caring	66	132	24	6	0
Housecleaning	6	12	12	6	0
Food preparation	6	6	12	0	0
Collecting firewood	6	24	84	60	24
Total	132	192	150	102	24
At school	0	54	84	72	0
Non-work activities					
Resting, eating	210	198	222	198	222
Playing	414	222	156	132	66
Social, religious activities	12	12	6	6	6
Away from village	6	0	24	78	264
Total	642	432	408	414	558
Sleeping	642	606	558	528	492
Daily total	1446	1440	1446	1458	1446

Adapted from Loucky[100].

Table 14 Time allocated to activities of different nature by 10–24-year-old men and women interviewed in a national study of physical activity in Finland

	Time allocated (min day^{-1}) at different ages			
	Men		Women	
Activity	10–14 years	15–24 years	10–14 years	15–24 years
Gainful work	0	173	0	115
Domestic work	43	72	58	130
At school	288	158	288	202
Free time	418	389	403	346
Sleeping and eating	691	648	691	648
Total	1440	1440	1440	1441

Adapted from Niemi *et al.*[101].

developing rural areas devoted more time to energy-demanding activities. Children in rural, traditional societies began domestic and productive work early in life, and at 10 years of age many had an important workload. On the other hand, school attendance, which involves low-energy activities, was seen less often and for shorter time among rural children in developing countries, especially after 12 years of age.

Table 15 Time allocated to activities with different energy demands by adolescent Swedish and Senegalese girls

	Time allocation (min day^{-1})						
Age	Sedentary	Light	Moderate	Heavy	Vigorous	Sleep	Other
Sweden							
14.7 years	573	220	67	32	10	538	
Senegal							
13.3 years	387	176	156				721

Adapted from Ekelund U *et al.*[37].
Adapted from Bénéfice E, Cames C[98].

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Table 16 Studies used to calculate time allocation by children from different countries

Acharya and Bennett[102]	Loucky[100]
Andersen *et al.*[103]	MacConnie *et al.*[118]
Banerjee and Saha[95]	Maffeis *et al.*[119]
Bénéfice and Cames[98]	McNaughton and Cahn[96,97]
Berio[104]	Mueller[120]
Bradfield *et al.*[99]	Munroe *et al.*[121]
Carbañero[105]	Munroe and Munroe[122]
Cain[106]	Nag *et al.*[123]
Colfer[107]	Niemi *et al.*[101]
Dresen *et al.*[108]	Paolisso and Sackett[124]
Durnin[109]	Ramirez and Torun[87]
Franklin and Harrell[110]	Rutenfranz *et al.*[125]
Ekelund *et al.*[59]	Saris *et al.*[126]
Gilliam *et al.*[111]	Seliger *et al.*[127]
Grossman[112]	Shephard *et al.*[128]
Guzmán[92]	Spady[85]
Hart[113]	Stefanik *et al.*[129]
Ho *et al.*[114]	Sunnegardh *et al.*[130]
Huenemann *et al.*[115]	Torun *et al.*[131]
Johnson *et al.*[116]	Turke[132]
Johnson and Johnson[117]	

Table 17 Estimation of the proportions of time allocated to actions requiring different levels of physical effort

	Proportion (%) of time			
Activity category	Sedentary	Light	Moderate	Heavy
School	67	33		
Domestic chores				
Cities and industrialised societies		50	50	
Rural developing societies		33	67	
Productive activities				
Cities and industrialised societies		50	50	
Rural developing countries		33	34	33
Non-work activities	30	30	30	10
Non-sedentary recreational activities		30	50	20

Source: Torun *et al.*[11].

Boys and girls of a given age group had relatively higher energy expenditure in rural areas of developing countries than counterparts in urban areas or industrialised countries. The small number of studies in cities of developing countries limits interpretation of the results, but time allocation and TEE in those settings tended to resemble those of children and adolescents in industrialised countries.

Table 18 Energy expenditure associated with the performance of activities involving different levels of physical effort

	Level of physical effort (METs)				
	Sleeping	Sedentary	Light	Moderate	Heavy
Boys					
5–9 years	1	1.3	2.2	2.9	3.6
10–14 years	1	1.3	2.2	2.9	3.6
15–19 years	1	1.3	2.2	3	5
Girls					
5–9 years	1	1.3	2.2	2.9	3.3
10–14 years	1	1.3	2.2	2.9	3.3
15–19 years	1	1.3	2.2	3	4.5

Suggested adjustments for habitual physical activity

Table 19 shows that mean TEE was about 10, 15 and 25% higher at ages 5–9, 10–14 and 15–19, respectively, among both boys and girls in rural developing areas, compared with counterparts in industrialised countries and cities in developing countries. The mean CV described previously for studies with DLW or HRM to measure TEE, were 19 and 17% for TEE day^{-1} and TEE kg^{-1} per day, respectively. Two times the SEE of TEE day^{-1} using the quadratic regression equations, were 12 and 17% of the mean estimates for boys and girls, respectively.

It is then suggested that for population groups over 5 years old who are less active than the average, 15% be deducted from the ER shown in Table 10. These are children and adolescents who most of the times engage in sedentary and light activities, and seldom do heavy physical work. Examples are children and adolescents who spend several hours at school; do not practise physical sports regularly; usually ride cars and buses, even over relatively short distances; and their main pastimes are watching television, using computers or reading.

Fifteen percent should be added to the values in Table 10 for more active population groups, where children and adolescents walk or ride bicycles every day over long distances; or move around on rugged terrains; or frequently practise sports that demand a high level of physical effort; or engage regularly in high energy-demanding chores, or heavy occupations.

Table 20 shows the suggested requirements and dietary energy recommendations for child and adolescent populations with less than average ('light'), average ('moderate'), and more than average ('heavy') habitual physical activity, applying the 15% adjustment to ER estimated for populations with average physical lifestyle. To facilitate recollection, figures were rounded to the closest 0.1 MJ (or 25 kcal) day^{-1}, 5 kJ (or 1 kcal) kg^{-1} per day, and 0.05 MET. As noted earlier, requirements are higher for boys than girls when expressed as energy units per day or per kg body weight, but they are similar from 1 to 12 years of age when expressed as multiples of BMR. Also noted, ER may be lower at 16–18 years of age due to the bias of quadratic equations at the extremes of the body weight range. This is supported by ER estimates for 18–30-year-old adults with different PAL values[39].

Requirements of mildly malnourished children

Children with moderate-to-severe degrees of malnutrition have special requirements for nutritional recovery that are beyond the scope of this revision. However, dietary

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Table 19 Weighted averages of time allocated to activities with different levels of physical effort, and factorial estimation of daily energy expenditure relative to basal metabolic rate[a]

	No. of studies	No. of children	Mean number of daily hours at: Sleep	Sedentary	Light	Moderate	Heavy	Mean MET or PAL[b]
Boys								
5–9 years								
Industrialised, urban and rural	5	225	10.5	6	4	2	1.5	1.60
Developing, urban	2	81	11	5	3	3	1	1.56[c]
Developing, rural	13	340	10	4	4.5	4	1.5	1.75
10–14 years								
Industrialised, urban and rural	10	903	10.5	5.5	4.5	2.5	1	1.60
Developing, urban	3	133	8.5	7.5	4	3.5	0.5	1.62
Developing, rural	12	450	9	4	4.5	4.5	2	1.85
15–19 years								
Industrialised, urban and rural	6	854	9.5	5	6	3	0.5	1.70
Developing, urban	1	32	8.5	7	6	2.5	0	1.60[c]
Developing, rural	9	200	8	3.5	5	5	2.5	2.13
Girls								
5–9 years								
Industrialised, urban and rural	4	232	10.5	6	4	2	1.5	1.58
Developing, urban	2	81	11.5	5	4	2.5	1	1.56[c]
Developing, rural	13	310	10	4	4.5	4	1.5	1.74
10–14 years								
Industrialised, urban and rural	4	700	10	6.5	4	2.5	1	1.58
Developing, urban	2	73	8.5	6	4.5	4.5	0.5	1.70[c]
Developing, rural	13	440	8.5	4	5	4.5	2	1.85
15–19 years								
Industrialised, urban and rural	8	1037	9.5	5.5	6	2.5	0.5	1.65
Developing, urban	1	32	8	7	6.5	2.5	0	1.62[c]
Developing, rural	9	180	8	3	5.5	5.5	2	2.06

[a] Sources are listed in Table 15. Averages were weighted on the number of children in each study, except as described in the text.
[b] Factorial calculation of total energy expenditure (TEE) based on time allocation and the energy costs shown in Table 17.
[c] Based on only one or two studies.

recommendations for universal application must satisfy the needs of mildly malnourished children who comprise a large segment of the world population. In addition to the weight deficit, most of those children are also stunted.

In absolute terms (i.e. total energy per day), stunted children have lower energy expenditure than well-nourished, non-stunted counterparts. This is related to body mass, as the difference disappears when TEE is adjusted for body weight or fat-free mass[61–63]. In contrast, TEE per unit of body weight is higher among stunted and mildly underweight children. This is not because such children live under conditions that demand more strenuous physical activity, since stunted and mildly underweight children usually have higher TEE kg^{-1} when compared with non-stunted, well-nourished children who live in the same environment and under similar social conditions (Table 21). The higher TEE kg^{-1} of stunted and underweight children may be due to differences in body composition and other metabolic factors. This is supported by the fact that when TEE is expressed in relation to the child's BMR (i.e. in METs) there are no consistent differences when compared with non-stunted children (Table 21).

Regardless of the physiological and metabolic mechanisms involved, a practical issue is the amount of dietary energy that should be recommended for populations with large proportions of mildly malnourished children. If calculations were based on their actual weight, a higher intake per kilogram would have to be recommended to satisfy the requirements of mildly malnourished populations. The prescription of diverse amounts of food for different population groups complicates the application of universal recommendations.

This problem is settled by prescribing dietary energy for all children, based on requirements of well-nourished, non-stunted children. For example, the 10- and 11-year-old children in the three studies in Table 21 on average weighed 26.61 (mildly malnourished) and 32.84 (well-nourished) kg. Their mean ER (Table 21 plus allowance for growth) were 302 kJ kg^{-1} per day or 8.04 MJ day^{-1} (mildly malnourished), and 266 kJ kg^{-1} per day or 8.73 MJ day^{-1} (well-nourished). Prescription of a daily energy intake of 9.00 MJ for all 10–11-year-olds, which corresponds to the requirements of average, well-nourished, boys who weigh 33.3 kg (i.e. 270 kJ $kg^{-1} \times 33.3$; see Table 10), will also satisfy the needs of mildly malnourished children, with some additional energy (36 kJ kg^{-1} per day or 0.96 MJ day^{-1} in this example) for catch-up growth.

Concluding remarks

There is now information on energy expenditure and on the energy cost of growth to calculate requirements and

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Table 20 Suggested energy requirements for populations with different levels of habitual physical activity

Age	Wt	Light physical activity					Moderate physical activity					Heavy physical activity				
		Daily energy requirement					Daily energy requirement					Daily energy requirement				
years	kg	$MJ\,day^{-1}$	$(kcal\,day^{-1})$	$kJ\,kg^{-1}day^{-1}$	$(kcal\,kg^{-1}day^{-1})$	MET	$MJ\,day^{-1}$	$(kcal\,day^{-1})$	$kJ\,kg^{-1}day^{-1}$	$(kcal\,kg^{-1}day^{-1})$	MET	$MJ\,day^{-1}$	$(kcal\,day^{-1})$	$kJ\,kg^{-1}day^{-1}$	$(kcal\,kg^{-1}day^{-1})$	MET
Boys																
1–1.9	11.5						4.0	(950)	345	(82)	1.45					
2–2.9	13.5						4.7	(1125)	350	(84)	1.45					
3–3.9	15.7						5.2	(1250)	335	(80)	1.45					
4–4.9	17.7						5.7	(1350)	320	(77)	1.50					
5–5.9	19.7						6.1	(1475)	310	(74)	1.55					
6–6.9	21.7	5.6	(1350)	260	(62)	1.35	6.6	(1575)	305	(73)	1.60	7.6	(1800)	350	(84)	1.85
7–7.9	24.0	6.0	(1450)	250	(60)	1.35	7.1	(1700)	295	(71)	1.60	8.2	(1950)	340	(81)	1.85
8–8.9	26.7	6.5	(1550)	245	(59)	1.40	7.7	(1825)	285	(69)	1.65	8.8	(2100)	330	(79)	1.90
9–9.9	29.7	7.0	(1675)	235	(56)	1.45	8.3	(1975)	280	(67)	1.70	9.5	(2275)	320	(76)	1.95
10–10.9	33.3	7.7	(1825)	230	(55)	1.45	9.0	(2150)	270	(65)	1.70	10.4	(2475)	310	(74)	1.95
11–11.9	37.5	8.3	(2000)	220	(53)	1.50	9.8	(2350)	260	(62)	1.75	11.3	(2700)	300	(72)	2.00
12–12.9	42.3	9.1	(2175)	215	(51)	1.55	10.7	(2550)	250	(60)	1.80	12.3	(2925)	290	(69)	2.05
13–13.9	47.8	9.8	(2350)	205	(49)	1.55	11.6	(2775)	240	(58)	1.85	13.3	(3175)	275	(66)	2.15
14–14.9	53.8	10.6	(2550)	200	(48)	1.60	12.5	(3000)	235	(56)	1.85	14.4	(3450)	270	(65)	2.15
15–15.9	59.5	11.3	(2700)	190	(45)	1.60	13.3	(3175)	225	(53)	1.85	15.3	(3650)	260	(62)	2.15
16–16.9	64.4	11.8	(2825)	185	(44)	1.55	13.9	(3325)	215	(52)	1.85	16.0	(3825)	245	(59)	2.15
17–17.9	67.8	12.1	(2900)	180	(43)	1.55	14.3	(3400)	210	(50)	1.85	16.4	(3925)	240	(57)	2.15
Girls																
1–1.9	10.8						3.6	(850)	335	(80)	1.45					
2–2.9	13.0						4.4	(1050)	335	(81)	1.45					
3–3.9	15.1						4.8	(1150)	320	(77)	1.45					
4–4.9	16.8						5.2	(1250)	310	(74)	1.50					
5–5.9	18.6						5.6	(1325)	300	(72)	1.55					
6–6.9	20.6	5.1	(1225)	245	(59)	1.35	6.0	(1425)	290	(69)	1.60	6.9	(1650)	335	(80)	1.80
7–7.9	23.3	5.5	(1325)	235	(57)	1.35	6.5	(1550)	280	(67)	1.60	7.5	(1775)	320	(77)	1.85
8–8.9	26.6	6.0	(1450)	225	(54)	1.40	7.1	(1700)	265	(64)	1.65	8.2	(1950)	305	(73)	1.90
9–9.9	30.5	6.6	(1575)	215	(52)	1.45	7.7	(1850)	255	(61)	1.70	8.9	(2125)	295	(70)	1.95
10–10.9	34.7	7.1	(1700)	205	(49)	1.50	8.4	(2000)	240	(58)	1.75	9.6	(2300)	275	(66)	2.00
11–11.9	39.2	7.6	(1825)	195	(47)	1.50	9.0	(2150)	230	(55)	1.75	10.3	(2475)	265	(63)	2.05
12–12.9	43.8	8.1	(1925)	185	(44)	1.55	9.5	(2275)	215	(52)	1.80	11.0	(2625)	245	(60)	2.05
13–13.9	48.3	8.5	(2025)	175	(42)	1.55	10.0	(2375)	205	(49)	1.80	11.4	(2725)	235	(57)	2.05
14–14.9	52.1	8.7	(2075)	165	(40)	1.50	10.2	(2450)	195	(47)	1.75	11.8	(2825)	225	(54)	2.00
15–15.9	55.0	8.9	(2125)	160	(39)	1.50	10.4	(2500)	190	(45)	1.75	12.0	(2875)	220	(52)	2.00
16–16.9	56.4	8.9	(2125)	160	(38)	1.50	10.5	(2500)	185	(44)	1.75	12.0	(2875)	215	(51)	2.00
17–17.9	56.7	8.9	(2125)	155	(37)	1.45	10.5	(2500)	185	(44)	1.70	12.0	(2875)	215	(51)	2.00

Requirements for 1–1.9 years adjusted by 7% to fit with requirements of infants (see text).
Moderate physical activity: (Boys) $MJ\,day^{-1} = (1.298 + 0.265\,kg - 0.0011\,kg^2) + 8.6\,kJ\,g^{-1}$ daily weight gain; (Girls) $MJ\,day^{-1} = (1.102 + 0.273\,kg - 0.0019\,kg^2) + 8.6\,kJ\,g^{-1}$ daily weight gain. $kJ\,kg^{-1}$ per day = ($MJ\,day^{-1}$)kg − 1 × 1000. MET = ($MJ\,day^{-1}$)/(predicted BMR day^{-1}).
Light physical activity: 15% < moderate physical activity. Heavy physical activity: 15% > moderate physical activity.
Body weight (Wt) at mid-point of age interval (WHO, 1983). Figures rounded to the closest 0.1 $MJ\,day^{-1}$, 25 $kcal\,day^{-1}$, 5 $kJ\,kg^{-1}$ per day, 1 $kcal\,kg^{-1}$ per day, 0.05 MET.

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Table 21 TEE of well-nourished, non-stunted children, and of mildly malnourished or stunted children with the same socioeconomic conditions

			Well-nourished, not stunted			Mild malnutrition, stunted[b]			
Age	Gender[a]	Method[a]	*n*	kJ kg^{-1} per day	MET	*n*	kJ kg^{-1} per day	MET	Reference
5	B and G	DLW	15	279	1.40	15	285	1.33	Wren *et al.*[62]
7	B	HRM	24	302	1.60	21	262	1.46	Spurr & Reina[61]
7	G	HRM	21	264	1.53	16	283	1.40	Spurr & Reina[61]
10	B	DLW	14	282	1.73	13	328	1.89	Hoffman *et al.*[63]
10	G	DLW	14	262	1.73	12	281	1.70	Hoffman et al[63]
11	B	HRM	14	254	1.67	19	287	1.77	Spurr & Reina[88]
11	B	HRM	18	253	1.74	23	282	1.74	Spurr & Reina[61]
11	G	HRM	11	196	1.45	21	231	1.57	Spurr & Reina[61]
15	B	HRM	20	244	1.94	26	274	1.93	Spurr & Reina[61]
15	G	HRM	19	174	1.61	22	203	1.61	Spurr & Reina[61]

[a] B – boys; G – girls; DLW – doubly labelled water method; HRM – heart rate monitoring.
[b] Studies in Guatemala[62] and Brazil[63]: height deficit > 1.5 standard deviations below the WHO median for age[15]. In Colombia[61,88]: weight-for-height < 95% of Colombian standards[133].

make dietary energy recommendations for children and adolescents. Although only a small proportion of studies were done in urban areas of developing countries, their results fell in line with those from industrialised nations. However, there still is a paucity of experimental data from rural developing societies. Information on the habitual activity of children and adolescents in those societies allowed making inferences about their energy expenditure and requirements.

Publication of ER must be prescriptive, since references for comparison are often used as standards. Some studies on TEE may involve large proportions of individuals who are undernourished, overweight or with a low level of habitual physical activity, and use of their results as standards must be avoided. Standards must be based on requirements of healthy, well-nourished population groups with lifestyles that reduce the risk of developing diseases associated with inadequate diets and physical activity. With that purpose, previous FAO/WHO Expert Committees and Consultations excluded data from developing countries with high prevalence of undernourished individuals. The same principle must be applied to data from societies where obesity and sedentary behaviours are commonplace. The high prevalence of these undesirable conditions in many industrialised countries is illustrated by the fact that the average weight of participants described in several studies as 'healthy, well-nourished' or 'randomly selected from the population at large', is above the 85th, or even the 95th, percentile of current international references. Such studies were excluded from the present analysis.

Few studies provided details about habitual physical activity. It was then assumed that the weighted mean values of the revised studies corresponded to an 'average' level of adequate activity. The variance in TEE within studies, and information about time allocation in different societies, allowed suggesting requirements for populations that are more or less active than the average.

A certain amount of habitual physical activity is desirable for biological and social well-being. Therefore, recommendations for activity compatible with long-term health and a low risk of developing diseases associated with a sedentary lifestyle, must accompany recommendations for dietary intakes that will satisfy requirements. This is particularly important for societies with a large proportion of sedentary children and adolescents, or where epidemiological information suggests an increasing trend towards sedentary behaviour. Societal customs and environmental conditions must be taken into account to make practical recommendations that will permit the performance of physical activity on a regular basis.

Conclusions

- ER of children and adolescents can be calculated from their daily energy expenditure plus the energy needs for growth.
- Recommendations for dietary energy intake must be based on ER of healthy, well-nourished children and adolescents who have an appropriate level of habitual physical activity.
- ER proposed in 1985 were: (1) overestimated for boys under 10 and girls under 8 years of age; and, (2) underestimated for boys over 12 and girls over 11 years old.
- Beginning as early as 5 years of age, children and adolescents in rural developing societies have higher energy expenditure and dietary requirements than in cities or industrialised countries.
- ER and dietary energy recommendations must be adjusted according to the physical activity habitually performed by children and adolescents. At present the levels of adjustment can be estimated from their lifestyle and from statistical inferences.
- Studies with DLW or other equivalent methods are needed in traditional and transitional rural societies of

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developing countries to confirm or modify those estimates.

- Recommendations for appropriate levels of physical activity must accompany recommendations for dietary intakes. These should include practical suggestions on how to perform such activity within the physical and social environment of the target population.
- Dietary recommendations for populations with large proportions of children with mild-to-moderate undernutrition can be calculated using the median weight of optimally nourished children of the same age and gender.

Future research

- TEE of children and adolescents must be measured with DLW or equivalent methods in urban and rural areas of developing countries, to confirm or modify the requirements proposed in this paper. High priority must be given to studies in rural societies with traditional indigenous lifestyles, and in societies undergoing a transition from traditional to more modern lifestyles. Mean weights-for-height of study groups must be within ±1 ((15th–85th percentile) of accepted international or local references.
- DLW is the method of choice to measure TEE but its cost and the availability of ^{18}O and dual-collector mass spectrometers limit its use. HRM gives acceptable average group values of TEE when appropriate instruments and individual calibration on heart rate-oxygen consumption are used. Research is needed to develop and/or validate other techniques and methods that will permit measuring TEE of children and adolescents in different societies.
- More qualitative and quantitative information is needed on the habitual physical activity of children and adolescents in traditional and transitional societies of developing countries in various parts of the world. The social sciences literature must be revised to identify studies with information that may allow making estimates of daily energy expenditure.
- More information is needed about the minimal and optimal duration, intensity and frequency of physical activity that is consistent with normal growth and development of children and adolescents.
- Information is needed to establish the optimal amounts of energy intake and physical activity that will incite catch-up growth in body mass and stature of undernourished and stunted children.
- Large numbers of children in developing countries have repeated episodes of acute infections, which are often accompanied by decreased appetite and/or increased metabolic activity that lead to a negative energy balance. Biological and behavioural studies are needed to achieve appropriate levels of energy intake during the episodes of disease and convalescence.
- Overweight and obesity are linked to a positive (i.e. surplus) energy balance. Biological and behavioural investigations are needed to develop and test methods that will stimulate children and adolescents to eat foods and perform regular physical activity at levels that will reduce the risk of overweight.
- Techniques must be developed to stimulate children and adolescents to perform an appropriate level of physical activity in the context of different geographic, cultural and socioeconomic environments.

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