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# Determinants of fat mass in prepubertal children

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The aim of the present study was to compare variables of metabolism, physical activity and fitness to body composition in normal and overweight children in a cross-sectional study design. Body composition was assessed by anthropometric measurements and bioelectrical impedance analysis in forty-eight prepubertal children (age 5–11 years, thirteen normal-weight, thirty-five overweight). Total energy expenditure (EE) was measured by combination of indirect calorimetry (for measurement of resting EE) and individually calibrated 24 h heart-rate (HR) monitoring. Activity-related EE and physical activity level (PAL) were calculated. Time spent with min-by-min HR > FLEX HR was also used as a marker of moderate habitual and vigorous activities. Aerobic fitness ($O_2$ pulse ($O_2$ consumption:HR at submaximal steady-state heart rate), submaximal $O_2$ consumption ($V_{O2submaximal}$), RER at a HR of 170 beats per min) was determined by bicycle ergometry. Muscle strength of the legs (maximal isometric strength of *musculus quadriceps* and of *musculus ischiocruralis* (Fa max and Fb max respectively)) was measured by computer tensiometry. When compared with normal children, overweight children had higher skinfold thicknesses (sum of skinfold thicknesses at four sites + 160 %), fat mass (+142 %), waist (+24 %) and hip circumferences (+14 %), resting EE (+13 %) and RER (+5 %). No significant group differences were found for fat-free mass, muscle mass, total EE, activity-related EE, PAL, HR > FLEX HR, $V_{O2submaximal}$, $O_2$ pulse, Fa max and Fb max as well as the fat-free mass- or muscle mass-adjusted values for resting EE, aerobic fitness and muscle strength. When compared with normal children, overweight children had a lower measured *v.* estimated resting EE (Δ resting EE) and spent more time watching television. There were positive relationships between fat-free $mass_{(x)}$ and resting $EE_{(x)}$, total $EE_{(y)}$, aerobic $fitness_{(y)}$ and muscle $strength_{(y)}$, but only Δ resting $EE_{(x)}$ and HR > FLEX $HR_{(x)}$ correlated with fat $mass_{(y)}$. In a stepwise multivariate regression analysis resting EE adjusted for fat-free mass and Δ resting EE were significant determinants of % fat mass and explained 29·7 % of its variance. Thus, in the present cross-sectional study, resting EE was the most important determinant of fat mass.

**Energy expenditure: Fitness: Physical activity: Prepubertal children**

Physical activity and energy expenditure (EE) are important components of body weight regulation. In adults, physically active individuals have lower % body fat, whereas reduced activity is seen in many obese subjects (Schulz & Schoeller, 1994). In addition, weight gain is closely linked to physical inactivity (Weinsier *et al.* 2002). In contrast to adults, the relationship between physical activity and childhood obesity is far from clear (Fontvielle *et al.* 1993; DuRant *et al.* 1994; Davies *et al.* 1995; Goran *et al.* 1998). Children have a great variation in their activities. These can be assessed by qualitative and quantitative measures. Results from the US National Children and Youth Fitness Study suggested that leaner children were rated as more physically active than their overweight counterparts (Ross & Pate, 1987). Using activity diaries in school children, two recent studies found surprisingly low levels of physical activity, which were associated with an increased prevalence of overweight in this age group (Armstrong *et al.* 1990; Henry *et al.* 1999). Some studies found strong relationships between time spent watching television (i.e. an index of physical inactivity) and fat mass (FM) as well as the prevalence of obesity in children (Klesges *et al.* 1993; DuRant *et al.* 1994; Gortmaker *et al.* 1996; Crespo *et al.* 2001). By contrast, other authors could

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**Abbreviations:** EE, energy expenditure; Fa max, maximal isometric muscle strength of the *musculus quadriceps*; Fb max, maximal isometric muscle strength of the *musculus ischiocruralis*; FFM, fat-free mass; FM, fat mass; HR, heart rate; PAL, physical activity level; SFT, skinfold thickness.

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not support this finding (Wolf *et al.* 1993; DuRant *et al.* 1994; Fogelholm *et al.* 1999). In addition, the level of the child's habitual but not vigorous activity was weakly and inversely related to the prevalence overweight (Fogelholm *et al.* 1999).

Compared with these qualitative results, doubly-labelled water, heart-rate (HR) monitoring and accelerometers have been used as objective measures of EE and physical activity in normal and overweight children (Haskell *et al.* 1993; Murgatroyd *et al.* 1993; Davies *et al.* 1995; Maffeis *et al.* 1995; Goran *et al.* 1998; Goran, 2001; Trost *et al.* 2001). These studies did not show consistently an association between EE or movement and the degree of fatness in children. The inconsistencies may be explained by methodological problems (e.g. use of different methods to assess activity and EE, short-term measurements of EE) or by conceptional issues (i.e. the fact that physical activity is a complex phenomenon). Thus, other characteristics of physical activity, e.g. physical fitness, body composition and/or skill-related components, have also to be taken into consideration.

Fitness integrates a number of influences, e.g. long-term physical activity and training, biological influences, an interaction between heredity and physical activity, ability to display a maximum performance at testing. In practice, fitness is characterized by testing cardiorespiratory function as well as muscular-skeletal function. Aerobic fitness has been addressed in normal and overweight children, but contradictory results were reported. Aerobic fitness was found to be normal (Maffeis *et al.* 1994; Treuth *et al.* 1998) or reduced (Boileau *et al.* 1985; Sasaki *et al.* 1987) in overweight prepubertal children. The relationship between EE and aerobic fitness has been assessed in normal and overweight children (Maffeis *et al.* 1994), but there was no clear association between these variables. Even more confusing, the association between fitness and

**Table 1.** Characteristics of the study population†
(Mean values, standard deviations and ranges)

| | Children | | | | | |
|---|---|---|---|---|---|---|
| | Overweight (*n* 35) | | | Normal weight (*n* 13) | | |
| | Mean | SD | Range | Mean | SD | Range |
| Gender boys (*n*), girls (*n*) | 22, 13 | | | 7, 6 | | |
| Age (years) | 7·3 | 1·5 | 4·8–11·4 | 7·9 | 2·0 | 5·5–11·4 |
| Body height (m | 1·32 | 0·12 | 1·13–1·65 | 1·31 | 0·11 | 1·16–1·58 |
| Body weight (kg | 41·1* | 14·1 | 24·0–89·0 | 28·5 | 8·0 | 19·6–47·0 |
| BMI (kg/m$^2$) | 22·9** | 3·4 | 18·4–32·7 | 16·2 | 2·1 | 13·1–19·9 |
| Anthropometric measurements | | | | | | |
| SFT (mm) | | | | | | |
| Triceps | 24·0** | 6·9 | 11·0–39·0 | 11·31 | 3·3 | 6·0–19·0 |
| Biceps | 19·7** | 6·0 | 6·7–31·0 | 7·9 | 3·0 | 4·0–15·0 |
| Subscapular | 24·1** | 8·7 | 13·0–47·7 | 8·3 | 3·8 | 4·0–18·0 |
| Abdominal | 28·1** | 9·2 | 15·7–54·7 | 11·2 | 7·6 | 3·7–32·0 |
| Sum of SFT at four sites (mm) | 97·3** | 28·9 | 53·7–166·3 | 37·4 | 16·7 | 20·0–84·3 |
| Mid-arm circumference (cm) | 24·9** | 3·4 | 20·0–34·0 | 20·5 | 2·9 | 16·5–26·0 |
| Waist circumference (cm) | 75·9** | 12·6 | 59·0–112·0 | 61·0 | 9·8 | 49·3–87·0 |
| Hip circumference (cm) | 80·8* | 9·6 | 64·0–107·0 | 70·9 | 8·8 | 60·0–89·0 |
| waist:hip ratio | 0·94* | 0·08 | 0·76–1·13 | 0·86 | 0·06 | 0·78–0·98 |
| Bioelectrical impedance analysis | | | | | | |
| *R* (Ω) | 692·7** | 52·8 | 563·0–784·0 | 743·7 | 74·1 | 638·0–849·0 |
| Xc (Ω) | 68·0 | 7·1 | 53·0–81·0 | 68·9 | 5·0 | 60·0–77·0 |
| Z (Ω) | 698·1* | 268·5 | 565·5–787·9 | 750·6 | 331·1 | 641·5–851·7 |
| Φ (°)‡ | 5·6 | 0·5 | 4·4–6·7 | 5·4 | 0·6 | 4·3–6·6 |
| Resistance index (H (cm)$^2$/*R* (Ω)) | 25·8 | 6·4 | 17·3–48·4 | 23·6 | 5·1 | 17·4–33·6 |
| Body composition | | | | | | |
| Fat mass | | | | | | |
| kg§ | 13·3** | 5·1 | 7·4–30·2 | 5·5 | 2·5 | 2·2–11·3 |
| %§ | 32·4** | 4·2 | 21·1–43·8 | 18·8 | 4·6 | 10·5–25·2 |
| Fat mass index‖ (kg/m$^2$) | 7·4** | 1·6 | 4·5–11·5 | 3·1 | 1·0 | 1·5–4·5 |
| Fat-free mass | | | | | | |
| kg§ | 27·8 | 9·5 | 16·6–58·8 | 22·9 | 5·9 | 16·7–35·7 |
| %§ | 67·9** | 4·4 | 58·4–78·9 | 81·2 | 4·6 | 74·8–89·5 |
| Fat-free mass index¶ (kg/m$^2$) | 15·5** | 2·3 | 12·5–21·6 | 13·1 | 1·4 | 11·1–15·5 |
| Muscle mass (kg) | 17·3 | 3·2 | 12·6–23·5 | 17·0 | 2·4 | 13·7–21·1 |

SFT, skinfold thickness.
Mean values were significantly different from those of the normal-weight group: $*P \leq 0·05$, $**P \leq 0·01$.
† For details of procedures, see p. 547.
‡ Φ, Phase angle = atan (Xc/*R*) × 57·297.
§ Measured by bioelectrical impedance and anthropometry, estimated according to Goran *et al.* (1996).
‖ Height-normalized fat mass.
¶ Height-normalized fat-free mass.

fatness was true for some markers of fitness (RER at a heart rate of 170 beats per min) but not for others (submaximal $O_2$ consumption ($V_{O2submaximal}$), muscle strength; Grund *et al.* 2000*a*). We therefore reinvestigated resting EE, total EE, physical activity, aerobic fitness, muscle strength and body composition in a group of normal and overweight children. The possible relationships between FM and other variables were investigated.

## Methods

### *Subjects*

Between July 1998 and March 1999, forty-eight prepubertal children (thirty-five overweight children, thirteen normal-weight children, between 5 and 11 years old) were examined in Kiel, Germany. Overweight children were defined as those with a BMI $>$90th percentile, using a recent German database for children according to Hesse (1997). The 90th BMI percentiles for boys and girls respectively were: 5 years 16·3 and 17·0 kg/m$^2$; 6 years 16·8 and 17·1 kg/m$^2$; 7 years 17·0 and 17·4 kg/m$^2$; 8 years 17·4 and 17·9 kg/m$^2$; 9 years 18·0 and 18·4 kg/m$^2$; 10 years 18·4 and 19 kg/m$^2$; 11 years 19·0 and 19·6 kg/m$^2$. Prepubertal stages were assessed by inspection by school physicians. All children were classified as Tanner staging $<$2 (Tanner, 1962). The characteristics of the study population are represented in Table 1.

The investigations were performed at the Institute of Human Nutrition and Food Science and the Institute of Sport and Sport Science (Department of Sport Medicine) at the Christian-Albrechts-University of Kiel. Parents gave information about physical activity of their children as well as socio-economic factors by the use of a standardized questionnaire as described previously by Grund *et al.* (2001*b*). The procedures had been explained to the parents as well as to the children. All parents gave their informed written consent. The ethical committee of the Christian-Albrechts-University of Kiel had approved the study.

### *Measurement of body composition*

Body composition was measured by anthropometric methods (body weight and height, triceps, biceps, abdominal, suprailiac and subscapular skinfold thicknesses (SFT), mid-arm circumference, muscle mass, FM and waist and hip circumferences) and by bioelectrical impedance analysis (FM and fat-free mass (FFM); Multi-Frequency-Analyser 2000-M; Data Input GmbH, Frankfurt/M, Germany) as described previously (Mast *et al.* 1998, 2002*a*,*b*). All measurements were performed by one investigator (A. G.). The standard measurement conditions (50 kHz, 800 mA) were used for bioelectrical impedance analysis. The CV of anthropometric (triceps SFT) and bioelectrical impedance analysis measurements (resistance index *R*, reactance *Xc*) in prepubertal children were 4·2, 1·0 and 2·1 % respectively. The measurements took place in the morning after an overnight fast of 8–12 h and after voiding.

In a previous study (Mast *et al.* 1998), we compared bioelectrical impedance analysis-derived FM with FM assessed by anthropometric measurements in 610 5–7-year-old children. In that study, bioelectrical impedance analysis data systematically overestimated anthropometrically derived FM at low FM, whereas the opposite was true at high FM (Mast *et al.* 1998). To overcome this problem, a combination of data from anthropometry and bioelectrical impedance analysis were used in the present study. This approach has been proposed by Goran *et al.* (1996), who used dual energy x-ray absorptiometry as a reference method in a group of Caucasian children. FFM was calculated according to the following formula:

$$\begin{aligned} \text{FFM (kg)} = (0{\cdot}16 \times (\text{height (cm)})^2/R\,(\Omega))) \\ + 0{\cdot}67 \times \text{weight (kg)}) \\ - (0{\cdot}11 \times \text{triceps SFT (mm)}) \\ - (0{\cdot}16 \times \text{subscapular SFT (mm)}) \\ + (0{\cdot}43 \times \text{gender}) + 2{\cdot}41 \text{ (kg)}, \end{aligned}$$

where gender is 0 for girls and 1 for boys. FM was the difference between body weight and FFM. Recalculating our previous results (Mast *et al.* 1998) by the use of this formula showed a reduction of the systematic deviation (Mast *et al.* 2002*b*). However, when compared with anthropometric data, there was still some over- and underestimation of FM by the use of the combined method at low or high FM. Muscle mass was obtained from anthropometric measurements as described previously (Mast *et al.* 1998). Height-normalized indices FFM and FM were also calculated according to VanItallie *et al.* (1990).

### *Measurement of resting energy expenditure*

Resting EE and RER ($V_{CO2}/V_{O2}$) were assessed in the morning as described previously (Müller *et al.* 1989). The children arrived in our metabolic ward after an overnight fast (i.e. 8–12 h after their last meal). Measurements of $V_{O2}$ and $V_{CO2}$ were performed continuously for at least 1 h by indirect calorimetry (gas exchange measurement; Europa Scientific, Crewe, Ches., UK). The subjects were emotionally relaxed and the environment was thermoneutral. In prepubertal children, the CV of resting EE measurements was estimated to be 2·1 % (based on three repeated measurements of six children performed on three different days within a 2-week period). Resting EE was calculated from measured gas exchange according to Weir's formula (Weir, 1949):

$$\begin{aligned} \text{resting EE (MJ/24 h)} = 1{\cdot}44 \times (3{\cdot}9\ V_{O2}\,(\text{ml/min}) \\ + 1{\cdot}1\ V_{CO2}\,(\text{ml/min})). \end{aligned}$$

Resting EE was adjusted for FFM according to Ravussin &

Bogardus (1989):

$$\text{resting EE}_{\text{adjusted}}\,(\text{MJ}/24\,\text{h}) = \text{resting EE}_{\text{measured}}\,(\text{MJ}/24\,\text{h}) + ((\text{FFM}_{\text{group mean}}(\text{kg}) - \text{FFM}_{\text{measured}}(\text{kg})) \times a),$$

where *a* is the slope derived from the regression analysis between FFM and resting EE in the total group of subjects (resting $EE = a \times FFM + b$). In accordance with this procedure, adjustments for FFM were also performed for total EE, $O_2$ pulse ($O_2$ consumption:HR at submaximal steady-state HR) and muscle strength. Resting EE was also estimated from the World Health Organization formulas as described previously (Grund *et al.* 2000*a*,*b*).

Resting and 24 h HR were measured with an HR monitor (Physio-Trend; med-Natic, Munich, Germany) as described previously (Grund *et al.* 1999, 2000*a*,*b*, 2001*a*). The correlation between HR and $V_{O2}$ of the entire study population at rest was used to calculate a regression equation for the data.

### *Ergospirometry*

The individual relationship between HR and $V_{O2}$ made it necessary to establish individual regression lines for HR *v.* $V_{O2}$ on a bicycle ergometer (Ergostar; PMS Professional Medical Systems, Basel, Switzerland) (Grund *et al.* 1999). There were no motor coordination problems in our children. The workload was calculated individually depending on the weight of the children according to Grund *et al.* (1999). We started with a workload of 0·25 W/kg body weight. It was increased by 0·25 W/kg body weight every 2–3 min after HR and $V_{O2}$ had reached a steady state. The whole protocol lasted 10–12 min. Submaximal workload was reached at a HR of about 175 beats per min. $O_2$ pulse and RER at this HR were used as an index for aerobic fitness. Because of the strong relationship between $O_2$ pulse and body mass, $O_2$ pulse was adjusted for FFM from the regression analysis between $O_2$ pulse and FFM. RER was used as a weight-independent variable of aerobic fitness. Peak $V_{O2}$ was estimated from the linear regression between HR and $V_{O2}$. A HR at 220 beats per min was estimated as maximum HR for all prepubertal children (Grund *et al.* 2000*b*).

### *Measurement of total energy expenditure and physical activity by heart-rate monitoring*

The HR monitor (Physio-Trend; med-Natic) was fixed with three standard electrodes at the thorax. Measurements were performed continuously (min-by-min) for 24 h. The HR monitor saved the 24 h data. Children were instructed to have normal activities except that they should not swim. The relationship between HR and $V_{O2}$ was used to calculate 24 h EE from 24 h HR monitoring in free-living conditions. Total EE was calculated by the FLEX HR-monitoring method (Spurr *et al.* 1988). FLEX HR was defined as the mean of the highest HR during sitting on the bicycle ergometer and the lowest HR during light working on the ergometer. Individually estimated FLEX HR was used to discriminate between resting and exercise HR. When HR $<$ FLEX HR the regression for $V_{O2}$ *v.* HR at rest was used to calculate EE. When HR $>$ FLEX HR, EE was derived from the individual regression (HR *v.* $V_{O2}$ according to Schulz *et al.* (1989)), as described previously (Grund *et al.* 1999, 2000*b*, 2001*a*). Activity-related EE was calculated from the difference between total EE and the sum of resting EE and diet-induced thermogenesis (assumed to be 5 % total EE). The total EE:resting EE ratio was the physical activity level (PAL). In addition, total time spent with min-by-min HR $>$ FLEX HR was used as a marker of moderate habitual plus vigorous activities.

In six children (three boys, three girls, age 6·4–11·4 years, BMI 18·7–24·5 kg/m$^2$, triceps SFT 12·3–24·0 mm), 24 h HR was measured for a period of 3 d (2 d during the week, 1 d at the weekend). The intra-individual CV in sleeping EE and total EE varied from 0·3 to 4·2 % and 0·8 to 8·5 % respectively. There was a tendency for higher total EE values at the weekend. A strong correlation was seen between total EE on weekdays and total EE at the weekend (*r* 0·95).

### *Measurement of muscle strength of the legs*

The maximal isometric muscle strength of the *musculus quadriceps* (Fa max) and the *musculus ischiocruralis* (Fb max) was measured by computer tensiometry (Grund *et al.* 2000*a*, 2001*a*). For each child, both legs were measured at the same time. During the measurement of Fa max the children sat and during measurement of Fb max they lay on their front. During both measurements the angle between the calf and the thigh was 90°. The impulse of muscle strength was registered by an automatic receptor and sent to a personal computer. The registration of muscle strength lasted 3 s. Each measurement was repeated three times, but only the maximal data of the Fa max and Fb max were used. The CV were 3·5 and 3·9 % respectively. Fa max and Fb max were adjusted for FFM and also for muscle mass from the regression analysis between FFM or muscle mass and muscle strength (see earlier).

### *Statistical analyses*

SPSS (version 7.5; SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. The significance of the biological data was tested by a factorial design using a two-way ANOVA considering the factors gender and weight status (overweight *v.* normal weight). The significance of the questionnaire data was tested by $\chi^2$ test. Differences in resting EE, total EE, activity-related EE, $O_2$ pulse, Fa max and Fb max observed between boys and girls matched for FFM were tested by the unpaired samples *t* test. The sample size calculated to be adequate to detect differences between the groups was 40–80 subjects. Multiple linear regression analysis was performed using SPSS. Statistical significance is denoted by $P < 0.05$ or $P < 0.01$. Results are presented as mean values, standard deviations and ranges, or as mean values and percentages.

## Results

### *Characterization of the study population*

When compared with normal children, overweight children had a similar height, but greater body weight (+44 %), sum of SFT at four sites (+160 %) and FM (+142 %) (Table 1). Height-normalized indices of FM (+138 %) and FFM (+18 %) were greater in overweight when compared with normal children (Table 1). Waist (+24 %) and hip (+14 %) circumferences as well as the waist:hip ratio (+9 %) were all greater in overweight children. There were no group differences in anthropometrically-derived muscle mass, reactance, impedance, phase angle and resistance index (height (cm)$^2$/*R* (Ω); Table 1). However, a lower resistance (7 %) was observed in overweight children (Table 1). Muscle mass showed a close correlation with FFM (FFM (kg) = 2·144 × muscle mass (kg) − 10·366; *r* 0·69, $P<0·01$).

No differences in socio-demographic characteristics were observed between the two study groups (Table 2). Overweight children more frequently had obese mothers (Table 2). When compared with normal-weight children, watching television >1 h/d was more frequently observed in overweight children (Table 2).

**Table 2.** Estimates of physical activity and inactivity of the children, nutritional state of the parents and some socio-demographic characteristics of the study population*

(Mean values and percentages)

| | Children: Overweight (*n* 35) | | Children: Normal weight (*n* 13) | | Statistical significance of effect ($\chi^2$ test): *P* |
|---|---|---|---|---|---|
| | Mean | % | Mean | % | |
| Activity and inactivity of the children | | | | | |
| Estimated by parents | | | | | NS |
| Active | 6 | 17·1 | 6 | 46·2 | |
| Moderate active | 22 | 62·9 | 4 | 30·8 | |
| Inactive | 0 | 0·0 | 0 | 0·0 | |
| No answer | 7 | 20·0 | 3 | 23·1 | |
| Membership in a sports club | | | | | NS |
| Yes | 18 | 51·4 | 6 | 46·2 | |
| No | 14 | 40·0 | 4 | 30·8 | |
| No answer | 3 | 8·6 | 3 | 23·1 | |
| Time watching television (h/d) | | | | | <0·01 |
| <1 | 9 | 25·7 | 8 | 61·5 | |
| ≥1 | 21 | 60·0 | 2 | 15·4 | |
| No answer | 5 | 14·3 | 3 | 23·1 | |
| Nutritional state of the parents | | | | | |
| Nutritional status of the mother | | | | | <0·05 |
| Overweight or Obese† | 19 | 54·3 | 3 | 23·1 | |
| Normal weight† | 16 | 45·7 | 10 | 76·9 | |
| Nutritional status of the father | | | | | NS |
| Overweight or Obese† | 14 | 40·0 | 3 | 23·1 | |
| Normal weight† | 21 | 60·0 | 10 | 76·9 | |
| Socio-demographic characterization | | | | | |
| Education of the mother | | | | | NS |
| Junior high school | 11 | 31·4 | 2 | 15·4 | |
| Modern secondary school | 10 | 28·6 | 4 | 30·8 | |
| Secondary school | 5 | 14·3 | 5 | 38·5 | |
| No answer | 9 | 25·7 | 2 | 15·4 | |
| Education of the father | | | | | NS |
| Junior high school | 16 | 45·7 | 5 | 38·5 | |
| Modern secondary school | 2 | 5·7 | 1 | 7·7 | |
| Secondary school | 6 | 17·1 | 6 | 46·2 | |
| No answer | 11 | 31·4 | 1 | 7·7 | |
| Monthly income spent on food (%) | | | | | NS |
| >33 | 9 | 25·7 | 8 | 61·5 | |
| <33 | 13 | 37·1 | 4 | 30·8 | |
| No answer | 13 | 37·1 | 1 | 7·7 | |
| Nationality of the parents | | | | | NS |
| German | 30 | 85·7 | 12 | 92·3 | |
| Other country | 5 | 14·3 | 1 | 7·7 | |

* For details of subjects and procedures, see Table 1 and pp. 547–548.
† Normal weight BMI 20–25 kg/m$^2$, overweight BMI 25–30 kg/m$^2$, obese BMI >30 kg/m$^2$.

**Table 3.** Energy expenditure (EE) and physical activity of prepubertal normal and overweight children†
(Mean values, standard deviations and ranges)

| | Children | | | | | |
|---|---|---|---|---|---|---|
| | Overweight (*n* 35) | | | Normal weight (*n* 13) | | |
| | Mean | SD | Range | Mean | SD | Range |
| Indirect calorimetry | | | | | | |
| Resting EE (MJ/24 h) | 5·3* | 0·9 | 3·9–7·4 | 4·7 | 0·7 | 3·6–6·0 |
| Resting EE adjusted (MJ/24 h)‡ | 4·9 | 0·5 | 4·1–6·1 | 5·3 | 0·4 | 4·3–5·7 |
| Resting EE estimated (MJ/24 h)§ | 5·7** | 1·0 | 3·9–8·2 | 4·6 | 0·6 | 3·9–5·7 |
| Δ Resting EE (MJ/24 h)§ | −0·45** | 0·54 | −1·46–1·07 | 0·05 | 0·58 | −0·85–1·64 |
| Δ Resting EE (%)§ | −9·2** | 10·9 | −28·9–21·7 | −0·2 | 12·2 | −21·2–28·8 |
| Resting RER‖ | 0·88 | 0·04 | 0·82–0·96 | 0·90 | 0·04 | 0·83–0·98 |
| Heart rate monitoring | | | | | | |
| Sleeping heart rate (beats per min)¶ | 73·9 | 7·8 | 59·1–98·0 | 70·0 | 10·7 | 56·0–89·3 |
| Resting heart rate (beats per min)†† | 87·5 | 6·8 | 77·2–100·0 | 83·9 | 11·2 | 63·0–105·0 |
| 24 h heart rate (beats per min)‡‡ | 99·1 | 9·4 | 80·9–127·0 | 100·5 | 10·8 | 88·6–127·0 |
| FLEX HR (beats per min)§§ | 114·0 | 10·3 | 96·0–135·0 | 108·9 | 7·0 | 98·0–120·0 |
| Time HR > FLEX HR (%)‖‖ | 14·9 | 9·2 | 3·3–37·7 | 24·7 | 13·0 | 7·6–47·3 |
| Total EE (MJ/24 h)¶¶ | 7·6 | 2·6 | 4·5–16·6 | 6·8 | 2·7 | 4·7–15·0 |
| Total EE adjusted (MJ/24 h)††† | 6·9 | 2·0 | 4·8–13·3 | 7·6 | 2·2 | 5·3–13·3 |
| Activity-related EE (MJ/24 h)‡‡‡ | 2·0 | 2·0 | −0·1–9·7 | 2·0 | 2·6 | −0·8–8·3 |
| Physical activity level§§§ | 1·4 | 0·4 | 1·0–2·7 | 1·5 | 0·4 | 1·0–2·6 |

Mean values were significantly different from those of the normal-weight group: *$P \leq 0·05$, **$P \leq 0·01$.
† For details of subjects and procedures, see pp. 547–548.
‡ Resting EE adjusted for fat-free mass according to Ravussin *et al.* (1989).
§ Estimated resting EE according to World Health Organization formula: Δ resting EE = resting EE − resting EE estimated (Grund *et al.* 2000*a*,*b*).
‖ RER measured by indirect calorimetry.
¶ Sleeping heart rate is the lowest heart rate during the night which lasted at least 1 % of night time.
†† Resting heart rate is the mean heart rate during indirect calorimetry.
‡‡ 24-h heart rate is the mean heart rate during 24 h heart-rate monitoring.
§§ FLEX HR is the mean between the lowest HR during low physical activity and the highest HR during physical inactivity.
‖‖ Time of the day spent (%) with the min-by-min heart rate above FLEX-HR.
¶¶ Total EE measured by 24 h heart-rate monitoring.
††† Total EE adjusted for fat-free mass, calculated from total EE + (fat-free mass (kg) − fat-free mass (kg) × *a*) according to Ravussin & Bogardus (1989).
‡‡‡ EE for physical activity calculated from the difference between total EE (−5% was used as correction for diet-induced-thermogenesis) and resting EE.
§§§ Physical activity level = total EE/resting EE.

### *Energy expenditure in normal and overweight children*

When compared with normal-weight children, estimated (+24 %) and measured resting EE (+13 %) were both elevated in overweight children (Table 3). However, this was only true for boys (5·5 (SD 1·0) *v.* 4·6 (SD 1·0) MJ/24 h in overweight and normal-weight boys respectively, $P<0·05$). By contrast, there were no differences between overweight and normal-weight girls (4·8 (SD 0·6) *v.* 4·7 (SD 0·6) MJ/24 h, NS). Measured resting EE was significantly lower than estimated resting EE in overweight children (Table 3, $P<0·05$). There were no group (overweight *v.* normal-weight children) and gender differences in resting EE adjusted for FFM, resting RER, sleeping HR, resting HR, 24 h HR, FLEX HR, total EE, activity-related EE and PAL (Table 3). There were also no group differences in the total time spent with the min-by-min HR > FLEX HR (Table 3).

### *Aerobic and muscular fitness in normal and overweight children*

There were no group differences in exercise-induced $V_{O2}$, $V_{O2submaximal}$, theoretical $V_{O2}$ and $O_2$ pulse (Table 4). However, after adjusting $O_2$ pulse for body weight (0·16 (SD 0·04) *v.* 0·21 (SD 0·05) ((ml/min)/(beats per min)) per kg, $P<0·01$) or body weight$^{0·75}$ (0·21 (SD 0·05) *v.* 0·28 (SD 0·06) ((ml/min)/(beats per min)) per kg; $P<0·01$) overweight children had lower values when compared with normal-weight children. By contrast, $O_2$ pulse adjusted for FFM showed no group differences (Table 4). At submaximal exercise, overweight children had greater RER values (Table 4). There were no significant group differences in Fa max and Fb max (Table 4). Muscle mass was correlated with Fa max ($r$ 0·34, $P<0·05$), Fb max ($r$ 0·34, $P<0·05$) and Fa max + Fb max ($r$ 0·37, $P<0·05$).

### *Effect of gender on energy expenditure and fitness*

Regarding gender differences in normal-weight children, % FM was higher in girls than in boys (21·4 (SD 3·4) *v.* 15·6 (SD 3·7) %, $P<0·05$). By contrast, boys had a higher FFM (78·6 (SD 3·4) *v.* 84·4 (SD 3·7) %, $P<0·05$). In overweight children, there were no gender differences in body composition. Altogether, boys had a higher resting EE than girls (5·1 (SD 1·0) *v.* 4·8 (SD 0·6) MJ/24 h, $P<0·05$), but gender differences disappeared after adjustment for FFM. There were no gender differences in resting EE, total EE, activity-related EE, PAL and RER in normal-weight children. By contrast, overweight boys had a higher resting EE than overweight girls (5·5 (SD 1·0) *v.* 4·8 (SD 0·6) MJ/24 h, $P<0·01$), but there were no gender differences in resting EE and total EE after adjustment for FFM. Boys had a higher $O_2$ pulse than girls (6·6 (SD 2·0) *v.* 5·6

**Table 4.** Oxygen consumption ($V_{O_2}$) and oxygen pulse at different levels of activity, RER and muscular fitness (maximal isometrical muscle strength) of normal and overweight children†

(Mean values, standard deviations and ranges)

| | Children | | | | | |
|---|---|---|---|---|---|---|
| | Overweight (*n* 35) | | | Normal weight (*n* 13) | | |
| | Mean | SD | Range | Mean | SD | Range |
| Aerobic fitness | | | | | | |
| $V_{O_2}$ at 120 beats per min (ml/min)‡ | 539·2 | 278·2 | 57·8–1664·9 | 461·3 | 129·8 | 243·2–743·7 |
| $V_{O_2}$ at rest/$V_{O_2}$ at 120 beats per min‡ | 0·45 | 0·4 | 0·15–2·63 | 0·47 | 0·38 | 0·23–1·78 |
| $V_{O_2}$ at 150 beats per min (ml/min)§ | 921·9 | 392·0 | 381·8–2630·9 | 840·6 | 196·0 | 414·2–1235·7 |
| $V_{O_2}$ at rest/$V_{O_2}$ at 150 beats per min§ | 0·21 | 0·06 | 0·09–0·40 | 0·26 | 0·22 | 0·15–1·00 |
| $V_{O_2}$ at 170 beats per min (ml/min)‖ | 1171·8 | 482·2 | 560·7–3274·4 | 1100·3 | 255·2 | 528·2–1563·7 |
| $V_{O_2}$ at rest/$V_{O_2}$ at 170 beats per min‖ | 0·17 | 0·04 | 0·08–0·27 | 0·20 | 0·17 | 0·12–0·78 |
| Theoretical peak $V_{O_2}$ (ml/min)¶ | 1739·9 | 694·4 | 676·9–4884·9 | 1727 | 408·3 | 0·8–2·5 |
| RER at 170 beats per min †† | 1·11* | 0·06 | 1·02–1·26 | 1·06 | 0·07 | 0·91–1·20 |
| $O_2$ pulse (ml/beats per min)‡‡ | 6·7 | 2·5 | 2·9–16·4 | 5·7 | 1·4 | 2·9–8·1 |
| $O_2$ pulse adjusted (ml/min)/(beats per min)§§ | 6·4 | 1·4 | 3·7–10·4 | 6·4 | 1·1 | 4·0–8·1 |
| Muscle strength | | | | | | |
| Fa max (N) | 250·0 | 88·2 | 60·9–483·6 | 271·1 | 162·2 | 60·8–737·0 |
| Fa max adjusted$_1$ (N)§§ | 248·0 | 79·2 | 67·1–445·3 | 278·0 | 141·0 | 115·0–667·7 |
| Fa max adjusted$_2$ (N)‖‖ | 247·6 | 85·3 | 70·8–433·6 | 254·0 | 173·8 | 60·3–710·9 |
| Fb max (N) | 134·3 | 59·4 | 24·5–304·2 | 98·4 | 41·5 | 24·1–169·0 |
| Fb max adjusted$_1$ (N)§§ | 133·1 | 46·5 | 18·9–241·3 | 108·5 | 35·1 | 44·0–152·2 |
| Fb max adjusted$_2$ (N)‖‖ | 126·2 | 62·8 | −17·1–264·2 | 94·3 | 48·3 | 20·5–156·2 |
| Fa+Fb (N) | 382·5 | 132·4 | 197·5–746·2 | 343·1 | 206·2 | 150·9–906·0 |
| Fa+Fb adjusted$_1$ (N)§§ | 378·1 | 124·0 | 177·0–638·4 | 406·0 | 140·5 | 234·2–740·0 |
| Fa+Fb adjusted$_2$ (N)‖‖ | 389·9 | 139·2 | 94·2–734·9 | 366·9 | 213·3 | 195·8–874·2 |

Fa max, Maximal isometrical strength in the *musculus quadriceps*; Fb max, maximal isometric strength in *musculus ischiocruralis*.
Mean values were significantly different from those of the normal-weight group: $*P\le 0·05$, $**P\le 0·01$.
† For details of subjects and procedures, see Table 1 and pp. 547–548.
‡ $O_2$ consumption during low physical activity with a heart rate from about 120 beats per min.
§ $O_2$ consumption during moderate physical activity with a heart rate from about 150 beats per min.
‖ $O_2$ consumption during vigorous physical activity with a heart rate from about 170 beats per min.
¶ Peak $V_{O_2}$ is the maximal $O_2$ consumption calculated by the estimated maximal heart rate (heart rate 220 beats per min).
†† RER ($V_{CO_2}/V_{O_2}$) during vigorous physical activity with a heart rate from about 170 beats per min.
‡‡ $O_2$ pulse is the $O_2$ consumption:heart rate ratio at the last submaximal steady state (heart rate 170 beats per min).
§§ Adjusted for fat-free mass.
‖‖ Adjusted for muscle mass.

**Table 5.** Relationships (*r*) among resting energy expenditure, aerobic fitness, muscle strength, activity and different variables of body composition in pre-pubertal normal and overweight children†

(Correlation coefficients)

| | FFM (kg) | FM (%) | Σ Skinfold thicknesses at four sites |
|---|---|---|---|
| Resting EE | | | |
| Resting EE (MJ/24 h) | 0·847*** | 0·317* | 0·487*** |
| Δ Resting EE (MJ/24 h) | NS | −0·397** | −0·388** |
| Aerobic fitness | | | |
| $V_{O_2}$submaximal (ml/min) | 0·843*** | NS | 0·330* |
| $O_2$ pulse (ml/min)/(beats per min)‡ | 0·827*** | NS | 0·395** |
| RER at 170 beats/min | NS | NS | NS |
| Muscle strength | | | |
| Fa max (N) | 0·503** | NS | NS |
| Fb max (N) | 0·666*** | NS | NS |
| Fa + Fb (N) | 0·637*** | NS | NS |
| Activity | | | |
| Total EE (MJ/24 h) | 0·596*** | NS | NS |
| Activity EE (MJ/24 h) | 0·387** | NS | NS |
| Physical activity level | NS | NS | NS |
| HR>Flex HR (%)§ | NS | −0·377* | −0·373* |

FFM, fat-free mass; FM, fat mass; EE, energy expenditure; Fa max, maximal isometric strength in the *musculus quadriceps*; Fb max, maximal isometric strength in the *musculus ischiocruralis*; HR, heart rate.
$*P<0·05$, $**P<0·01$, $***P<0·001$.
† For details of subjects and procedures, see Table 1 and pp. 547–548.
‡ $O_2$ pulse is the $O_2$ consumption:HR ratio at the last submaximal steady state.
§ FLEX HR is the mean between the lowest HR during low physical activity and the highest HR during physical inactivity.

(SD 1·6) (ml/min)/(beats per min), $P<0{\cdot}05$). Gender differences in aerobic fitness disappeared after adjustment for body mass or FFM. There were no gender differences in Fa max, Fb max and $V_{O2}$ at different PAL.

*Association between resting energy expenditure, fitness, muscle strength, physical activity and body composition*

$FFM_{(x)}$ was a strong determinant of resting $EE_{(y)}$, total $EE_{(y)}$ and $O_2$ $pulse_{(y)}$ as well as muscular strength (Table 5). There were no associations between $FFM_{(x)}$ and the different markers of physical activity (results not shown). Resting $EE_{(x)}$ and total $EE_{(x)}$ correlated with $O_2$ $pulse_{(y)}$ ($r$ 0·66, $P<0{\cdot}001$ and $r$ 0·40, $P<0{\cdot}01$ respectively) and muscle $strength_{(y)}$ ($r$ 0·58, $P<0{\cdot}001$ and $r$ 0·32, $P<0{\cdot}05$ respectively). There were no associations between markers of physical $activity_{(x)}$ and the variables of aerobic or muscular $fitness_{(y)}$ tested (results not shown). The relationships among resting $EE_{(x)}$ or total $EE_{(x)}$ and aerobic and muscular fitness disappeared after adjustment for FFM (results not shown).

There were no relationships between % $FM_{(y)}$ and total $EE_{(x)}$, $PAL_{(x)}$, the variables of aerobic $fitness_{(x)}$ and muscle $strength_{(x)}$ tested. However, resting EE, resting $EE_{adjusted}$ ($r$ 0·29, $P<0{\cdot}05$), Δ resting EE and HR>FLEX HR correlated with % FM and the sum of SFT at four sites (Table 5). The latter variable also positively correlated with $V_{O2submaximal}$ and $O_2$ pulse. By contrast, the sum of SFT at four sites and % FM had no associations with muscle strength.

Using a multiple regression analysis, 29·7 % of the variance in the sum of SFT at four sites were explained by resting $EE_{adjusted}$ and the deviation between estimated and measured resting EE (Δ resting EE) (sum of SFT at four sites $= 40{\cdot}2 \times$ resting $EE_{adjusted} - 0{\cdot}14 \times \Delta$ resting $EE_{measured} - 137{\cdot}43$). The explained variance in the sum of SFT at four sites was increased to 42·4 % by including aerobic fitness ($O_2$ $pulse_{adjusted}$) and muscle strength (Fa $max_{adjusted}$ + Fb $max_{adjusted}$) into the analysis (sum of SFT at four sites $= 47{\cdot}08 \times$ resting $EE_{adjusted} - 0{\cdot}15 \times \Delta$ resting $EE_{measured} + 7{\cdot}63 \times O_2$ $pulse_{adjusted} - 0{\cdot}08 \times$ Fa $max_{adjusted}$ + Fb $max_{adjusted} - 190{\cdot}89$). Following the same approach, 36·8 % of the variance in % FM was explained, but only resting $EE_{adjusted}$ and Δ resting EE were significant determinants.

## Discussion

We compared resting EE, physical activity, time spent watching television, aerobic fitness, muscle strength and body composition in a group of normal and overweight children. The relationships between the metabolic and physiological variables and body composition were tested. The limitations of the present study include inaccuracies associated with the measurement techniques (e.g. assessment of aerobic fitness by cycle ergometry in children) as well as the relatively small sample size (see p. 548 for calculation of sample size). There were no group differences in total EE, activity-related EE, PAL, HR>FLEX HR (Table 3) and aerobic fitness (Table 4), but overweight children had a higher resting EE (Table 3). In previous studies, measures of resting EE, activity, cardiorespiratory fitness and muscle strength showed different associations with overweight in children (Boileau *et al.* 1985; Sasaki *et al.* 1987; Murgatroyd *et al.* 1993; Livingstone, 1994; Maffeis *et al.* 1994; Davies *et al.* 1995; Maffeis *et al.* 1995; Treuth *et al.* 1998; Grund *et al.* 2000*b*; Goran, 2001; Trost *et al.* 2001). These discrepancies are partly explained by body composition. In fact, after adjustment for FFM, the between-group differences in resting EE disappeared (see p. 552). Altogether, our cross-sectional findings do not suggest that: (1) overweight children are relatively less active and also have less muscle strength than normal-weight children; (2) a low physical activity and also a low muscular-skeletal function contributes to overweight.

We found some associations between: (1) resting EE, Δ resting EE and HR>FLEX HR (a marker of moderate plus vigorous activity); (2) % FM (Table 5). The results of linear regression analysis suggest that the difference between measured and predicted resting EE is a determinant of % FM in children (Table 5): a relatively low resting EE is associated with a higher % FM. By contrast, aerobic fitness did not show an association with FM (Table 5). The associations between variables of aerobic fitness and the sum of SFT at four sites may reflect the influence of body weight on these variables. This is because body weight correlates with % FM ($r$ 0·42, $P<0{\cdot}01$) and FFM ($r$ 0·97, $P<0{\cdot}001$). Since there is an association between body weight or FFM and fitness and also between body weight and FM, these associations may be simply propagated during the calculation procedure.

The inconsistencies observed in the literature may be also due to the methods used to assess EE in children. EE and physical activity can be assessed in a respiration chamber, by the doubly-labelled water technique, pedometry or accelerometry and HR monitoring (Schulz *et al.* 1989; Murgatroyd *et al.* 1993). Measurements in a respiration chamber are most reliable, but cannot reflect free-living conditions. Pedometry was also used to assess physical activity, but it has a weak accuracy. Accelerometry-estimated EE did not increase with increasing workloads, resulting in limitations to quantify EE (Jakicic *et al.* 1999). HR monitoring showed a very high correlation with $V_{O2}$ at different activity levels. It has been validated by indirect calorimetry and doubly-labelled water (Spurr *et al.* 1988; Schulz *et al.* 1989). Measuring daily EE in children, a close correlation between results from HR monitoring and doubly-labelled water was observed (Livingstone *et al.* 1992; Maffeis *et al.* 1995). In one study, total EE discrepancies were between −16·7 and +18·8 %, and 64 % of the total EE values by 24 h HR monitoring were ±10 % estimates by the doubly-labelled water method (Livingstone *et al.* 1992). However, slightly higher differences between total EE estimates by HR monitoring and doubly-labelled water method were reported for obese children (i.e. by about 6 %; Maffeis *et al.* 1995).

Since HR: (1) does not only increase in response to exercise, but also in response to emotional stress; (2) may have a delay in response to changes in movements; (3) is affected by the fitness level of the child, this method has limitations with regard to the assessment of 24 h EE. It has thus been proposed that mean daily HR may be more representative of children's fitness (Eston *et al.* 1998). However, after adjustment for FFM, we could not observe a significant relationship among total EE estimates by 24 h HR monitoring and markers of aerobic or muscular fitness respectively (see p. 550). These results suggest that the possible association between HR and fitness reflects the influence of FFM. A combination of HR monitoring with accelerometry was also used to measure total EE in infants and adults (Eston *et al.* 1998; Rennie *et al.* 2000). The combined use of both methods may increase the accuracy of activity estimates.

The limited time frame of the measurements (1–14 d) is a general drawback of all techniques described to assess EE. This may affect how representative the results of 24 h HR monitoring are. However, in the children in the present study, repeated intra-individual measurements showed a low variance. The results of objective measures of physical activity are in part contrary to the results of qualitative assessments of inactivity or activity in children. In most, but not in all studies, qualitative results show some associations between low activity and/or inactivity and overweight (Table 2; Ross & Pate, 1987; Klesges *et al.* 1993; DuRant *et al.* 1994; Davies *et al.* 1995; Gortmaker *et al.* 1996; Goran *et al.* 1998; Crespo *et al.* 2001). However, watching television itself had no association with physical activity, aerobic fitness and/or muscle strength (Grund *et al.* 2001*c*).

Estimating physical activity from measurements of EE is also limited because of conceptual issues. Physical activity is a behaviour that characterizes lifestyle. Contrary to physical activity, physical fitness is an attribute. Physical fitness results from physical activity as well as training over longer time periods (Grund *et al.* 2001*c*). Fitness by itself has to be divided into aerobic and muscular fitness. In addition, skill-related components (e.g. agility, coordination) have been also considered in children. Up to now, only limited and inconsistent results on aerobic fitness have been reported for normal and overweight children (Boileau *et al.* 1985; Sasaki *et al.* 1987; Maffeis *et al.* 1994; Treuth *et al.* 1998; Grund *et al.* 2000*a*). Regarding aerobic fitness, our present results are in accordance with two studies (Maffeis *et al.* 1994; Treuth *et al.* 1998), but contrary to the two others (Boileau *et al.* 1985; Sasaki *et al.* 1987). The possible differences between the studies might be explained: (1) by the use of different markers and methods; (2) by adjustment of data (e.g. for body composition). In the present study, we used regression analysis (see p. 548) for the adjustment of metabolic and fitness data (Tables 3 and 4). It is obvious that the between group differences disappeared after adjustment for body composition (Tables 3 and 4, p. 550).

In children, the association between EE, activity, fitness and fatness is controversial. Using uncalibrated HR monitoring, other authors found no relationship between FM and HR (Rowlands *et al.* 1997). By contrast, accelerometry-derived activity results, as well as aerobic fitness, correlated negatively with fatness (Rowlands *et al.* 1999). Since resting EE, Δ resting EE, as well as muscle strength, were not considered as possible determinants of body fat in the study of Rowlands *et al.* (1999), we feel that future studies on the relationships between activity, fitness and fatness in children should be extended beyond the use of activity monitors. Our cross-sectional results provide evidence for the idea that resting EE is a major determinant of % FM in prepubertal children. Future studies should use more precise measures of body composition, total EE, movement and fitness with a larger number of children.

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