Energy expenditure in preadolescent African American and white boys and girls: the Baton Rouge Children's Study[1–3]

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ABSTRACT

Background: Low energy expenditure has been identified as a potential risk factor for body fat gain.

Objective: The objective was to determine the relations between race, sex, body fat, and energy expenditure.

Design: As part of the Baton Rouge Children's Study, energy expenditure was examined in 131 preadolescent African American and white girls and boys, further stratified as obese or lean. Total daily energy expenditure (TDEE) was measured by the doubly labeled water method. Resting metabolic rate (RMR) and the thermic effect of food were measured by indirect calorimetry. Fat-free mass and fat mass were measured by dual-energy X-ray absorptiometry. To account for differences in body size, energy expenditure variables were adjusted with the use of fat-free mass or fat-free mass and fat mass as covariates.

Results: The African American children had lower TDEE and RMR than did the white children. A lower level of energy expended in physical activity by the African American girls and a lower RMR in the African American boys accounted for the racial differences in TDEE. The white boys had a higher RMR than did the white girls. The girls had a lower TDEE and expended less energy in activity than did the boys. Energy expended in activity was lower in the obese children.

Conclusions: The African American children expended less energy than did the white children. The obese children spent less time engaged in activity or engaged in lower-intensity activity. Obese children may maintain their obese state by spending less time in physical activity, but they do not have a reduced RMR or thermic effect of food. *Am J Clin Nutr* 2002;75:705–13.

KEY WORDS Resting metabolic rate, thermic effect of food, doubly labeled water, total daily energy expenditure, physical activity, obesity, children, Baton Rouge Children's Study

INTRODUCTION

The prevalence of obesity in the United States among 6–11-y-olds has increased 54% over a 15-y period (as shown by the National Health Examination Survey and the second National Health and Nutrition Examination Survey; 1). A 2-fold increase in the prevalence of overweight in children was observed from 1973–1974 to 1994 in the Bogalusa Heart Study (2). Overweight in adolescence, independent of adult weight after 55 y of follow-up, is a risk factor for many adverse health effects (3). Thus, the identification and treatment of high-risk individuals in their adolescent years have important implications for health.

On the basis of some reports of energy intake, it was proposed that obese children have a greater energy efficiency or a lower physical activity than do nonobese children (4). Energy intake was also reported to be higher in obese children (5). One reason for this discrepancy is that energy intake data obtained from dietary records usually underestimate actual energy expenditure. With the use of the doubly labeled water (DLW) method, it was shown that obese children actually have a higher total daily energy expenditure (TDEE) than do lean children and that obese children underestimate their self-reported dietary intakes more than do lean children (6, 7).

TDEE can be partitioned between resting metabolic rate (RMR), the thermic effect of food (TEF), and physical activity, any or all of which may be affected and lead to obesity. It was proposed that obese individuals have a reduced RMR and therefore have to eat less than expected to maintain a normal weight (4). Most reports have shown that total RMR is greater in obese persons but equal to that in lean individuals when adjusted for lean body mass or per unit surface area (8–10). Physical activity, the second largest component of TDEE, is the most variable, even in subjects confined in a respiratory chamber (11). Because of its magnitude and variability, physical activity is a likely component of energy expenditure involved in the etiology of obesity.

Racial and sex differences may also affect energy expenditure. A lower RMR was observed in African American girls than in white girls in some studies (12–14). On the other hand, in a study of 98 children that included approximately equal numbers of African American and white girls and boys, there was no racial effect on RMR, but boys did have a higher RMR than girls (15).

The current study was designed to examine the components of energy expenditure in a large group of African American and white girls and boys. We hypothesized that RMR would be lower in the African American girls than in the white girls. In addition,

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the selection criteria for entry into the study dictated that we would have equal numbers of lean and obese children. We hypothesized that physical activity would be lower in the obese children than in the lean children, but that there would be no significant difference in RMR after adjustment for fat-free mass (FFM).

SUBJECTS AND METHODS

Subjects

Because we wanted to study preadolescent children, only children at Tanner stages 1 and 2 were accepted (16). To enroll the children, we obtained registration information, broken down by race and grade, for each elementary school in the East Baton Rouge Parish School System. The elementary schools had only 50–100 students per grade. Therefore, we had to conduct screening in several schools. Because the goal was to obtain equal numbers of African American and white children, we chose schools with relatively large numbers of 5th-grade students and roughly equivalent racial makeups. Letters were sent to the principals of 10 schools with information about the study and a request to conduct the study at their school. We received responses from 9 principals, and 8 gave their approval. To enroll in the study, children had to be healthy and not taking any medication that would affect growth or energy metabolism. The children agreed to participate in all aspects of the study. The children and a parent or guardian signed both a screening consent and a protocol consent form approved by the Louisiana State University Institutional Review Board.

Screening study

The procedures included measurement of subscapular and triceps skinfold thicknesses, height, and weight; recording of medication information; and Tanner staging. Screening was carried out in the 8 schools over a 2-y period in a total of 333 children. During the second year, we screened children in the 4th grade in addition to the 5th grade to obtain enough preadolescent African American girls. The breakdown by race and sex gave us 79 African American boys, 70 African American girls, 81 white boys, 82 white girls, and 12 boys and girls of other races.

General protocol

The screening data were used to select children meeting all the entrance criteria. In addition to these criteria, we used the upper and lower quartiles of the sum of the subscapular plus triceps skinfold thicknesses measured at screening to enroll equal numbers of lean and obese children. Once enrolled in the study, children were classified as lean if they had <25% body fat and obese if they had ≥25% body fat according to the data obtained by dual-energy X-ray absorptiometry. The general protocol for children enrolled in the main study began with the child and at least one parent or guardian attending an information session at the Pennington Biomedical Research Center on a weekend. At this session, body-composition measurements and a familiarization RMR were carried out. All other testing was performed during school days and had to be scheduled around special testing and school holidays.

Within a few days of the determination of body composition, a second RMR was measured for 30 min, followed by a test meal. Metabolic rate was then measured for 3 h to estimate the TEF. On another day, the children were dosed with DLW for the determination of TDEE. These procedures were carried out at the school in a mobile laboratory.

Doubly labeled water measurement of total daily energy expenditure

After the children had fasted overnight during the week of the RMR measurement, a urine sample was collected for the measurement of baseline isotopic enrichment. The children then drank a dose of heavy water containing 0.3 g $H_2{}^{18}O$/kg total body water and 0.14 g ^2H_2O/kg total body water. The container was washed with an additional 50 mL tap water and this was also given to the children. Saliva samples were taken after 2 and 3 h for measurements of total body water. Children provided morning urine samples 1, 8, and 9 d after the administration of the heavy water for the determination of isotope elimination and energy expenditure. All isotope enrichments were measured in duplicate. Total body water was calculated by using the ^{18}O isotopic enrichments measured in the baseline urine samples and in the 2- and 3-h (averaged) postdose saliva samples (17). Mean daily carbon dioxide production was calculated according to Schoeller (18) with revised dilution space constants (19) and with the use of the average elimination rates calculated from the day 8 and day 9 urine samples. Energy expenditure was calculated by multiplying mean daily carbon dioxide production (mol/d) by the energy equivalent of carbon dioxide for an assumed 24-h respiratory quotient of 0.86.

Once TDEE was determined and RMR and TEF were measured, energy expended in physical activity (AEE) was calculated as follows:

$$AEE = TDEE - RMR - TEF \quad (1)$$

The daily energy expenditure associated with TEF in the above calculation was the percentage of the meal expended above RMR during the 3-h TEF test, multiplied by total daily intake (estimated as TDEE, assuming energy balance).

The isotope abundance of ^{18}O was measured on a gas-inlet isotope ratio mass spectrometer (model 252; Finnigan MAT, Bremen, Germany) with a carbon dioxide–water equilibration device (20). Briefly, urine and saliva samples were equilibrated with carbon dioxide at 21 °C in a shaking water bath for ≥8 h. The carbon dioxide was then cryogenically purified under vacuum before being introduced into the mass spectrometer. The isotopic abundance of deuterium was also measured on a Finnigan MAT 252 gas-inlet isotope ratio mass spectrometer, as previously described (20). Briefly, urine and saliva samples were distilled under vacuum into Vycor tubes containing zinc reagent (Friends of Biogeochemistry, Bloomington, IN). The reduction tube was sealed with a flame and placed in a 500 °C oven for 30 min to reduce the water to hydrogen gas that could then be introduced into the mass spectrometer. All samples were analyzed in duplicate. If the SD of duplicate deuterium abundance was >5‰ or ^{18}O abundance was >0.25‰, isotope analyses were repeated. The average SD for all ^{18}O analyses was 0.14‰ and that for deuterium analyses was 3.8‰. The initial enrichments of ^{18}O and deuterium were ≈150‰ and 1000‰, respectively, whereas the lowest final enrichments were 32‰ and 332‰.

Indirect calorimetry

RMR and TEF were measured in a mobile metabolic laboratory that was driven to the school each day. The laboratory is a customized ≈10-m (34-ft) motor home equipped with a generator, air conditioning, heating, 2 metabolic carts with canopies (Sensormedics 2900Z, Yorba Linda, CA), and power conditioners installed for the metabolic carts. In addition, there are 2 beds, each with a television and video cassette player, a restroom, a laboratory area for sample preparation with a refrigerator for storage, and a kitchen area for preparation of the standard meal for the TEF tests. Metabolic rate was calculated by the Weir equation (21) by using an estimated 8.2 g urinary N/d for RMR and measured urinary nitrogen for TEF:

$$\text{Metabolic rate (kcal/min)} = 3.941 \times \dot{V}O_2 + 1.106 \times \dot{V}CO_2 - 2.17 \times \text{g urinary N} \quad (2)$$

where $\dot{V}O_2$ is oxygen consumption and $\dot{V}CO_2$ is carbon dioxide production. The values obtained were then converted to kJ/min.

Children arrived at the laboratory fasting. They were allowed to rest for 30 min before having the hood put on. After the measurement of RMR for 30 min the children emptied their bladders and then received a meal consisting of Ensure (10.9% protein, 54.3% carbohydrate, and 34.9% fat; Ross Laboratory, Columbus, OH). The size of the energy load was 35% of each subject's measured RMR (22). Metabolic rate was measured for 3 h after completion of the meal. To enhance the enjoyment of this procedure, videos were shown. At the end of the 3-h period, a complete urine voiding was collected for the measurement of urinary nitrogen. The energy expenditure value calculated during the measurement of RMR was subtracted from the energy expenditure value calculated after the meal to determine the absolute TEF. For some children, the last measurement of energy expenditure (3 h) had not reached the baseline RMR; more often, energy expenditure returned to baseline before the end of the 3 h period. The increased energy expenditure following a meal was divided by the total meal size to calculate the percentage of meal energy expended.

Body composition

Dual-energy X-ray absorptiometry scans were performed with a QDR-2000 whole-body scanner (Hologic Inc, Waltham, MA) in array mode. The protocol requires the subject to lie on a table while the scanner emits low-energy X-rays and a detector passes across the body. The scan takes ≈6 min and the radiation dose to the child is <5 Sv (<0.5 mrem), equal to ≈6 h of background radiation from the sun while outside. Two distinct energies are used to determine bone mineral and soft tissue content. An attenuation ratio is determined from a known tissue content. Variations in the attenuation ratio determine the fat content of the tissue at each pixel, thereby calculating the percentage of body fat. The pixels containing bone are used to calculate bone density. The scans were analyzed with enhanced WHOLE BODY software (version 6.0; Hologic Inc). To examine the CV of this technique in our laboratory, we compared repeat scans made of 5 young adults. The CV for weight was 0.09%; the CVs for bone mineral content and bone mineral density were 0.8% and 1.3%, respectively; and the CVs for lean mass, fat mass, and percentage of body fat were 0.8%, 1.6%, and 1.7%, respectively.

Data analysis

The components of energy expenditure were compared by using general linear model analysis of variance (SAS, release 6.12 for WINDOWS; SAS Institute Inc, Cary, NC). Data are presented as least-squares means ± SEMs with use of the full model including race, sex, and obesity group. Various parameters were used in the analysis of variance models as covariates to adjust for differences in body composition. Post hoc tests for differences in group means were accomplished by using a Tukey multiple-comparison adjustment.

RESULTS

Subject characteristics and energy expenditure components of the race-by-sex groups are given in **Table 1**. By design, all children were below Tanner stage 3, with 101 at stage 1 and 30 at stage 2. The only significant difference in body composition observed between the races was a higher FFM in the African American children (29.3 ± 0.5 compared with 27.8 ± 0.5 kg, $P < 0.05$). There were several sex differences, with the boys being taller, heavier, and having a higher BMI and FFM than the girls. However, percentage of body fat was not significantly different between the girls and boys. No significant differences in TEF or in the respiratory quotient during the TEF test were observed between any of the groups.

The RMR measured during the familiarization session at the center (RMR1, Table 1) was higher ($P < 0.001$) than the second RMR measured at the school in the mobile laboratory (RMR2, Table 1). However, there was no significant difference between the RMR measures in the African American girls. The lowest RMR was used as the RMR for all subsequent analyses (RMR, Table 1).

There were significant racial differences in energy expenditure (**Tables 2** and **3**). The white children had a higher TDEE than did the African American children after adjustment for FFM or FFM and fat mass (Table 2). This was also apparent when TDEE was plotted against FFM (**Figure 1**A). RMR was not significantly different between the white and African American children (Table 1). However, the African American children had a significantly lower RMR after adjustment for differences in body size (Table 2 and **Figure 2**A). The African American and white children did not differ significantly in TEF (6.6 ± 0.4% compared with 5.5 ± 0.4%, $P = 0.082$). There were no significant racial differences in AEE (Table 2 and **Figure 3**A).

There were also several sex differences in energy expenditure. The boys selected for the study were larger and hence had higher TDEE, RMR, and AEE than did the girls (Table 1). When FFM or FFM and fat mass were used as covariates to adjust for differences in size, however, there were no longer any sex differences in RMR (Table 2 and Figure 2B). TDEE and AEE, on the other hand, were higher in the boys than in the girls regardless of the method of adjustment (Table 2, Figure 1B, and Figure 3B).

Examining energy expenditure in the race-by-sex groups (Table 3) compared with the race and sex groups separately (Table 2) showed several differences. The boys had a higher TDEE than did the girls for both the African American and white children when body weight was used as a covariate (Table 3). The higher RMR observed in the whites than in the African Americans (Table 2) was due to a higher RMR in the white boys than in the African American boys (Table 3). There was no significant difference in RMR between the white and African American girls. The white boys had a higher RMR than did the white girls, whereas this sex difference was not observed in the African American children. The higher AEE observed in the boys than in the girls (Table 2) was due almost entirely to a lower AEE in the African American girls (Tables 1 and 3).

Subject characteristics and energy expenditure components of the lean and obese children are presented in **Table 4**. The lean

TABLE 1
Subject characteristics and energy expenditure components of race-by-sex groups[1]

	African American		White	
	Girls ($n = 32$)	Boys ($n = 33$)	Girls ($n = 33$)	Boys ($n = 33$)
Age (y)	10.7 ± 0.1	10.9 ± 0.1	10.7 ± 0.1	10.9 ± 0.1
Weight (kg)	37.5 ± 1.5[a]	45.1 ± 2.1[b]	37.8 ± 1.8[a]	42.6 ± 1.8[a,b]
Height (cm)	145.2 ± 1.2[a,b]	146.0 ± 1.2[a,b]	142.1 ± 1.3[b]	146.8 ± 1.0[a]
BMI (kg/m^2)	18.2 ± 0.7[a]	20.8 ± 0.7[b]	18.5 ± 0.7[a]	19.3 ± 0.7[a,b]
FFM (kg)	27.2 ± 0.7[a,b]	31.5 ± 0.8[c]	26.0 ± 0.7[a]	29.7 ± 0.6[b,c]
Body fat (kg)	9.6 ± 1.1	13.0 ± 1.4	11.1 ± 1.3	12.2 ± 1.3
Percentage body fat (%)	24.6 ± 1.7	26.8 ± 1.9	27.5 ± 1.8	27.0 ± 1.7
TDEE (MJ/d)[2]	8.71 ± 0.21[a]	10.30 ± 0.29[b]	8.79 ± 0.21[a]	10.34 ± 0.21[b]
RMR1 (MJ/d)[2]	5.74 ± 0.17[a]	6.53 ± 0.17[b]	5.99 ± 0.17[a]	6.78 ± 0.17[b]
RMR2 (MJ/d)[2]	5.82 ± 0.17[b,c]	6.11 ± 0.21[a,b]	5.44 ± 0.21[c]	6.57 ± 0.17[a]
RMR (MJ/d)[2]	5.40 ± 0.17[a]	5.87 ± 0.21[a,b]	5.40 ± 0.21[a]	6.38 ± 0.17[b]
RQ during RMR	0.81 ± 0.02	0.83 ± 0.01	0.82 ± 0.01	0.83 ± 0.02
TEF (% meal)	6.54 ± 0.68	6.78 ± 0.51	6.02 ± 0.51	5.12 ± 0.58
RQ during TEF	0.85 ± 0.01	0.87 ± 0.01	0.87 ± 0.01	0.88 ± 0.01
AEE (MJ/d)[2]	2.35 ± 0.17[a]	3.48 ± 0.21[c]	2.81 ± 0.17[a,b]	3.27 ± 0.17[b,c]
Physical activity level	1.52 ± 0.04[a]	1.71 ± 0.05[b]	1.65 ± 0.05[a,b]	1.59 ± 0.04[a,b]
AEE/wt (KJ/kg)	65.7 ± 5.0[a]	82.1 ± 5.9[b]	80.0 ± 6.7[a,b]	80.4 ± 5.4[a,b]

[1] Least-squares $\bar{x}$ ± SEM. FFM, fat-free mass; TDEE, total daily energy expenditure; RMR1, resting metabolic rate measured during the first session at the Pennington Center; RMR2, RMR measured at the school in the mobile laboratory; RMR, the lowest RMR measured (used as the RMR for all subsequent analyses); RQ, respiratory quotient; TEF, thermic effect of food; AEE, activity energy expenditure. Means within a row with different superscript letters are significantly different, $P < 0.05$.
[2] Unadjusted for differences in body size.

and obese children were the same age, but the obese children were significantly heavier, taller, and had a higher FFM, body fat mass, and percentage of body fat. The obese children also had a higher RMR and TDEE. AEE was lower in the obese children than in the lean children (2.68 ± 0.13 compared with 3.30 ± 0.13 MJ/d, $P < 0.0001$). After adjustment for body size with the use of FFM as a covariate (Table 4), RMR remained higher in the obese children (Figure 2C) but there was no longer a significant difference in TDEE (Figure 1C). When both FFM and fat mass were included as covariates, however, there was no longer a significant difference in RMR. No matter how activity (AEE) was expressed (unadjusted, with the use of FFM as a covariate, or in terms of the physical activity level), AEE was higher in the lean than in the obese children (Table 4 and Figure 3C). However, the findings with physical activity level may be spurious because the regression line for TDEE versus RMR does not pass through zero. This leads to differences in physical activity level (TDEE/RMR) even along the regression line. For example, the physical activity level corresponding to an RMR of 4.19 MJ/d is 1.82, whereas that for an RMR of 8.38 MJ/d is 1.36. No significant differences in TEF or in the respiratory quotient during the TEF test were observed between the lean and obese children.

The energy expenditure of the children stratified by race, sex, and obesity group are shown in **Table 5**. The sample sizes in this

TABLE 2
Energy expenditure components of race and sex groups adjusted for differences in body size[1]

	Race		Sex	
Energy expenditure component and adjustment	African American ($n = 65$)	White ($n = 66$)	Girls ($n = 65$)	Boys ($n = 66$)
TDEE (MJ/d)				
FFM	9.32 ± 0.13	9.76 ± 0.1[2]	9.24 ± 0.1	9.84 ± 0.1[3]
FFM + fat mass	9.34 ± 0.13	9.76 ± 0.1[2]	9.25 ± 0.1	9.84 ± 0.1[3]
Body weight	9.40 ± 0.13	9.66 ± 0.13	9.00 ± 0.31	10.09 ± 0.13[3]
RMR (MJ/d)				
FFM	5.53 ± 0.08	6.01 ± 0.08[2]	5.71 ± 0.08	5.83 ± 0.08
FFM + fat mass	5.54 ± 0.08	6.00 ± 0.08[2]	5.69 ± 0.08	5.84 ± 0.08
Surface area	5.57 ± 0.08	5.96 ± 0.08[2]	5.62 ± 0.08	5.91 ± 0.08[3]
/(Body weight)$^{0.75}$	0.350 ± 0.005	0.376 ± 0.005[2]	0.356 ± 0.005	0.370 ± 0.005[3]
AEE (MJ/d)				
FFM	2.87 ± 0.13	3.11 ± 0.13	2.68 ± 0.13	3.27 ± 0.13[3]
FFM + fat mass	2.87 ± 0.13	3.12 ± 0.13	2.78 ± 0.13	3.21 ± 0.13[3]
Body weight	2.93 ± 0.13	3.06 ± 0.13	2.60 ± 0.13	3.39 ± 0.13[3]

[1] Least-squares $\bar{x}$ ± SEM. TDEE, total daily energy expenditure; FFM, fat-free mass; RMR, resting metabolic rate; AEE, activity energy expenditure.
[2] Significantly different from African American, $P < 0.05$.
[3] Significantly different from girls, $P < 0.05$.

TABLE 3
Energy expenditure components of race-by-sex groups adjusted for differences in body size[1]

Energy expenditure component and adjustment	African American Girls (n = 32)	African American Boys (n = 33)	White Girls (n = 33)	White Boys (n = 33)
TDEE (MJ/d)				
FFM	9.05 ± 0.17	9.59 ± 0.17	9.42 ± 0.17	10.09 ± 0.17
FFM + fat mass	9.05 ± 0.17	9.59 ± 0.17	9.42 ± 0.17	10.09 ± 0.17
Body weight	8.98 ± 0.17[a]	9.82 ± 0.17[b]	9.13 ± 0.17[a]	10.18 ± 0.17[b]
RMR (MJ/d)				
FFM	5.62 ± 0.13[a]	5.43 ± 0.13[a]	5.80 ± 0.13[a]	6.22 ± 0.13[b]
FFM + fat mass	5.63 ± 0.13[a]	5.45 ± 0.13[a]	5.75 ± 0.13[a]	6.24 ± 0.13[b]
Surface area	5.58 ± 0.13[a]	5.56 ± 0.13[a]	5.66 ± 0.13[a]	6.25 ± 0.13[b]
/(Body weight)$^{0.75}$	0.354 ± 0.008[a]	0.345 ± 0.008[a]	0.358 ± 0.008[a]	0.394 ± 0.008[b]
AEE (MJ/d)				
FFM	2.47 ± 0.21	3.31 ± 0.21	2.93 ± 0.17	3.22 ± 0.17
FFM + fat mass	2.51 ± 0.17	3.22 ± 0.17	3.04 ± 0.17	3.20 ± 0.17
Body weight	2.43 ± 0.21	3.35 ± 0.21	2.88 ± 0.21	3.26 ± 0.21

[1] Least-squares $\bar{x}$ ± SEM. TDEE, total daily energy expenditure; FFM, fat-free mass; RMR, resting metabolic rate; AEE, activity energy expenditure. Means within rows with different superscript letters are significantly different, $P < 0.005$.

analysis were much smaller (n = 13–19), making significant differences more difficult to detect. There were no significant three-way interactions; thus, no significant differences between means are noted.

DISCUSSION

This is the largest study to date of the complete components of energy expenditure in preadolescent children (n = 131). We studied >60 children in each race and sex group, and >30 children

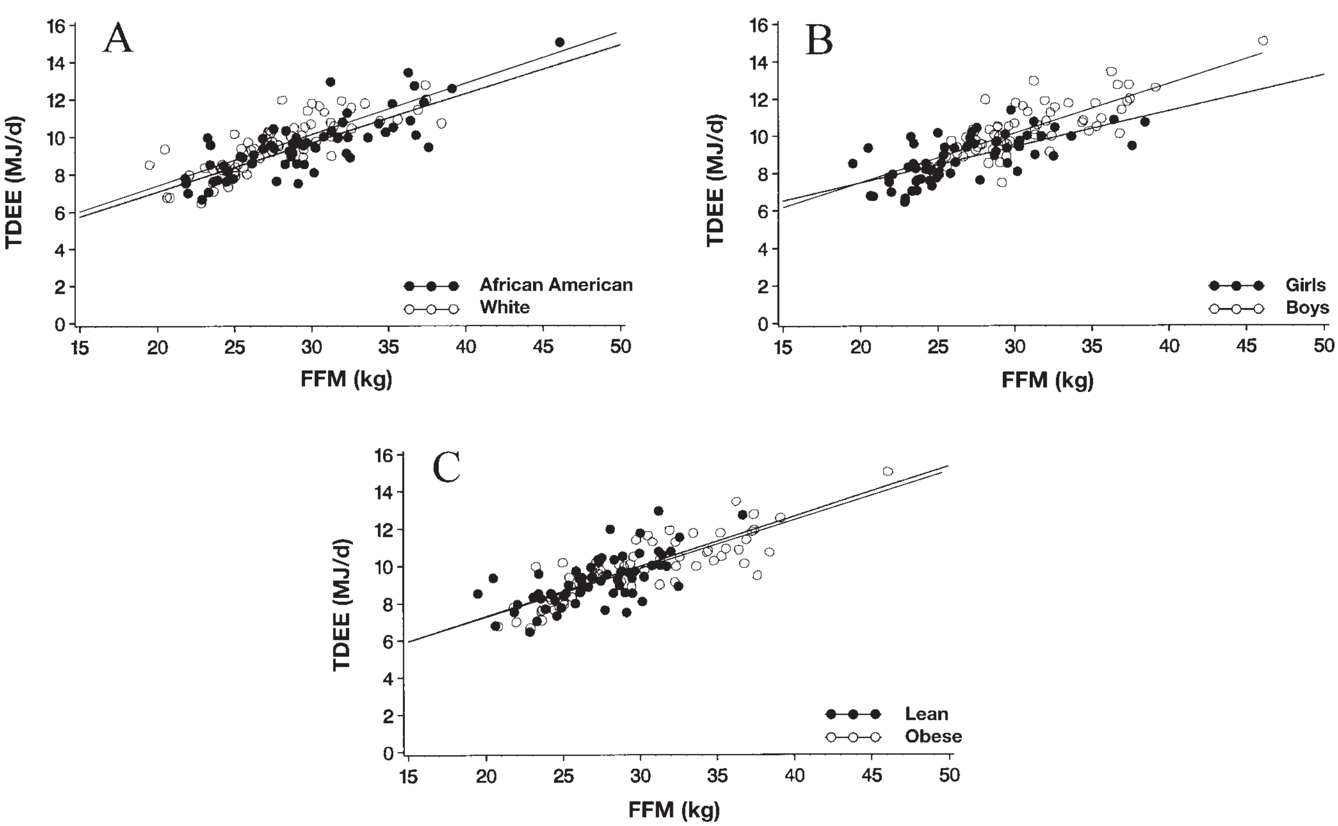

FIGURE 1. Total daily energy expenditure (TDEE) versus fat-free mass (FFM). For sample sizes, *see* Tables 1 and 4. A) African American children, TDEE = 0.262 × FFM + 1.831 (r^2 = 0.64, $P < 0.0001$); white children, TDEE = 0.274 × FFM + 1.924 (r^2 = 0.64, $P < 0.0001$). Results of ANOVA for simultaneous test of slopes and intercepts: $P < 0.02$. B) Girls, TDEE = 0.192 × FFM + 3.660 (r^2 = 0.44, $P < 0.0001$); boys, TDEE = 0.264 × FFM + 2.230 (r^2 = 0.61, $P < 0.0001$). Results of ANOVA for simultaneous test of slopes and intercepts: $P < 0.0003$. C) Lean children, TDEE = 0.268 × FFM + 1.937 (r^2 = 0.45, $P < 0.0001$); obese children, TDEE = 0.260 × FFM + 2.066 (r^2 = 0.70, $P < 0.0001$). None of the differences tested by ANOVA were significant.

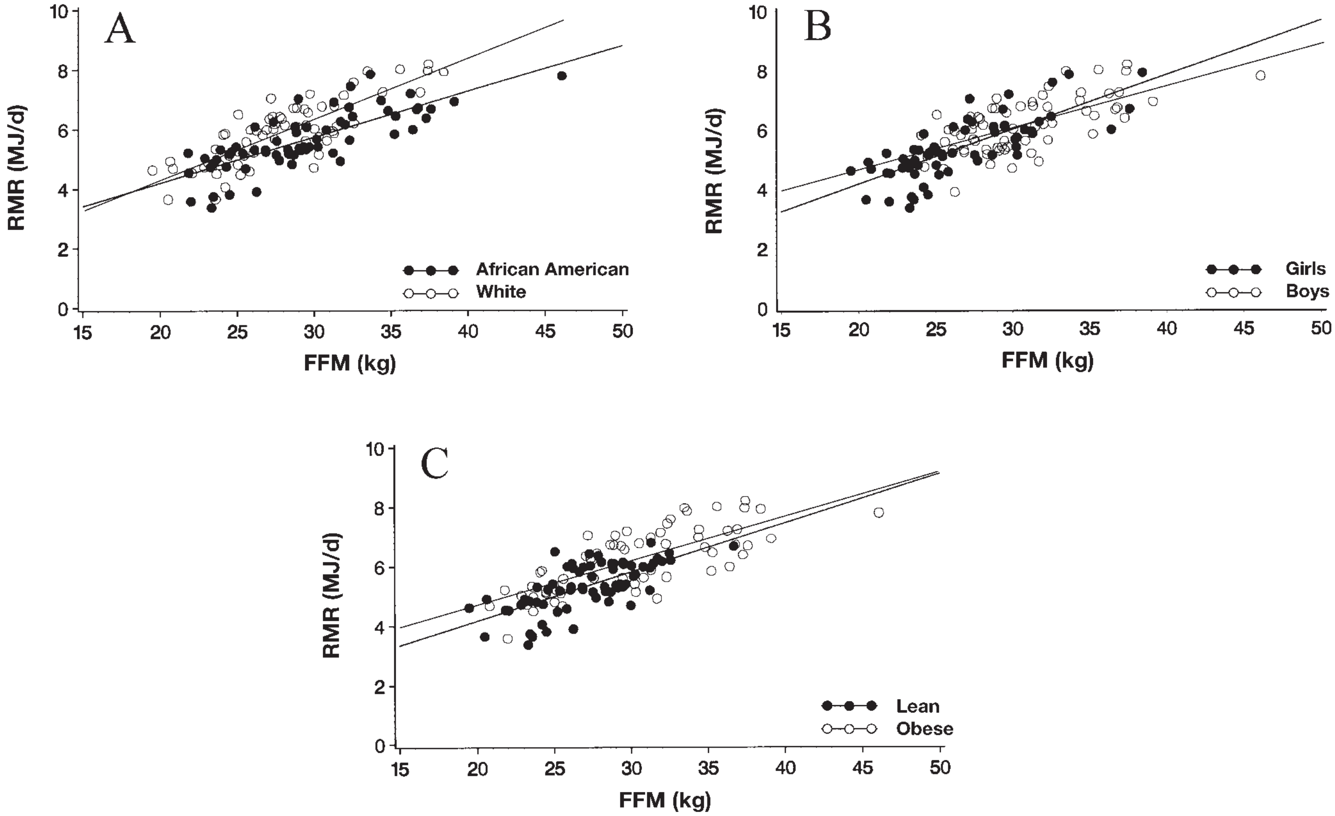

FIGURE 2. Resting metabolic rate (RMR) versus fat-free mass (FFM). For sample sizes, *see* Tables 1 and 4. A) African American children, RMR = 0.157 × FFM + 1.365 (r^2 = 0.51, P < 0.0001); white children, RMR = 0.204 × FFM + 0.310 (r^2 = 0.57, P < 0.0001). Results of ANOVA for differences in intercepts: P < 0.05; results of ANOVA for simultaneous test of slopes and intercepts: P < 0.0001. B) Girls, RMR = 0.177 × FFM + 0.932 (r^2 = 0.49, P < 0.0001); boys, RMR = 0.165 × FFM + 1.286 (r^2 = 0.42, P < 0.0001). None of the differences tested by ANOVA were significant. C) Lean children, RMR = 0.142 × FFM + 1.689 (r^2 = 0.29, P < 0.0001); obese children, RMR = 0.163 × FFM + 1.558 (r^2 = 0.56, P < 0.0001). Results of ANOVA for simultaneous test of slopes and intercepts: P < 0.005.

in the individual race-by-sex groups. When the racial groups were combined, the boys had a higher TDEE than did the girls. Among the white children, the boys had a higher RMR than did the girls, whereas this was not observed in the African American children. When the sex groups were analyzed together, TDEE was higher in the white children than in the African American children. The energy components accounting for these racial differences were different by sex. The African American and white boys had nearly identical AEEs, whereas the white girls tended to have a higher AEE (P = 0.16) than did the African American girls. The white boys had a higher RMR than did the African American boys, whereas in girls RMR was not significantly different by race. No significant differences in TEF were observed between groups.

Our finding of no significant difference in RMR between the African American and white girls is at odds with several previous reports (10, 12–15, 23; **Table 6**). In a study of 98 prepubertal and pubertal girls, white girls had a higher RMR than did African American girls (12). The reasons for this discrepancy are unclear, but the girls in our study were younger (10.7 compared with 11.4–11.9 y) and were therefore farther from puberty. We also had more preadolescent African American (32 compared with 9) and white (33 compared with 19) girls in our study. The fact that only 9 African American prepubertal girls were included in the study by Morrison et al (12) is a cause for concern. In another study, a lower RMR was observed in 41 African American (5.57 ± 0.54 MJ/d) than in 40 white (5.90 ± 0.54 MJ/d) pubertal girls (13). In a study of 34 prepubertal children with a wide age range ($\bar{x}$: ≈9.2 y; range: 5–12 y) RMR was lower in the African American children than in the white children (5.49 ± 0.17 compared with 6.37 ± 0.17 MJ/d) after adjustment for age, sex, weight, FFM, and fat mass (10). In that study, there were no reported sex effects so boys and girls were combined. When we combined the boys and girls in our study, we did see a race effect when we adjusted for FFM (Table 2). In a group of African American (n = 21) and white (n = 24) girls (9.3 y of age; 81% Tanner stage 1 or 2), RMR was 0.38-MJ/d lower in the African American girls when adjusted for FFM (14). On the other hand, in a study of 18 white girls and 21 white boys compared with 29 African American girls and 30 African American boys, no significant effects of ethnicity on RMR were observed, but boys had a higher RMR than did girls (15).

One interesting difference between our study and the others is that we included a familiarization RMR measurement. Bandini et al (7) reported that apprehension in some children causes inaccurate RMR measures. Therefore, we conducted a practice, familiarization RMR on the morning when body composition was measured at the Pennington Center. The RMR measured during the familiarization session was higher than that measured in the second session at the school in all groups except the

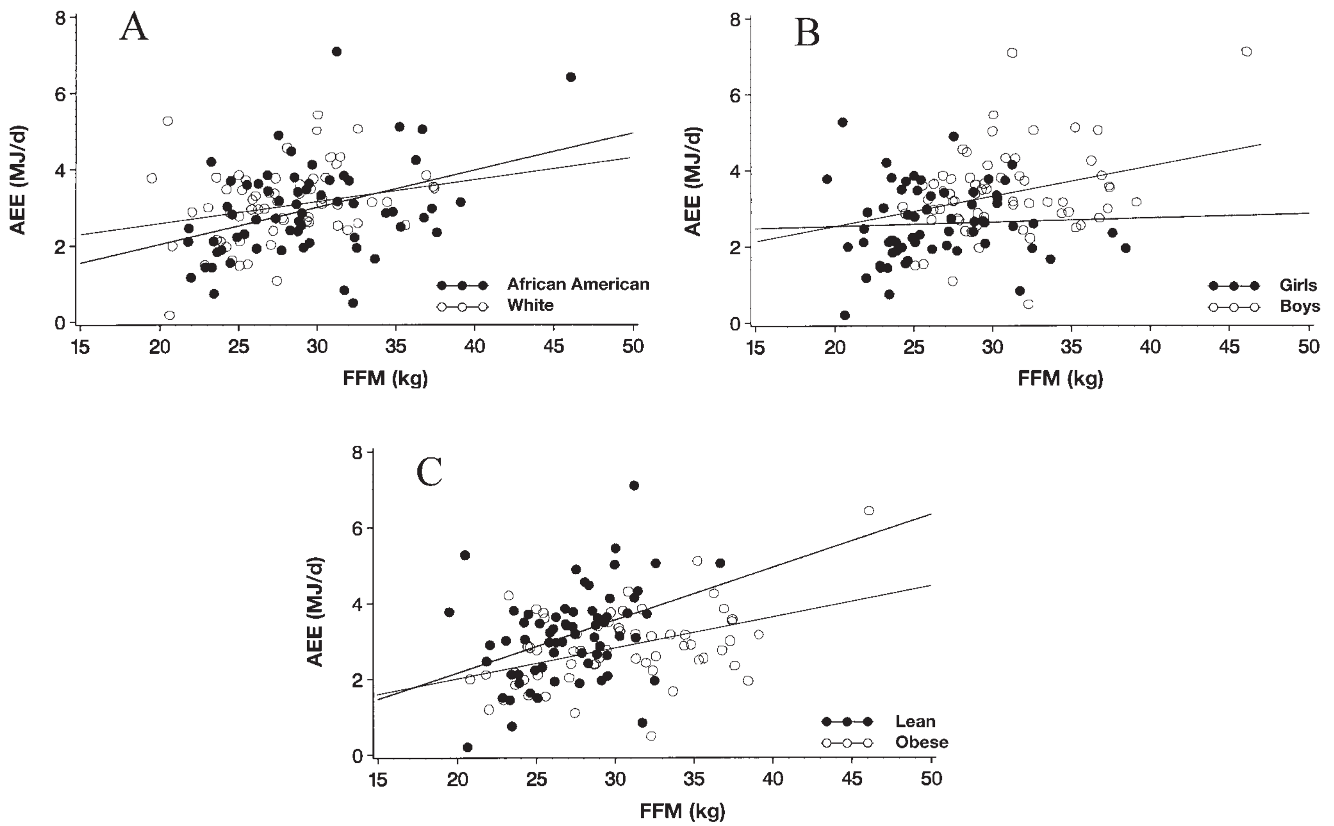

FIGURE 3. Activity energy expenditure (AEE) versus fat-free mass (FFM). For sample sizes, *see* Tables 1 and 4. A) African American children, AEE = 0.097 × FFM + 0.094 (r^2 = 0.14, $P < 0.002$); white children, AEE = 0.058 × FFM + 1.435 (r^2 = 0.05, $P < 0.05$). None of the differences tested by ANOVA were significant. B) Girls, AEE = 0.107 × FFM + 2.314 (r^2 = 0.01, P = 0.73); boys, AEE = 0.079 × FFM + 0.949 (r^2 = 0.08, $P < 0.02$). Results of ANOVA for simultaneous test of slopes and intercepts: $P < 0.008$. C) Lean children, AEE = 0.139 × FFM + 0.621 (r^2 = 0.13, $P < 0.002$); obese children, AEE = 0.081 × FFM + 0.379 (r^2 = 0.18, $P < 0.0005$). Results of ANOVA for simultaneous test of slopes and intercepts: $P < 0.003$.

African American girls (Table 1). When we compared the familiarization RMR between the African American and white girls (Table 6), we observed a higher metabolic rate in the white girls. However, there was no significant racial difference in girls when examining the second or the lowest of the 2 RMR measurements (although the mean RMR was 3.2% lower in the African American girls). It was interesting to note that there was no indication of a racial difference in RMR in the lean girls (Table 5). Both the familiarization and the second RMR measurements were higher in the white boys than in the African American boys (Table 6). When the data in Table 6 are taken as a whole, it seems clear that RMR is lower in African American children than in white children, although the difference may be small in girls and may not be apparent in prepubertal lean girls.

Although we found no significant racial difference in RMR in the girls in our study, we did find a lower TDEE and AEE in the African American girls (Table 3). TDEE measured with DLW and AEE have been reported to be lower in African American than in white pubertal girls (13). Lower physical activity was also shown in Pima Indian girls than in white girls with the use of activity questionnaires (24).

Sex differences in RMR have also been observed previously. In a study of 113 prepubertal (3.9–7.8 y) children of whom 71% were white and 29% were Mohawk Indian, RMR was lower in girls than in boys (25). In our study, we did not observe a lower RMR in the African American girls than in the African American boys, but

TABLE 4
Characteristics and energy expenditure components of lean and obese children[1]

	Lean (n = 67)	Obese (n = 64)
Age (y)	10.7 ± 0.1	10.8 ± 0.1
Weight (kg)	33.8 ± 0.5	48.1 ± 1.3[2]
Height (cm)	143.4 ± 0.8	146.7 ± 0.9[2]
BMI (kg/m²)	16.4 ± 0.3	22.1 ± 0.3[2]
FFM (kg)	27.2 ± 0.4	30.1 ± 0.7[2]
Body fat (kg)	6.0 ± 1.2	17.3 ± 0.8[2]
Percentage body fat (%)	17.9 ± 0.4	35.5 ± 0.8[2]
TDEE (MJ/d)	9.25 ± 0.17	9.80 ± 0.17[2]
Adjusted TDEE (MJ/d)[3]	9.59 ± 0.13	9.49 ± 0.13
RMR (MJ/d)	5.57 ± 0.13	6.41 ± 0.13[2]
Adjusted RMR (MJ/d)[3]	5.58 ± 0.08	5.95 ± 0.08[2]
Adjusted RMR (MJ/d)[4]	5.74 ± 0.10	5.79 ± 0.10
Adjusted AEE (MJ/d)[3]	3.30 ± 0.13	2.68 ± 0.13[2]
Physical activity level	1.69 ± 0.03	1.54 ± 0.03[2]
TEF (%)	5.92 ± 0.41	6.21 ± 0.42
RQ during TEF	0.87 ± 0.01	0.86 ± 0.01

[1] Least-squares $\bar{x}$ ± SEM. FFM, fat-free mass; TDEE, total daily energy expenditure; RMR, resting metabolic rate; AEE, activity energy expenditure; TEF, thermic effect of food; RQ, respiratory quotient.
[2] Significantly different from lean, $P < 0.05$.
[3] Adjusted for FFM.
[4] Adjusted for FFM and fat mass.

TABLE 5
Energy expenditure components of race-by-sex-by-obesity groups[1]

	African American				White				
	Girls		Boys		Girls		Boys		
	Lean (n = 19)	Obese (n = 13)	Lean (n = 17)	Obese (n = 16)	Lean (n = 16)	Obese (n = 17)	Lean (n = 15)	Obese (n = 18)	Significant effects
Adjusted TDEE (MJ/d)[2]	9.11 ± 0.21	9.00 ± .025	9.63 ± 0.21	9.59 ± 0.25	9.42 ± 0.25	9.42 ± 0.21	10.22 ± 0.21	9.97 ± 0.21	R, S
Adjusted RMR (MJ/d)[2]	5.51 ± 0.17	5.73 ± 0.21	5.24 ± 0.17	5.62 ± 0.21	5.50 ± 0.17	6.10 ± 0.17	6.08 ± 0.17	6.36 ± 0.17	R, R × S, O
Adjusted RMR (MJ/d)[3]	5.67 ± 0.15	5.59 ± 0.17	5.45 ± 0.17	5.45 ± 0.17	5.60 ± 0.16	5.90 ± 0.17	6.25 ± 0.17	6.23 ± 0.15	R, R × S
Adjusted AEE (MJ/d)[2]	2.55 ± 0.25	2.46 ± 0.29	3.68 ± 0.25	2.79 ± 0.25	3.30 ± 0.25	2.72 ± 0.25	3.66 ± 0.25	2.75 ± 0.25	S, O

[1] Least-squares $\bar{x}$ ± SE. TDEE, total daily energy expenditure; RMR, resting matabolic rate; AEE, activity energy expenditure. Significant effects are given for race (R), sex (S), and obesity group (O), as well as any interactions. There were no significant race × sex × obesity group interactions.
[2] Adjusted for fat-free mass.
[3] Adjusted for fat-free mass and fat mass.

RMR was lower in the white girls than in the white boys. We observed significantly lower TDEE and physical activity in the girls than in the boys. The sex difference in AEE was nearly completely explained by a 25% lower AEE in the African American girls (mean AEE, although not significantly different, was ≈9% lower in the white girls than in the white boys as well). A reduction in TDEE was noted in girls between the ages of 6.5 and 9.5 y, which was explained by a 50% reduction in physical activity (26). A lower TDEE and AEE were also observed in 15 girls (9.5 y of age) than in 22 boys (9.7 y age) with the use of heart rate monitors calibrated for each child (27). No sex differences in any energy expenditure components measured in a metabolic chamber were observed in a study of 235 female and 78 male subjects ranging in age from 15 to 64 y (28). However, measurements in a metabolic chamber preclude usual physical activity.

The obese children had a higher TDEE than did the lean children, but this difference disappeared after adjustment for differences in body size. Even after adjustment for FFM, however, the

TABLE 6
Reported measurements of resting metabolic rate (RMR) and sleeping metabolic rate (SMR) in African American (A) and white (W) children[1]

Reference	Measurement	Adjustment	Percentage < Tanner stage 3	Metabolic rate[2] White	Metabolic rate[2] African American	P
			%	*MJ/d*		
Wong et al, 1996 (23)	Chamber:	Mean BW of ethnic groups	33.7 (W), 2.7 (A)			
	BMR next morning			5.65 [76 G]	5.44 [42 G]	0.02
	SMR overnight			4.94	4.73	0.01
Wong et al, 1999 (13)	Chamber:	Lean tissue mass	0			
	BMR next morning			5.90 [40 G]	5.57 [41 G]	0.01
	SMR overnight			5.49	5.19	0.03
Sun et al, 1998 (15)	RMR after overnight fast	FFM and FM	100[3]	5.11 [18 G]	5.11 [29 G]	0.8
	admitted to CRC previous afternoon		100[3]	5.36 [21 B]	5.32 [30 B]	0.8
Morrison et al, 1996 (12)	RMR after 3-h fast	LBM, race, maturation	Prepubertal	5.86 [19 G]	4.86 [9 G]	0.01
			Prepubertal and premenarcheal	5.74 [14 G]	5.36 [19 G]	NS
			Postmenarcheal	4.86 [18 G]	4.61 [19 G]	NS
Kaplan et al, 1996 (10)	RMR while watching videos, after 12-h fast, standardized evening meal	Age, sex, weight, FFM, ethnic background	100 (obese)	6.66 [8]	5.70 [9]	0.05
			100 (nonobese)	6.11 [7]	5.28 [10]	0.05
Yanovski et al, 1997 (14)	Admitted to center previous afternoon, familiarized with hood, RMR after 12-h fast	None	96 (W), 81 (A)	4.73 [24 G]	4.52 [21 G]	NS[4]
Current study[5]	Familiarization	FFM	100 (G)	6.37	5.95	0.01
	RMR: overnight fast, rest 30 min		100 (B)	6.66	6.11	0.01
	RMR: Overnight fast,	FFM	100 (G)	5.80	5.62	NS
	rest 30 minutes		100 (B)	6.22	5.43	0.01

[1] B, boys; BW, body weight; CRC, Clinical Research Center; FFM, fat-free mass; FM, fat mass; G, girls; LBM, lean body mass.
[2] n in brackets.
[3] Assumed (mean age of the children was 7.8 ± 1.5).
[4] Difference from whites after adjustment for FFM: −0.38 MJ (P = 0.01).
[5] For sample sizes, *see* Table 1.

obese children had a higher RMR and a lower AEE than did the lean children. A higher RMR was also observed in obese children in several other studies (29, 30). However, when RMR was adjusted for FFM and fat mass in those studies there was no longer a significant difference between lean and obese children. In a model attempting to explain the variance in RMR in the present study, FFM was the first variable entering the model, explaining 57% of the variance. The next variable to enter the model ($P < 0.0001$) was fat mass, explaining an additional 4.8% of the variance. Several investigators have shown that fat mass is a determinant of RMR, which makes some sense because adipose tissue is metabolically active (11, 25). An alternative explanation for fat mass being involved in RMR is that fat tissue secretes a component, such as leptin, in proportion to fat mass, which in turn increases energy expenditure.

The lower AEE in the obese children than in the lean children was most apparent in the boys (2.77 ± 0.21 compared with 3.67 ± 0.17 MJ/d for the boys and 2.59 ± 0.21 compared with 2.93 ± 0.17 MJ/d for the girls), although there was no significant sex $\times$ obesity group interaction. Differences between sexes in the relation between physical activity and current body fat or longitudinal body fat gain were observed in Pima Indian children and adults (24, 31). Sport leisure activity over the past year correlated negatively with percentage of body fat in Pima Indian boys but not girls (24).

In summary, in this study of 131 preadolescent children, we observed several racial and sex differences in the various components of energy expenditure. In addition, the obese children had a higher RMR than did the lean children. On the other hand, the obese children expended less energy in physical activity, which was most apparent in the boys. This lower AEE may contribute to the maintenance of obesity in these children.

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