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Developmental Changes in Energy Expenditure and Physical Activity in Children: Evidence for a Decline in Physical Activity in Girls Before Puberty

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ABSTRACT. ***Objective.*** **To examine individual changes in energy expenditure and physical activity during prepubertal growth in boys and girls.**

Methods. **Total energy expenditure (TEE), resting energy expenditure, physical activity-related energy expenditure, reported physical activity, and fat and fat-free mass were measured three times over 5 years in 11 boys (5.3 ± 0.9 years at baseline) and 11 girls (5.5 ± 0.9 years at baseline).**

Results. **Four-year increases in fat (~6 kg) and fat-free mass (~10 kg) and resting energy expenditure (~200 kcal/day) were similar in boys and girls. In boys, TEE increased at each measurement year, whereas in girls, there was an initial increase from age 5.5 (1365 ± 330 kcal/day) to age 6.5 (1815 ± 392 kcal/day); however, by age 9.5, TEE was reduced significantly (1608 ± 284 kcal/day) with no change in energy intake. The gender difference in TEE changes over time was explained by a 50% reduction in physical activity (kcal/day and hours/week) in girls between the ages of 6.5 and 9.5.**

Conclusions. **These data suggest a gender dimorphism in the developmental changes in energy expenditure before adolescence, with a conservation of energy use in girls achieved through a marked reduction in physical activity.** ***Pediatrics*** **1998;101:887–891;** ***obesity, children, body composition, growth, maturation.***

ABBREVIATIONS. REE, resting energy expenditure; TEE, total energy expenditure; AEE, physical activity-related energy expenditure.

It is becoming evident that there are distinct periods of the growth and development process during which risk for obesity is markedly increased. Dietz et al[1] have described the three critical stages of obesity development in children as early infancy, adiposity rebound during prepubertal growth, and the adolescent growth phase. Epidemiologic evidence points to a particular importance of the emergence of obesity during adolescence for several reasons. First, the increasing prevalence of obesity is most apparent during this period, especially among girls.[2] Second, obesity during adolescence compared with before adolescence is more predictive of obesity[3] and mortality[4] later in life.

The role of energy expenditure in the development of obesity and body weight regulation remains controversial. We have hypothesized previously that the ambiguous findings in the literature might be explained by the possibility that differences in energy expenditure and its impact on the development of obesity are different at the various stages of maturation.[5] Previous longitudinal studies in children have shown that the impact of individual differences in energy expenditure on future changes in weight and body composition do differ according to stage of growth and development and therefore support this hypothesis. During early infancy, a reduced energy expenditure was shown to be a risk factor for weight gain in the first 3 months of life.[6] However, during the steady period of prepubertal growth, we have found that 4-year changes in fat relative to fat-free mass are not influenced by individual differences in total, resting, or physical activity-related energy expenditure (AEE).[5] This lack of effect also could be explained by type II error and lack of measurement precision, because even in the most extreme cases of obesity development, the daily energy imbalance resulting in excess adiposity over 4 years was estimated to be 2% of energy flux, or 23 kcal/day,[5] a level that is beyond detection even with the most sophisticated techniques.

Because the changes in body composition are most rapid during early infancy and during the adolescent growth spurt, these periods of growth may be optimal dynamic models for studying the etiology of obesity. Because the gender difference in body composition and obesity prevalence[2] become most marked during adolescence, we hypothesized that immediately before adolescence, girls would have a significant reduction in energy expenditure as an energy-conserving mechanism. Moreover, we hypothesized that this energy conservation would occur via changes in AEE because this component of energy expenditure represents the greatest source of plasticity in energy use and has been associated previously with other energy-conserving adaptations.[7] We examined this hypothesis through prospective observations of the various components of energy expenditure and body composition in boys and girls between the ages of ~5.5 years to 9.5 years.

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METHODS

Subjects

Our sample included 11 white girls (mean age at baseline, 5.5 ± 0.9 years) and 11 white boys (mean age at baseline, 5.3 ± 0.9 years). The children were recruited from Burlington, VT, and the surrounding area (predominantly Chittenden County) using newspaper advertisements and word of mouth. There were no major inclusion/exclusion criteria other than the absence of major illness since birth. All studies were performed during the school year, but not during the severe winter months (December to February). The nature, purpose, and possible risks of the study were explained carefully to both parents before obtaining consent. All measurements were performed at the General Clinical Research Center at the University of Vermont between 1991 and 1996. The experimental protocol was approved by the Committee on Human Research for the Medical Sciences of the University of Vermont.

General Outline of Protocol

Children returned for testing on an annual basis; follow-up visits were scheduled for the same date as the original visit within ± 4 weeks. All subjects had three measures of height, weight, anthropometry, body composition, resting energy expenditure (REE) and total energy expenditure (TEE) in years 1, 2, and 5 of the study (approximate mean ages were 5.5, 6.5, and 9.5 years). On the evening before testing, children came to the laboratory for collection of baseline urine samples, oral dosing with doubly labeled water, and familiarization with the investigators and testing equipment. On the following morning, the children returned to the laboratory for additional urine collections and measurement of REE and body composition. The children returned to the laboratory 2 weeks after initial testing for repeated measurement of REE and body composition and the collection of two additional urine samples for doubly labeled water analysis.

Measurement of Energy Expenditure Components and Energy Intake

REE was measured under postprandial conditions (2 to 3 hours after the children consumed their usual breakfast at home) in duplicate (14 days apart) by indirect calorimetry using a Deltatrac metabolic monitor (Yorba Linda, CA) as described previously.[8] TEE was measured over 14 days under free-living conditions with the doubly labeled water technique, using a protocol with a theoretical error of <5%, as described previously.[8] Samples were analyzed in triplicate for $H_2{}^{18}O$ and ^2H_2O by isotope ratio mass spectrometry at the University of Vermont (samples from year 1) and the University of Alabama at Birmingham (samples from years 2 and 5), as described previously.[9] The instruments in both laboratories have been cross-validated as described previously.[9] CO_2 production rate was determined using equation *R2* of Speakman et al,[10] energy expenditure was calculated using equation 12 of de Weir,[11] and the mean value for the food quotient of the children's diet (0.90) was determined from a food frequency questionnaire. AEE was estimated from the difference between TEE and postprandial REE. No correction for the thermic effect of feeding was necessary because REE was measured under postprandial conditions.

Qualitative information on physical activity patterns in children was estimated using the structured activity questionnaire of Kriska et al.[12] Mothers were interviewed in the presence of the child. The questionnaire is designed to assess hours per day spent sleeping, watching television, and performing various recreational physical activities, and the major outcome variable is physical activity expressed in hours per week.

Energy intake was measured in years 4 and 5 (approximate ages of 8.5 and 9.5 years) with repeated 24-hour recalls using the multiple-pass interview approach, which we have cross-validated previously for group accuracy in children relative to TEE via doubly labeled water.[13] Two recalls were obtained during a 14-day study period, and the data averaged. We did not compare energy intake in earlier years because we used a food frequency questionnaire that was found later to overestimate energy intake by ~40%.[14]

Assessment of Anthropometry and Body Composition

Height was measured without shoes using a stadiometer. Weight was measured in light clothing on an electronic scale. Skinfolds (axilla, chest, subscapular, suprailiac, abdomen, triceps, calf, and thigh) were measured using the procedures of Lohman et al.[15] Whole body resistance was measured in duplicate (14 days apart) in children using an RJL 101A bioelectrical impedance analyzer (Mt Clemens, MI). Fat and fat-free mass was estimated from the combination of anthropometry and bioelectrical resistance using an equation developed in children with dual energy x-ray absorptiometry as a criterion method.[16]

Statistics

We used a two-factor (with repeated measures on one of the factors) analysis of variance design to examine changes in energy expenditure in boys and girls. Measurements were performed on three occasions in each individual. For this two-factor analysis, the assumptions were: 1) the sum of the effect of each factor is zero, and 2) errors (residuals) are independently and normally distributed with a mean of zero and an unknown variance. The two assumptions are common for a two-factor analysis. The longitudinal, within-subject analysis afforded us the opportunity to examine individual changes over time, without the need for adjusting energy expenditure for body composition. Data were analyzed using SAS software version 6.10 (Carey, NC), with a significance set at $P < .05$ for all tests.

RESULTS

Physical characteristics and growth parameters of children at each assessment are summarized in Table 1. Parameters relating to doubly labeled water are summarized in Table 2. Energy expenditure, body composition, and physical activity of children at each assessment is summarized in Table 3. The increase in body weight, as well as in fat and fat-free mass, was similar in boys and girls (ie, the time-by-sex interaction was not significant). For TEE, there was a significant effect of time, but also a significant interaction with sex ($P = .004$), implying that the level of

TABLE 1. Physical Characteristics in Boys and Girls at Three Different Ages*

		Year 1	Year 2	Year 5	Significant Effects (Time, Sex, or Time by Sex)
Age (y)	Boys	5.3 ± 0.9	6.4 ± 0.9	9.3 ± 1.0	Time
	Girls	5.5 ± 0.9	6.6 ± 0.9	9.5 ± 0.9	
Weight (kg)	Boys	21.3 ± 4.7	25.2 ± 6.6	37.8 ± 12.0	Time
	Girls	21.5 ± 5.3	24.8 ± 6.7	38.0 ± 11.4	
Height (m)	Boys	1.13 ± 0.07	1.20 ± 0.07	1.38 ± 0.08	Time
	Girls	1.14 ± 0.09	1.21 ± 0.09	1.39 ± 0.09	
Height for age (*z* score)	Boys	0.38 ± 1.45	0.60 ± 1.40	0.75 ± 1.43	Time
	Girls	0.40 ± 1.15	0.43 ± 1.09	0.40 ± 1.10	
Weight for height (*z* score)	Boys	0.48 ± 1.19	0.83 ± 1.34	1.29 ± 1.67	Time
	Girls	0.25 ± 1.09	0.67 ± 0.93	2.13 ± 1.48	

TABLE 2. Doubly Labeled Water Parameters in Boys and Girls at Three Different Ages*

		Year 1	Year 2	Year 5
K_h (days^{-1})	Boys	−0.1138 ± 0.0180	−0.1117 ± 0.0207	−0.0995 ± 0.0145
	Girls	−0.1042 ± 0.0145	−0.0924 ± 0.0114	−0.0818 ± 0.0123
K_o (days^{-1})	Boys	−0.1595 ± 0.0264	−0.1550 ± 0.0227	−0.1374 ± 0.0149
	Girls	−0.1465 ± 0.0184	−0.1387 ± 0.0145	−0.1137 ± 0.0135
D_h (moles)	Boys	723.5 ± 505.0	875.1 ± 254.0	1191.5 ± 223.5
	Girls	667.4 ± 125.2	808.0 ± 149.3	1085.0 ± 217.2
D_o (moles)	Boys	688.5 ± 433.3	823.1 ± 234.8	1078.5 ± 218.7
	Girls	644.6 ± 118.6	770.5 ± 132.3	994.3 ± 161.2

* K_h and K_o are turnover rates (days^{-1}) for deuterium and oxygen-18; Dh and Do are dilution spaces (moles) for deuterium and oxygen-18. Data are means ± SD units.

TABLE 3. Body Composition and Energy Expenditure in Boys and Girls at Three Different Ages*

		Year 1	Year 2	Year 5	Significant Effects (Time, Sex, or Time by Sex)
FM (kg)	Boys	3.0 ± 1.5	4.2 ± 2.4	9.0 ± 5.3	Time
	Girls	4.2 ± 2.2	5.2 ± 3.3	10.5 ± 4.5	
% Fat	Boys	13.2 ± 4.0	15.8 ± 4.6	22.1 ± 7.2	Time
	Girls	18.8 ± 5.4	19.7 ± 5.6	27.0 ± 6.0	
FFM (kg)	Boys	18.4 ± 3.2	21.0 ± 4.3	28.8 ± 6.8	Time
	Girls	17.3 ± 3.5	19.6 ± 3.8	27.5 ± 7.5	
TEE (kcal/d)	Boys	1575 ± 303	1804 ± 614	2074 ± 423	Time
	Girls	1365 ± 330	1815 ± 392	1608 ± 284	Time by sex
REE (kcal/d)	Boys	1174 ± 201	1266 ± 225	1414 ± 201	Time
	Girls	1093 ± 118	1144 ± 186	1302 ± 158	
AEE (kcal/d)	Boys	401 ± 173	538 ± 463	660 ± 286	Time
	Girls	272 ± 247	671 ± 344	305 ± 196	Time by sex
Activity (h/wk)	Boys	7.1 ± 2.7	8.5 ± 4.0	8.2 ± 3.9	Time by sex
	Girls	5.6 ± 3.7	8.3 ± 5.1	3.3 ± 2.5	

* FM and FFM indicate fat mass and fat-free mass, respectively, by anthropometry using a prediction equation based on DXA; TEE, total energy expenditure by doubly labeled water; REE, resting energy expenditure by indirect calorimetry; and AEE, activity-related energy expenditure from the difference between TEE and REE. Data are means ± SD units.

change across time was significantly different in boys and girls (Table 3). In boys, TEE increased at each measurement year (total increase was ~500 kcal/day), whereas in girls, there was an initial increase from age 5.5 (1365 ± 330 kcal/day) to age 6.5 (1815 ± 392 kcal/day); however, by age 9.5, TEE was reduced significantly to 1608 ± 284 kcal/day (TEE was not measured at age 8.5 years). Individual changes in TEE in boys and girls are shown in Figure 1. Between the approximate ages of 6.5 and 9.5 years, 8 of the boys had an increase in TEE, 2 maintained the same values, and 1 boy had a decrease. During the same time period in girls, 7 subjects had a decrease in TEE, 2 maintained the same value, and 2 subjects had an increase (Figure). The gender difference in TEE changes over time was explained by a 50% reduction in AEE in girls between the ages of 6.5 (671 ± 344 kcal/day) and 9.5 (305 ± 196 kcal/day). Reported physical activity by questionnaire was similar in boys and girls; however, by age 9.5 it was also significantly lower in girls (8.2 ± 3.9 vs 3.3 ± 2.5 hours/week). One year earlier, at a mean age of ~8.5 years, reported physical activity was similar in boys and girls (6.3 ± 3.5 vs 5.8 ± 4.1 hours/week) (data not shown in table form). The fall in TEE in girls was not matched by a reduction in energy intake. Reported energy intakes were similar in boys and girls at ages 8.5 (1864 ± 308 and 1813 ± 367 kcal/day) and 9.5 (1853 ± 331 and 1811 ± 306 kcal/day).

DISCUSSION

Using a longitudinal study design, we have examined changes in energy expenditure, energy intake, and physical activity in boys and girls before puberty. Our results suggest that before puberty in girls, there is a reduction in TEE and a maintenance of REE. Together, these findings are explained by a 50% reduction in physical activity. This reduction in physical activity is apparent when expressed as kcal per day and in qualitative terms, in regard to hours per day of reported physical activity. The reduction in energy expenditure occurred despite a continued gain in fat and fat-free mass that would be expected to contribute to an increased energy expenditure and was also not associated with a concomitant reduction in energy intake. Collectively, these results suggest existence of an energy-conserving mechanism through reduced physical activity, before puberty in girls.

Previous studies have shown that tracking of physical activity is generally low to moderate during early childhood,[17] during adolescence, and into adulthood.[18] However, it is unclear whether there are specific periods of development during which distinct changes in physical activity may occur. We are aware of only a few other longitudinal studies that have followed energy expenditure and/or physical activity before puberty in boys and girls. Saris et al[19] tracked physical activity variables in 217 boys and

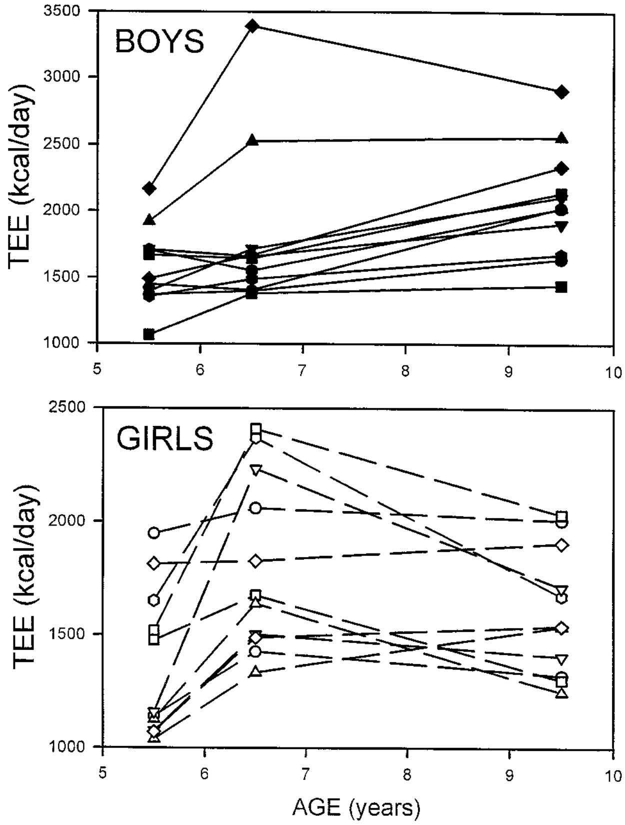

Figure. Individual changes in TEE in boys (top) and girls (bottom) at mean ages of approximately 5.5, 6.5, and 9.5 years.

189 girls between the ages of 6 and 12 years. In girls, there was a tendency for a reduction in physical fitness (expressed as per kilogram of body weight) by age 12 years. Brown et al[20] examined changes in REE in boys only, during the onset of puberty. A subgroup of boys identified as imminently pubertal (based on changes in salivary testosterone) had an increase in REE that was proportional to their increase in fat-free mass, suggesting a maintenance of energy homeostasis. However, only boys were studied and only REE (not TEE or physical activity) was measured. In the current study, we cannot discount the possibility of an energy-conserving mechanism in boys as well. Because boys generally mature later than girls, it is possible that they also may reduce physical activity at later ages closer to puberty. Additional longitudinal studies are required to examine this issue.

An alternative explanation of our findings relate to possible behavioral and/or environmental changes accompanying puberty. As young girls approach puberty, there may be a decrease in accessibility of structured activity and in social desirability of physical activity, leading to a reduction in AEE. This hypothesis is supported by empirical data; for example, 48% of high school girls do not exercise vigorously on a regular basis versus 26% of high school boys.[21] The environmental explanation is also supported by Egger and Swinburn,[22] who assert that obesity is a normal response to an abnormal environment, rather than vice versa. They present a model that suggests that the epidemic of obesity in populations is attributable to an increasingly obesogenic environment.

One of the limitations of our study was that we did not perform physical examinations for pubertal status, because this was not an objective of the original study design. According to a recent review of 17 077 medical records nationwide, the mean age of onset of breast development in white girls was 10 years and for menarche was 12.9 years.[23] The girls in the present study had a mean age of 9.5 years (range, 8.4 to 10.8 years) at the final measure when physical activity had declined, which corresponds to a period immediately before onset of puberty and breast development.

Previous studies from our laboratory have suggested a minor gender difference in TEE in young children that is detectable under some situations.[24] The gender difference observed previously in TEE is mostly attributable to slightly lower REE in girls compared with boys, independent of differences in body composition, by ~50 kcal per day.[25] This small gender difference in REE at young ages is independent of body composition and consistent across various ethnic groups;[24] because of the small magnitude of this effect, the difference is difficult to detect in small study groups and was not observed in the present study. The present study suggests that the gender difference in TEE in children becomes more extreme before puberty because of the reported decline in physical activity in girls before puberty.

Regardless of the explanation of our findings, the results provide important information about targeting obesity and health risk prevention programs. The rise in body weight in children[2] and its relation with increased disease risk early in life[26] and later in life[4] are likely to be addressed most successfully through population-based, public health prevention programs targeted at the critical stages of development. Our study suggests that, at least in girls, there is a need to target prevention before puberty, with an emphasis on increasing physical activity. Targeting a reduction in energy intake in isolation may compromise growth and necessary energy acquisition and exacerbate the risk of introducing eating disorders. Physical activity has many benefits in children, including improvement in body weight,[27] body composition,[28] attainment of psychological well-being,[21] and optimal bone health.[29] An additional advantage of promoting physical activity is an improvement in sedentary behavior, which is a major risk factor for obesity.[9,30]

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