Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: implications for energy requirements[1–3]

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ABSTRACT

Background: There are limited data on the influence of body composition, sex, seasonality, ethnicity, and geographic location on the components of energy expenditure in children.

Objective: The objective was to examine the determinants of total energy expenditure (TEE), resting energy expenditure (REE), and activity-related energy expenditure (AEE) in children.

Design: Cross-sectional data from 232 children (4–10 y of age) from 4 ethnic groups (white American, African American, Guatemalan Mestizo, and Native American Mohawk) were examined.

Results: In 104 white children studied in Vermont and Alabama, TEE was significantly higher in spring than in fall, higher in boys than in girls, and higher in children in Vermont (all effects: $\approx$0.42 MJ/d, $P < 0.05$). The significant effect of sex was explained through REE; the influences of season and location were explained through AEE. In all children, there was no effect of sex but a significant effect of ethnicity ($P < 0.01$) on TEE; a significant effect of sex ($P < 0.01$) and no effect of ethnicity ($P = 0.16$) on REE; and no effect of sex and a significant effect of ethnicity on AEE. The significant effects of ethnicity were due to lower values in Guatemalan children. TEE correlated most strongly with weight ($r = 0.81$) and fat-free mass ($r = 0.79$–0.81); REE with weight ($r = 0.85$) and fat-free mass ($r = 0.80$–0.87); and AEE with maximal oxygen consumption ($r = 0.54$), fat-free mass ($r = 0.50$), and fat mass ($r = 0.49$).

Conclusions: *1*) Season and location influenced TEE in children through their effects on AEE, *2*) a higher REE in boys was consistent across all groups examined, *3*) Guatemalan children had lower TEE due to a lower AEE, *4*) body weight may be the best predictor of TEE, and *5*) maximal oxygen consumption was the strongest marker of AEE. *Am J Clin Nutr* 1998; 68:675–82.

KEY WORDS Children, obesity, energy metabolism, physical activity, body composition, energy needs, ethnicity, seasonal effects, energy expenditure

INTRODUCTION

Energy requirements are defined as the amount of dietary energy needed to maintain health, growth, and an appropriate level of physical activity (1). The 1985 WHO/UNU/FAO report (1) recommended that energy needs be based on measurement of total energy expenditure (TEE) and requirements calculated as multiples of measured or predicted resting energy expenditure (REE). At the time of the original report, there were no available data on TEE or activity-related energy expenditure (AEE) in children; hence, estimates were based on reported energy intake data. Studies have shown that TEE in prepubertal children living in Burlington, VT (2, 3), Phoenix, AZ (4), Cambridge, United Kingdom (5), and Belfast, Northern Ireland (6) is ≈25% lower than that reflected by current recommendations.

In 1995, a panel was convened by the International Dietary Exchange Consultancy Group to review energy requirements in children and it agreed that, based on new TEE data, existing recommendations were too high for children <7 y of age (7). The panel also recognized that lifestyles among populations differed (eg, because of different degrees of development, differences between rural and urban settings, and socioeconomic differences) and that data to address these issues were lacking. On the basis of recent data on TEE in children, the panel recommended energy requirements based on multiples of measured or predicted REE. To develop recommendations, children are first categorized as having light, moderate, or heavy physical activity levels. In boys and girls 1–5 y of age, the new recommendations are 1.45 and 1.60 × REE for light and moderate levels of physical activity, respectively. In 6–13-y-old boys, the recommendations are 1.55 (light activity), 1.75 (moderate activity), and 1.95 (heavy activity) × REE and in 6–13-y-old girls, the recommendations are 1.50 (light activity), 1.70 (moderate activity), and 1.90 (heavy activity) × REE.

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Previous studies showed that factors such as body composition and REE account for only 50% of the variance in TEE (8). TEE is also known to be highly variable between and within individuals (8). Moreover, previous studies did not take into account the heterogeneity of the population with respect to factors such as age, body composition, ethnic background, physical activity, geographic location, and seasonality, all of which are potential modulators of energy needs. Thus, by pooling data from a diverse group of prepubertal children who we have studied over the past 6 y, we were able to examine the influence of sex, ethnicity, season, geographic location, body composition, and physical fitness on each of the components of daily energy expenditure (TEE, REE, and AEE).

SUBJECTS AND METHODS

Subjects

We studied 232 children (aged 4–10 y) from 4 different ethnic groups (white American children living in Burlington, VT, and Birmingham, AL; African American children living in Alabama; Guatemalan Mestizo children living in Guatemala City; and Native American Mohawk children living in Akwesasne, NY) summarized in **Table 1**. For studies in Vermont, Alabama, and New York, subjects were recruited by newspaper advertisements, distribution of fliers, and word of mouth and there were no major inclusion or exclusion criteria other than the absence of major illness since birth. In Guatemala the subjects were recruited from an ongoing study in one school and none showed symptoms of acute malnourishment at the time of the study. Studies were performed at various times of the year except winter, and season of study was classified as spring (March, April, and May; 103 observations, including all the Guatemalan children), summer (June, July, and August; 15 observations, most of which were in Mohawk children), and fall (September, October, and November; 103 observations). We have reported data from these children in several other studies (2, 3, 9–12). The descriptive characteristics of each group are listed in **Table 2.** The studies were approved by the Institutional Review Boards of the University of Vermont, The University of Alabama at Birmingham, and the Center for Studies of Sensory Impairment, Aging and Metabolism (CeSSIAM) in Guatemala City.

Measurement of total energy expenditure

TEE was measured over 14 d under free-living conditions with the doubly labeled water technique by using a protocol with a theoretical error rate <5%, as described previously (2). Samples were analyzed in triplicate for $H_2{}^{18}O$ and ^2H_2O by isotope-ratio mass spectrometry at the University of Alabama at Birmingham as described previously (11). When all samples of $^2H_2$ and ^{18}O were reanalyzed in 7 subjects, values of TEE were in close agreement (CV: 4.3%), as described previously (11). By analysis of variance (ANOVA), the ratio of ^2H to oxygen dilution space was not significantly influenced by ethnicity ($P = 0.15$) or sex ($P = 0.22$), or by the interaction of ethnicity and sex ($P = 0.97$). The dilution space ratio was 1.055 ± 0.04 and 1.059 ± 0.023 in white girls and boys, 1.048 ± 0.03 and 1.057 ± 0.01 in Mohawk girls and boys, 1.043 ± 0.03 and 1.048 ± 0.05 in Guatemalan girls and boys, and 1.058 ± 0.02 and 1.063 ± 0.02 in African American girls and boys. Thus, carbon dioxide production rates were determined by using a fixed assumption for the dilution space ratio (1.0427) in equation *R2* of Speakman et al (13), and energy expenditure was calculated by using equation *12* of de Weir (14), assuming a mean value for the dietary food quotient obtained by 24-h recall. The mean food quotient was 0.90 in white and Mohawk children, 0.87 in African American children, and 0.93 in Guatemalan children.

TEE data were screened for physiologic outliers by regressing TEE against body weight, fat-free mass, and REE. Values were defined as outliers if the standardized residual from any of these regressions was >3.0. By using these procedures, 7 TEE values were considered outliers and were not considered in the analysis (14.2, 14.3, 15.8, 12.6, 9.9, 4.9, and 3.3 MJ/d).

Measurement of resting energy expenditure

REE was assessed in all children by using a Deltatrac metabolic monitor and a canopy system for respiratory gas collection (SensorMedics, Yorba Linda, CA). One machine was used for the white children in Vermont and the Mohawk children, and another machine was used for the white and African American children in Alabama and the Guatemalan children (the machine was transported to Guatemala). Both machines were validated by an alcohol burn test every other month and calibrated before each test by using gases provided by the manufacturer. In the white children in Vermont and the Mohawk children, REE was measured in the morning by using an outpatient protocol in the postprandial state 2–3 h after the children consumed breakfast in their homes, as described previously (9). In a previous study in 19 healthy children (9), we compared REE measurements by using an inpatient protocol after an overnight fast with an alternative postprandial, outpatient protocol. REE was ≈11% higher with the postprandial, outpatient protocol (4.87 ± 0.63 MJ/d, or 1165 ± 151 kcal/d) than with the inpatient protocol (4.39 ± 5 MJ/d, or 1050 ± 151 kcal/d). Therefore, for comparative pur-

TABLE 1
Sex and ethnic composition of the study group[1]

Ethnic group	Boys	Girls
White		
Vermont	34 (1 summer, 20 fall, 13 spring)	32 (1 summer, 22 fall, 9 spring)
Alabama	22 (7 fall, 15 spring)	17 (10 fall, 7 spring)
Subtotal	56 (1 summer, 27 fall, 28 spring)	49 (1 summer, 32 fall, 16 spring)
Mohawk	17 (7 summer, 1 fall, 9 spring)	21 (4 summer, 1 fall, 16 spring)
Guatemalan	14 (14 spring)	16 (16 spring)
African American	30 (1 summer, 26 fall, 3 spring)	29 (1 summer, 27 fall, 1 spring)
Total	117 (9 summer, 54 fall, 54 spring)	115 (6 summer, 60 fall, 49 spring)

[1] *n* (*n*, season studied).

TABLE 2
Physical characteristics of the children in the study[1]

	All children (n = 232)	White (n = 105)	Mohawk (n = 38)	Guatemalan (n = 30)	African American (n = 59)
Age (y)	6.7 ± 1.6	7.0 ± 1.5	5.5 ± 0.8	5.4 ± 0.8	7.5 ± 1.5
Weight (kg)	26.4 ± 10.4	27.5 ± 10.0	20.6 ± 4.5	17.8 ± 2.3	32.5 ± 11.6
Height (m)	1.20 ± 0.12	1.23 ± 0.10	1.11 ± 0.06	1.06 ± 0.06	1.29 ± 0.11
FFM (kg)	20.6 ± 5.9	21.1 ± 5.1	17.0 ± 2.7	15.3 ± 1.9	24.7 ± 6.8
Fat mass (kg)	5.8 ± 5.1	6.5 ± 5.7	3.6 ± 2.1	2.6 ± 0.8	7.8 ± 5.4
Percentage body fat (%)	19.5 ± 8.6	20.8 ± 9.6	16.5 ± 5.3	14.3 ± 3.7	21.9 ± 8.5
TEE (MJ/d)	6.53 ± 1.59	6.75 ± 1.46	5.90 ± 0.94	5.04 ± 0.93	7.31 ± 1.73
REE (MJ/d)	4.61 ± 0.91	4.70 ± 0.82	3.99 ± 0.63	3.93 ± 0.47	5.18 ± 0.92
AEE (MJ/d)	1.27 ± 0.98	1.37 ± 0.91	1.31 ± 0.95	0.61 ± 0.72	1.41 ± 1.11

[1] $\bar{x}$ ± SD. Fat-free mass (FFM) and fat mass were determined by anthropometry. TEE, total energy expenditure; REE, resting energy expenditure; AEE, activity-related energy expenditure.

poses in the current analysis, postprandial measurements of REE were reduced by 11%. In Guatemalan children, REE was measured by using an outpatient protocol with subjects reporting for measurement in the fasted state. In white and African American children studied in Alabama, REE was measured by using an inpatient protocol in the early morning with children in the fasted state after they spent the night at the General Clinical Research Center.

REE data were screened for physiologic outliers by regressing REE against body weight and fat-free mass. Data were considered outliers if the residual from either of these regressions was >3 SDs from the mean. According to these criteria, no REE measurements were considered outliers.

Assessment of activity-related energy expenditure

AEE was estimated by subtracting REE from TEE after reducing TEE by 10% to account for the thermic response to meals (15), which was not measured in this study. We used the fasting measurements of REE or the adjusted postprandial measurement as described above.

Ten of 232 estimates of AEE made by using this approach yielded negative values. Data from 3 of these subjects were included in the doubly labeled water reanalysis described above, and the data were all reproducible. Also, the values of TEE and REE for these subjects fell within the screening criteria described above (ie, fell within the normal range relative to body weight and body composition). Thus, the negative values were retained in the analysis. We felt that deleting the negative values would bias the data because they are the result of random error propagation generated by the subtraction of REE from TEE, as described previously (9).

Assessment of body composition and anthropometry

Height of subjects without shoes was measured by using a stadiometer. Weight of subjects in light clothing was measured with an electronic scale (Cardinal Scale Manufacturing Co, Webb City, MO). Bioelectrical resistance was measured with a Xitron analyzer (Xitron Technologies, Inc, San Diego) (Guatemalan children) and an RJL 101 (RJL Systems, Detroit) (all other children) at 50 kHz by using the manufacturers' recommended tetrapolar electrode placement. Resistance was measured while the child was still and supine on a foam mattress with arms and legs slightly abducted. Skinfold thicknesses (axillar, chest, subscapular, suprailiac, abdomenal, triceps, calf, and thigh) were measured by using the procedures of Lohman et al (16). Fat and fat-free mass were estimated in all children by using an equation based on skinfold thicknesses, anthropometry, and bioelectrical resistance that we developed previously (17).

In a subgroup of children (white children in Vermont and Alabama and African American children), body composition was also measured by dual-energy X-ray absorptiometry (DXA) using a Lunar DPX-L densitometer (Lunar Corporation, Madison, WI) that we validated previously in the pediatric body weight range (18). Subjects were scanned in light clothing while lying flat on their backs with their arms by their sides. DXA scans were performed and analyzed by using pediatric software (version 1.5e) as described previously (17, 18). The DPX-L apparatus was calibrated on the day of each test by using the procedures provided by the manufacturer. In the current analysis, DXA measures of fat-free mass include soft lean tissue and bone mass.

Assessment of fitness

In a subgroup of children studied in Birmingham, AL, maximal oxygen consumption ($\dot{V}O_2$max) was measured during a treadmill test to exhaustion. Children walked for 4 min at 0% grade and 4 km/h, after which the treadmill grade was raised to 10%. Each ensuing work level lasted 2 min, during which the grade was increased by 2.5%. The speed remained constant until a 22.5% grade was reached, at which time the speed was increased by 0.6 km/h until the subject reached exhaustion. Oxygen consumption and carbon dioxide production were measured continuously via open-circuit spirometry and analyzed by using a SensorMedics metabolic cart (model 2900). Before each test session, the gas analyzers were calibrated with certified gases of known standard concentrations. During the treadmill test, heart rate was monitored by a Polar Vantage XL heart rate monitor (model 61204; Creative Health Products, Ann Arbor, MI). $\dot{V}O_2$max was defined by attainment of 2 of the following 3 criteria: *1*) a leveling or plateauing of oxygen consumption (defined as an increase of oxygen uptake $<2\ \mathrm{mL \cdot kg^{-1} \cdot min^{-1}}$), *2*) a heart rate >195 beats/min, and *3*) a respiratory exchange ratio >1.0.

Statistics

Differences in physical characteristics and energy expenditure were examined by using ANOVA and analysis of covariance (ANCOVA). TEE, REE, and AEE were examined as dependent variables with fat and fat-free mass (from either the anthropometric prediction equation or as measured by DXA) as covari-

ates, and sex, ethnic group, season of study, and geographic location as classification variables. We examined *1*) the effects of season (spring versus fall), geographic location (Vermont versus Alabama), and sex on TEE, REE, and AEE in white children; and *2*) the influence of sex and ethnicity (white, Mohawk, Guatemalan, African American) on TEE, REE, and AEE in all children. For ANCOVA models, similarity of regression slopes among the subgroups was examined by the significance of the interaction between the covariate and each of the 2 grouping variables. A nonsignificant interaction ($P > 0.05$) was a prerequisite for proceeding with the ANCOVA models. The determinants of TEE, REE, and AEE were examined by correlation analysis and forward, stepwise regression analysis.

All statistics were computed by using SAS for Windows version 6.10 (SAS Institute, Cary, NC). The level of statistical significance was set at a probability of $P \leq 0.05$ for all tests. Data are cited as means ± SDs unless otherwise noted.

RESULTS

Effects of season and geographic location on energy expenditure components in white children

The effects of season (spring versus fall) and geographic location (Vermont versus Alabama) were examined in 104 of the white children (3 children were excluded from this analysis because they were studied in the summer). After fat and fat-free mass were adjusted for, there were significant effects of season ($P = 0.03$), sex ($P = 0.04$), and geographic location ($P = 0.05$) on adjusted TEE values (no significant interactions among factors). As summarized in **Figure 1**, adjusted TEE was ≈0.42-MJ/d higher in boys than in girls, 0.42-MJ/d higher in spring than in fall, and 0.42-MJ/d higher in children in Vermont than in Alabama. In similar analyses for REE, there were no significant effects of season ($P = 0.29$) or geographic location ($P = 0.82$), but there was a significant effect of sex ($P = 0.001$), with boys having a higher REE by ≈0.42 MJ/d (Figure 1). For AEE, there was no significant effect of sex ($P = 0.66$), a marginal effect of season ($P = 0.096$), and a significant effect of geographic location ($P = 0.02$; Figure 1). AEE was 0.42–0.63-MJ/d higher in children in Vermont than in children in Alabama in both sexes and seasons of study (Figure 1). AEE was 0.21–0.42-MJ/d higher in children studied in spring than in those studied in the fall in all comparisons except for girls in Vermont, but the season effect was not significant ($P = 0.096$; Figure 1).

Examination of sex and ethnic effects on energy expenditure components in all children

The influence of sex and ethnicity on TEE, REE, and AEE was examined with ANCOVA. After fat-free mass, fat mass, and season were adjusted for, there was no effect of sex on TEE, a significant overall effect of ethnicity ($P < 0.01$), and no significant interaction between sex and ethnicity. The significant effect of ethnicity was due to a significantly lower adjusted TEE in Guatemalan children, whereas the other groups were not significantly different (**Figure 2**). For REE there was a significant effect of sex ($P < 0.01$), but not ethnicity, after fat-free mass, fat mass, and season were adjusted for. The higher REE in boys was apparent across all ethnic groups (Figure 2). For AEE there were no significant effects of sex, a significant effect of ethnicity ($P < 0.01$), and no significant interaction between sex and ethnicity. The significant effect of ethnicity on AEE was due to lower adjusted values in Guatemalan children (Figure 2).

Determinants of TEE, REE, and AEE

Simple correlations between TEE, REE, AEE, and various physical characteristics and body-composition variables are shown in **Table 3**. TEE and REE were most strongly correlated with body weight and fat-free mass ($r = 0.8$–0.85). Note that the correlations of TEE and REE with fat-free mass were similar whether fat-free mass was estimated by anthropometry or measured by DXA. AEE was most strongly correlated with fat-free mass, fat mass, and $\dot{V}O_2\text{max}$ ($r = 0.49$–0.54). When data were adjusted for weight, the partial correlation between AEE and $\dot{V}O_2\text{max}$ remained significant (partial $r = 0.33$), whereas other correlations with fat and fat-free mass were not significant.

In stepwise regression analysis of the entire cohort, TEE was significantly influenced by weight ($R^2 = 0.65$), as well as height, season of study, geographic location, and sex with a total model R^2 of 0.68 (**Table 4**). In stepwise regression in the subgroup that had

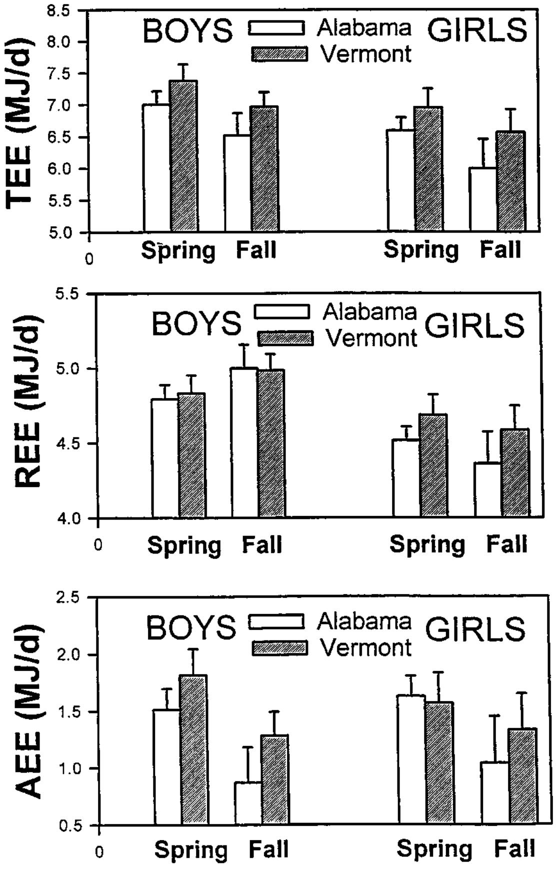

FIGURE 1: Total energy expenditure (TEE), resting energy expenditure (REE), and activity-related energy expenditure (AEE) in boys and girls studied in Alabama or Vermont during spring or fall. Least-square means ± SEs adjusted for fat-free mass and fat mass; sample sizes are provided in Table 1. TEE: significant main effect of season ($P = 0.03$), sex ($P = 0.04$), and geographic location ($P = 0.05$). REE: significant main effect of sex ($P = 0.001$), and no effect of season ($P = 0.29$) or geographic location ($P = 0.82$). AEE: significant main effect of geographic location ($P = 0.02$), a tendency toward a significant effect of season ($P = 0.096$), and no effect of sex ($P = 0.67$). All analyses were two-way ANOVAs. There were no significant interactions among variables.

TABLE 3
Pearson correlation coefficients (*r*) for relations between TEE, REE, and AEE and potential predictor variables in the entire cohort of children[1]

	Correlation with		
	TEE	REE	AEE
Body weight	0.81	0.85	0.40
FFM by DXA ($n = 142$)	0.81	0.80	0.50
FFM by anthropometry	0.79	0.87	0.35
Fat mass by DXA ($n = 142$)	0.75	0.62	0.54
REE	0.74	—	NS
$\dot{V}O_2$max ($n = 62$)	0.74	0.70	0.49
Fat mass by anthropometry	0.72	0.70	0.40
Percentage body fat by anthropometry	0.57	0.54	0.35
Age	0.56	0.61	0.15

[1] $n = 232$ unless otherwise indicated. TEE, total energy expenditure; REE, resting energy expenditure; AEE, activity-related energy expenditure; FFM, fat-free mass; DXA, dual-energy X-ray absorptiometry; $\dot{V}O_2$max, maximal oxygen consumption. All correlations significant, $P < 0.05$, except where denoted by NS.

measures of body composition by DXA, TEE was significantly predicted by fat-free mass ($R^2 = 0.66$), as well as fat mass, season, and sex, with a total model R^2 of 0.73 (Table 4). In children who had measures of body composition by DXA and fitness measures by $\dot{V}O_2$max ($n = 60$ white and African American boys and girls in Alabama), TEE was significantly influenced by fat-free mass (partial $R^2 = 0.66$) as well as $\dot{V}O_2$max and fat mass with a total model R^2 of 0.70, and there were no independent effects of sex, ethnicity, or season (Table 4).

In stepwise regression analysis of the entire cohort, REE was significantly influenced by fat-free mass by anthropometry (partial $R^2 = 0.63$) as well as fat mass by anthropometry, sex, height, and age and geographic location with a total model R^2 of 0.80 (Table 4). In stepwise regression in the subgroup who had actual measures of body composition by DXA, REE was significantly predicted by fat-free mass (partial $R^2 = 0.63$) as well as by fat mass, sex, height, and age with a total model R^2 of 0.72 (Table 4). In children who had measures of body composition by DXA and fitness measures by $\dot{V}O_2$max (the 60 children studied in Birmingham), REE was significantly influenced by fat-free mass (partial $R^2 = 0.59$) as well as fat mass and season with a total model R^2 of 0.67 (Table 4).

In stepwise regression analysis of the entire cohort, AEE was significantly influenced by fat mass by anthropometry (partial $R^2 = 0.16$), as well as season (0.23-MJ/d higher in spring than in fall), geographic location (0.22-MJ/d lower in Alabama than in Vermont), and height with a total model R^2 of 0.22 (Table 4). In stepwise regression in the subgroup who had actual measures of body composition by DXA, AEE was significantly predicted by fat-free mass (partial $R^2 = 0.25$) as well as fat mass, season (0.3-MJ/d higher in spring than in fall), and height with a total model R^2 of 0.32 (Table 4). In children who had measures of body composition by DXA and fitness measures by $\dot{V}O_2$max (the 60 children studied in Alabama), AEE was significantly influenced by $\dot{V}O_2$max (partial $R^2 = 0.29$) as well as fat mass, with a total model R^2 of 0.35 (Table 4).

DISCUSSION

The major objective of this study was to examine the determinants of TEE, REE, and AEE in an ethnically diverse group of 232 children (4–10 y of age) in different geographic locations. Our analysis revealed that TEE was influenced by sex (higher in boys), ethnicity (lower in Guatemalan children), seasonality (higher in spring than in fall), and geographic location (higher in Vermont than in Alabama), as well as body composition (positively influenced by both fat and fat-free mass). Sex exerted an influence on TEE through its effect on REE, whereas season and geographic location influenced TEE through their effects on AEE. The only significant effect of ethnicity was a lower TEE due to a lower AEE in Guatemalan than in other children. $\dot{V}O_2$max was the strongest predictor of AEE, the most variable component of TEE.

This is the first report of independent effects of factors such as season and geographic location on TEE in children. We were able to perform this analysis by comparing data in white children that we have studied in Vermont and Alabama at different times of the year. Typically, we only perform studies in the spring and fall to avoid the harsh winter months in Vermont and the summer months in general because of disruption in physical activity and diet schedules. However, our data show that there is an effect of season on TEE when comparing spring and fall, with higher val-

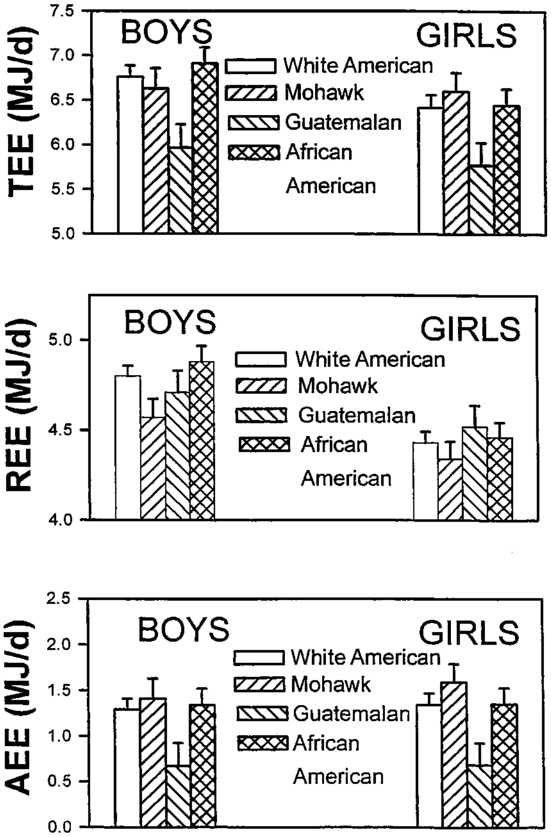

FIGURE 2: Total energy expenditure (TEE), resting energy expenditure (REE), and activity-related energy expenditure (AEE) in white American, Mohawk, Guatemalan mestizo, and African American boys and girls. Least-square means ± SEs adjusted for fat-free mass, fat mass, and season; sample sizes are provided in Table 1. TEE: significant main effect of ethnicity ($P = 0.006$), which was explained in post hoc testing by a significantly lower mean adjusted TEE in Guatemalan children than in the other groups. REE: significant main effect of sex ($P < 0.01$) but not ethnicity ($P = 0.16$); in post hoc testing, the higher REE in boys was apparent in all groups. AEE: significant main effect of ethnicity ($P = 0.003$) due to a lower AEE in Guatemalan children, but no effect of sex ($P = 0.64$). All analyses were two-way ANOVAs.

TABLE 4

Stepwise regression analysis for determinants of TEE, REE, and AEE[1]

Dependent variable and subgroup	Prediction equation	Model r^2
TEE (MJ/d)		
All children ($n = 232$)	$(0.107\times\text{weight}) + (2.91\times\text{height}) + (0.284\times\text{season}) - (0.167\times\text{geographic location}) + (0.284\times\text{sex}) - 0.268$	0.68
Children with DXA ($n = 142$)	$(0.170\times\text{FFM}) + (0.112\times\text{FM}) + (0.38\times\text{season}) + (0.435\times\text{sex}) + 1.66$	0.73
Children with DXA and $\dot{V}O_2$max ($n = 62$)	$(0.115\times\text{FFM}) + (0.056\times\text{FM}) + (1.12\times\dot{V}O_2\text{max}) + 2.74$	0.70
REE (MJ/d)		
All children ($n = 232$)	$(0.080\times\text{FFM}) + (0.035\times\text{FM}) + (0.305\times\text{sex}) + (2.18\times\text{height}) - (0.101\times\text{age}) - (0.088\times\text{geographic location}) - 0.564$	0.80
Children with DXA ($n = 142$)	$(0.055\times\text{FFM}) + (0.038\times\text{FM}) + (0.347\times\text{sex}) + (3.57\times\text{height}) - (0.133\times\text{age}) - 0.217$	0.72
Children with DXA and $\dot{V}O_2$max ($n = 62$)	$(0.061\times\text{FFM}) + (0.060\times\text{FM}) + (0.30\times\text{season}) + 1.59$	0.67
AEE (MJ/d)		
All children ($n = 232$)	$(0.07\times\text{FM}) + (0.234\times\text{season}) - (0.217\times\text{geographic location}) + (1.87\times\text{height}) - 1.73$	0.22
Children with DXA ($n = 142$)	$(0.103\times\text{FFM}) + (0.038\times\text{FM}) + (0.339\times\text{season}) - (2.62\times\text{height}) + 1.47$	0.32
Children with DXA and $\dot{V}O_2$max ($n = 62$)	$(0.96\times\dot{V}O_2\text{max}) + (0.04\times\text{FM}) - 0.17$	0.35

[1] TEE, total energy expenditure; REE, resting energy expenditure; AEE, activity-related energy expenditure; FFM, fat-free mass (in kg); FM, fat mass (in kg). $\dot{V}O_2$ max, maximal oxygen consumption (in L/min). Weight is in kg; height is in m; age is in y; season is coded as 1 for summer, 2 for fall, and 3 for spring; geographic location is coded as 0 for Burlington, VT, and Akwesasne, NY, as 1 for Guatemala, and 2 for Birmingham, AL; sex is coded as 0 for girls and 1 for boys.

ues in the spring months. The effect of season was consistent among sexes and geographic locations. After fat and fat-free mass were adjusted for, there was a marginal influence of season on AEE (similar to that seen for TEE, as shown in Figure 1) but not on REE. Thus, the influence of season on TEE is mainly explained by differences in AEE. Although we were able to show the effect of season (≈0.42-MJ/d higher in spring than in fall) in 2 separate cohorts of prepubertal children, one major limitation of this finding is that the data were cross-sectional, and further longitudinal studies within the same subjects are needed to clarify our findings. The seasonality effect points out that single measures of TEE over 14 d from 1 y may not be representative of TEE at different times of the year. Therefore, repeated measures may be necessary to fully characterize an individual.

There are only a few other studies that have reported seasonal differences in physical activity. Baranowski et al (19) provided the only other evidence for seasonal differences in physical activity in children by repeated measurements of physical activity (by observation) in 191 children aged 3 and 4 y. Physical activity varied by month of year, which was explained somewhat by the amount of time children spent outside. In adults studied in Scotland, there was evidence from epidemiologic data (a telephone survey of 16 000 adults) to suggest seasonal variation in physical activity (20). Thirty-two percent of respondents reported exercising for ≥20 min on ≥3 occasions during a week in July, and this dropped to 23% of respondents in the winter; in addition, older subjects had greater seasonal variation in activity. In developing countries there is evidence of seasonal variation in 24-h and basal metabolism (21) as well as physical activity (22) in subsistence communities. For example, physical activity levels, by observation, were much higher during the monsoon period than during the winter in male and female farmers in Nepal (22).

In addition to examining the influence of season, we also examined geographic location by comparing children in Vermont to children in Alabama. Within each sex and season there was a consistently higher TEE in children studied in Vermont. This higher TEE was also explained by a higher AEE and no difference in REE (Figure 1). Thus, children living in Vermont appear to have a more physically active lifestyle (independent of body composition, sex, and season), which may be a reflection of habitual recreational activities or school-organized physical activity classes. Further studies using more detailed measures of physical activity patterns are needed to more fully describe the differences between groups.

We examined the influence of ethnicity by comparing TEE, REE, and AEE in white, Mohawk, Guatemalan, and African American children after adjusting for differences in fat-free mass, fat mass, and season of study. The only ethnic effect that we could measure was a significantly lower adjusted TEE, due to a lower adjusted AEE, in the Guatemalan children compared with the other groups (Figure 2). One possible explanation is that some of the Guatemalan children had low stature for weight and age. However, in a previous report (12) we showed no difference in any component of TEE between short and normal-stature children after adjusting for differences in fat and fat-free mass. Another possible explanation is that the Guatemalan children were younger than some of the other cohorts; however, the mean age was similar to that of the Mohawk cohort (Table 2) and Mohawk children had TEE values that were similar to those of the white and African American cohorts. Also, the addition of age as a covariate to the ANCOVA model did not influence the significance of the main effects of ethnicity on TEE, REE, and AEE. Another potential explanation may be altitude, because the Guatemalan cohort lived ≈1.6 km (1 mi) above sea level, whereas the other children lived at approximately sea level. This difference may influence physical activity, or alternatively, altitude may have unexplained measurement effects on either indirect calorimetry or doubly labeled water. Finally, differences in diet between the groups may lead to differences that were not accounted for by assuming that the thermogenic effect of food was 10% of TEE in all children. Collectively, these data suggest that the lower TEE in Guatemalan children is explained by a lower AEE compared with other ethnic groups; further studies are needed to verify this finding with regard to the issues discussed above.

We reported a significantly higher REE in white and Mohawk prepubertal boys compared with girls (23), consistent with sex differences in adults (24). Here, we have extended this finding to other ethnic groups, showing a consistently higher REE in African American and Guatemalan boys than in girls, independent of differences in body composition. In a previous meta-analysis in adults, we showed that TEE was significantly higher in men than in women (25). The influence of sex on TEE or AEE has not been studied extensively in children. In the current analysis, the overall effect of sex on TEE was only marginally significant (Figure 2) and there was no effect of sex on AEE. Thus, we conclude that in prepubertal children the main influence of sex on energy expenditure is through an effect on REE only. One of our previous concerns with this finding was that we had not used robust measures of body composition. In the present study, we reproduced the sex effect with children in whom body composition was assessed by DXA (0.26 MJ/d in boys as shown in Table 4), a much stronger and more accurate body-composition assessment method (18) than that of our previous study (23), which used bioelectrical resistance.

Data from this study are inconsistent with a previous report from our laboratory showing a higher TEE in Mohawk than in white children studied in Vermont (10). This difference may be due to the larger sample size of Mohawk children (38 in the current study, 28 in the previous report), and the fact that in the present analysis, the sample of white children was more diverse, incorporating children from Alabama. When we compared white children with Mohawk children, excluding the children from Alabama, there was still no influence of ethnicity. Thus, our previous finding of a higher TEE in Mohawk children may have been a type I error due to a lower sample size.

The single best predictor of TEE was body weight. Even when body composition was measured by DXA, the correlation between TEE and fat-free mass was comparable with that observed with weight (Table 3). The relation between TEE and weight was consistent across ethnic groups and sex (data not shown). The strong effect of weight on TEE is an additive effect of the combined positive and independent effects of both fat and fat-free mass on TEE (Table 4). The positive effect of fat mass on TEE is explained by a combination of the positive influence of fat mass on REE and a positive influence of fat mass on AEE (Table 4).

Our findings have potentially important implications for pediatric energy requirements. Previous approaches to estimating energy requirements in children were based on assessment of food intake by using equations with body weight and sex (1). A more recent consensus workshop suggested categorizing individuals in different age groups as having either a light, medium, or heavy physical activity levels and making estimates of TEE based on multiples of REE (7). Our analysis supports the alternative use of body weight as a simple predictor of TEE, but the parameters of our regression equation are different from those recommended previously (1). There are several advantages of basing estimates of TEE on body weight and other easily measured variables. First, body weight is a very simple and practical measure, whereas REE is not and may have to be estimated itself—introducing a further source of error. Second, the REE factorial approach first requires a subjective decision to be made regarding the activity level of the subject in person; this is a recursive approach because the activity level itself is the major determinant of energy requirements. Third, body weight explains more of the variance in TEE than does REE. Thus, overall estimates based on simple equations of body weight represent a simple and practical approach that may yield more accurate estimates. When more rigorous measures of body composition (eg, DXA) are available, the prediction of TEE is further improved to a combined model R^2 of 0.73. In addition, our analysis showed that the addition of height, season, ethnicity, and geographic location may be important factors for the optimal prediction of TEE because of their effects on either REE or AEE. Although $\dot{V}O_2$max was also an important determinant of TEE, because of its relation with AEE, we do not think that it is a practical measure that can be used for estimating energy requirements.

By far, the most variable component of daily energy expenditure is AEE (8). Because of the difficulty and cost in measuring AEE with doubly labeled water, and because of error propagation from subtracting REE from TEE (9), it may be necessary to identify surrogate measures. We showed previously that the measurement of activity indexes by questionnaire in young children (hours per day of activity) was unrelated to AEE in white children (11). In a previous study in the elderly we suggested that $\dot{V}O_2$max may be a useful proxy indicator of AEE (26), and we are unaware of previous studies in children addressing this idea. In the current study, $\dot{V}O_2$max was the most significant correlate of AEE ($r = 0.54$), and in stepwise regression analysis was a unique predictor of AEE. In additional analysis, the relation between AEE and $\dot{V}O_2$max remained independent of fat-free mass by DXA (partial r after adjusting for fat-free mass = 0.33, $P < 0.01$). Thus, our data extend previous findings to support the use of $\dot{V}O_2$max as an indicator of AEE in children. It is still not known whether a higher AEE causes a higher $\dot{V}O_2$max or whether children with a higher $\dot{V}O_2$max are able to maintain a higher AEE.

Our data fail to support the hypothesis that energy expenditure is inversely related to fat mass or other indexes of adiposity. All components of energy expenditure were positively related to fat mass, whether estimated by anthropometry or measured by DXA (Table 3), and these effects remained significant in multiple regression models after taking fat-free mass into account (Table 4). In a previous study, we found no significant correlation between AEE and fat mass in white children (11). However, in the current study, with a larger sample size and more accurate body-composition assessment techniques, we observed a weak but significant positive correlation between AEE and fat mass by anthropometry ($r = 0.30$, $P < 0.05$) and fat mass by DXA ($r = 0.45$, $P < 0.05$). Moreover, the positive correlation between AEE and fat mass by DXA remained significant after fat-free mass was adjusted for (partial $r = 0.17$, $P = 0.04$), suggesting that fat mass contributes positively to AEE, independently of fat-free mass. This is counterintuitive to the idea that fatter people are less physically active. We explained this finding previously (11) by the opposing effects of the increased energy cost of activities in larger subjects and the decreased tendency toward physical activity in larger subjects.

Several limitations of our study should be recognized. This study was a retrospective analysis and was not designed to systematically address the influence of seasonality or geographic location on energy expenditure components. Thus, seasonal comparisons were limited to a cross-sectional comparison of white children studied in fall and spring. REE was measured by using different protocols, and, despite the use of common equipment and calibration procedures, in some cases the use of different equipment and protocols was unavoidable. Some subjects were measured in the fed state, some after an inpatient, overnight fast, and some as outpatients after a request to fast overnight. These differences in REE protocols were systematically aligned within certain subgroups of the study. These methodologic differences may bias measures of REE and estimates of AEE. Also, because the different ethnic groups that we studied were in distinct geographic locations (with the exception of some white children studied in both Vermont and Alabama), it was difficult to separate the independent effects of ethnicity and geographic location from each other. Finally, as with all studies of this type, and particularly those in heterogeneous study groups, data analysis may be confounded by the multicolinearity of variables such as fat-free mass, fat mass, and age. Thus, the findings reported herein require confirmation with a more rigorous and appropriately designed study.

Given these limitations and the general complexities of performing these types of studies in a large, diverse group of children, the significance of our findings can be summarized as follows:

1) This is the first study to suggest significant effects of environmental factors on TEE. In 104 white children studied in either Vermont or Alabama, TEE was significantly influenced by season of study (≈0.42-MJ/d higher in spring than in fall), sex (≈0.42-MJ/d higher in boys), and geographic location (≈0.42-MJ/d higher in Vermont), after fat-free mass and fat mass were adjusted for. The influence of season and geographic location on TEE were mediated through their effects on AEE.

2) The effect of sex on energy expenditure was explained mainly by the well known influence of sex on REE. The influence of sex on REE was consistent across all ethnic groups studied and remained significant when more rigorous measurements of body composition (DXA) were available.

3) The only apparent effect of ethnicity on TEE was a lower value in children living in Guatemala; this effect was independent of fat-free mass, fat mass, season, and age.

4) TEE was primarily influenced by, and most significantly correlated with body weight through the combined and positive effects of fat-free mass and fat mass on both REE and AEE. Thus, estimation of energy requirements based on body weight may provide a more accurate and more practical approach than the currently recommended REE factorial method.

5) $\dot{V}O_2$max was the strongest marker of AEE, which is the most variable component of TEE.

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