Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

HHS Public Access

Author manuscript

Am J Prev Med. Author manuscript; available in PMC 2018 February 21.

Published in final edited form as:

Am J Prev Med. 2009 July ; 37(1 Suppl): S40–S49. doi:10.1016/j.amepre.2009.04.010.

Physical Activity, Energy Intake, Sedentary Behavior, and Adiposity in Youth

Janet E. Fulton, PhD, **Shifan Dai, MD, PhD**, **Lyn M. Steffen, PhD**, **Jo Anne Grunbaum, EdD**, **Syed M. Shah, MD, PhD**, and **Darwin R. Labarthe, MD, MPH, PhD**

Division of Nutrition, Physical Activity, and Obesity (Fulton), Division for Heart Disease and Stroke Prevention (Dai, Labarthe), and Division of Adult and Community Health (Grunbaum), CDC, Atlanta, Georgia; Division of Epidemiology and Community Health, School of Public Health, University of Minnesota (Steffen), Minneapolis, Minnesota; and Department of Community Medicine, Faculty of Medicine and Health Sciences, United Arab Emirates University (Shah), Al Ain, United Arab Emirates

Abstract

Background—It is unclear to what extent factors affecting energy balance contribute to the development of body fatness in youth. The objective of the current study was to describe the relationship of physical activity, energy intake, and sedentary behavior to BMI, fat free–mass index (FFMI), and fat mass index (FMI) in children aged 10–18 years.

Methods—In the subsample studied, participants were 245 girls and 227 boys (aged ≥10 years at entry or during follow-up assessments, or aged 11–14 years at entry) followed for 4 years from entry at ages 8, 11, or 14 years. At baseline and anniversary examinations, trained interviewers used a questionnaire to assess time spent daily in moderate-to-vigorous physical activity (MVPA), sedentary behavior, and energy intake (kcal/day). Sexual maturation was assessed by direct observation of pubic-hair development (Tanner Stages 1–5). Triplicate recordings of height and weight were used to estimate BMI by the standard formula (kg/m^2); bioelectric impedance was used to estimate percent body fat for calculating FFMI and FMI (kg/m^2). Multilevel models were used to examine the association of MVPA, energy intake, and sedentary behavior with BMI, FFMI, and FMI. Data were analyzed in 2007–2008.

Results—Energy intake was unrelated to FMI or FFMI in models adjusted for age or sexual maturation or in any model to BMI. Sedentary behavior was unrelated to FMI in any model or to FFMI or BMI in models adjusted for age or sexual maturation. MVPA was inversely related to FMI.

Conclusions—In children aged 10–18 years, MVPA was inversely associated with fat mass and with BMI. Investigations in youth of dietary intake and physical activity, including interventions to prevent or reverse overweight as represented by BMI, should address its fat and lean components and not BMI alone.

Address correspondence and reprint requests to: Janet E. Fulton, PhD, Division of Nutrition, Physical Activity, and Obesity, Centers for Disease Control and Prevention, 4770 Buford Highway NE, Mailstop K-46, Atlanta GA 30341-3724. jkf2@cdc.gov.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Introduction

The increasing prevalence of overweight and obesity in the U.S. and elsewhere is one of today's most critical public health concerns.[1–3] The combination of increases in portion sizes of foods served, increases in intake of sugar-sweetened beverages,[4] and decreases in physical activity[5] may explain the rise in the number of overweight children. Still, it is unclear to what extent the forces of energy imbalance contribute to this number.

Energy intake and energy expenditure are the forces leading to changes in body weight.[6] In youth, small increases in the energy differential theoretically account for current trends in overweight[7]; however, the relative responsibility of increased energy intake and decreased energy expenditure (related to physical activity levels) remains unclear. Few prospective studies[8–12] of youth have examined this question while taking into account the concurrent effects of dietary intake and physical activity (including sedentary behavior) on changes in weight or adiposity. Other studies showed that dietary components (total calories and percentage of calories consumed from fat)[13] and sedentary behavior (primarily TV viewing)[14] were directly associated with adiposity. Some prospective studies that adjusted for dietary intake found that physical activity was inversely related to increases in BMI[8,9] and adiposity,[10,11] but others did not.[12] Few studies, however, report the specific contributions of physical activity, energy intake, and sedentary behavior to the development of weight and adiposity. It has therefore been difficult to determine the relative importance of these behaviors to weight change.

A recent review[14] of longitudinal studies of physical activity and sedentary behavior among youth and their relationship to weight and adiposity concluded that findings generally, although not uniformly, showed an inverse association with physical activity and a direct association with sedentary behavior. That review noted that the effect of physical activity and sedentary behavior on the development of overweight may be small and therefore difficult to detect in studies with inadequate designs, imprecise measurements, or less than optimal analytic techniques. Improving the design and analysis of studies by using valid measurement methods, shorter intervals between assessments, longer follow-up times, direct measures of adiposity, and statistical procedures that take into account the prospective nature of the study design may, therefore, help to clarify previous, inconsistent findings.

Project HeartBeat!, a prospective cohort study of children and adolescents,[15] offered a unique opportunity to examine the relative importance of physical activity, energy intake, and sedentary behavior on differences in body mass and its lean, or fat-free, and fat components in youth aged 10–18 years. Specifically, the current study examined the hypothesis that greater energy intake and time spent in sedentary behaviors is directly associated with higher values of BMI and the fat component of BMI (the fat mass index [FMI]), and that more time spent in moderate-to-vigorous physical activity (MVPA) is inversely associated with these two indices. The primary objective of the current study was to describe the relationship of physical activity, energy intake, and sedentary behavior with concurrent values of BMI, FFMI, and FMI in children aged 10–18 years. The findings were based on data adjusted for age, gender, race/ethnicity, and sexual maturation.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Methods

Study Population

Project HeartBeat! was a longitudinal study designed to evaluate the dynamics of change in cardiovascular disease (CVD) risk factors and their behavioral determinants among children and adolescents.[15] Of the 678 participants, 49.1% were female, 74.6% were white, 20.1% were black, and 5.3% were of other race/ethnicity. Three cohorts of children, aged 8 (Cohort 1), 11 (Cohort 2), and 14 (Cohort 3) years, were enrolled between October 1991 and July 1993 from The Woodlands and Conroe TX. The children were examined three times per year, at 4-month intervals, through August 1995. The design and methods of Project HeartBeat! have been summarized previously.[15,16]

The mean number of examinations was 8.3 per participant over 4 years of data collection. Cumulative withdrawals (153 participants, 22.6% by the close of data collection) were mainly a result of relocation (73/153, 48%). Participants who withdrew had similar gender and ethnicity distributions and were slightly older at baseline than those who continued (mean ages at entry were 11.6 vs 10.6 years, respectively). After accounting for age, no other significant differences in baseline characteristics were found between those who did and did not continue.

The study protocol was approved by the IRBs of The University of Texas at Houston Health Science Center and of Baylor College of Medicine. For each participant, informed consent or assent and parental consent were obtained.

Sexual Maturation

Trained observers visually assessed each participant's sexual maturation stage three times per year according to Tanner Stages 1 (prepubertal) to 5 (adult), on the basis of genitalia and pubic-hair development for boys, and breast and pubichair development for girls. Staging of secondary sexual characteristics, based on the work of Reynolds and Wines,[17,18] later popularized by Tanner,[19,20] is a simple and straightforward means to classify the sexual development of children and adolescents on the basis of a 5-point scale. Pubic-hair stage was used in the analysis to estimate stage of sexual maturation, as it was the measure collected for both boys and girls.

Physical Activity and Sedentary Behavior

Physical activity was assessed using a 24-hour, interviewer-administered recall questionnaire adapted from a 7 day–recall instrument modified for use with pre-adolescent children. This questionnaire has been previously[21] validated among 3rd- and 5th-grade children; in fifth graders, correlations between the questionnaire and two validation standards ranged from 0.63 (accelerometer) to 0.72 (heart rate monitor). Using a segmented-day approach, trained interviewers asked participants to recall the physical activities and sedentary behaviors in which they participated during the preceding 24 hours. For each recalled physical activity, participants estimated three time segments: (1) total time spent in the activity (e.g., 2-hour baseball game); (2) time spent truly participating in the activity (e.g., 1 hour spent actively participating in the baseball game); and (3) time spent in vigorously intense activity (activity

Author Manuscript

that makes one breathe hard or sweat; e.g., 10 minutes of the baseball game). Time segments were added as a modification to the original questionnaire. Based on published estimates of physical activity energy expenditure,[22,23] time spent in physical activities of moderate or greater intensity (e.g., ≥3.0 METs) defined MVPA (min/day). Time spent truly participating in activity was used for analysis. As part of the questionnaire, participants also recalled time spent in three sedentary behaviors (min/day): TV viewing, reading, and computer use. Physical activity was assessed at baseline and yearly thereafter.

Energy Intake

Energy intake (kcal/day) was estimated from a food-frequency questionnaire (FFQ) designed for school-aged children.[24] Trained interviewers questioned participants about the frequency and quantity of 137 foods consumed during the preceding week. The food list was based on an extensive database available from a prior study[24] of food intake among children and adults in The Woodlands TX. The database included important food sources of nutrients associated with CVD. Dietary interviews were conducted in the home of the participant or at the field center. The parent who was involved with food preparation was asked to be available to help participants aged <11 years. Dietary intake was assessed at baseline and yearly thereafter. Nutrient amounts were calculated with the use of nutrient and gram weight information from the U.S. Department of Agriculture Survey Nutrient Database, version 4.0, and were expressed as amounts of the average daily nutrient intake consumed during the preceding week. Total energy intake was calculated as described elsewhere.[25]

Body Mass Index

Anthropometric measurements were obtained for each participant three times per year by two trained and certified observers working together using standardized protocols.[26,27] To improve reliability, triplicate measures of weight and height were taken for each participant. Participants were barefoot and wore surgical scrub suits over underwear while measurements were taken. Weight was measured to the nearest 0.1 kg with a beam-balance scale; height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. BMI was calculated by standard formula (kg/m^2).

Percent Body Fat, FFMI, and FMI

Bioelectric impedance and anthropometric measurements were used to estimate percent body fat (PBF). Bioelectric impedance assessments were obtained every 4 months, according to standardized procedures (arm-to-leg), with use of an RJL Systems bioelectric impedance analyzer BIA-101-A to measure reactance and resistance.[28] PBF was calculated by the gender-specific formulas of Guo and colleagues[29] using resistance, anthropometry (weight, height, arm muscle circumference), and skinfold measurements (using a Tanner–Whitehouse skinfold dial caliper; for both boys and girls: lateral calf; for girls only: triceps, subscapular; for boys only: midaxillary).

These formulas were chosen because they have been cross-validated in several studies[30] that included children and young adults and have the smallest SEs among the various formulas for bioimpedance. The SEs of these prediction equations appear typical of those from other body composition techniques, such as body density from underwater weighing.[31] The use of

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

prediction equations such as these have two advantages over simpler anthropometry: They estimate a specific aspect of body composition (in this case, body fat), and carefully cross-validated formulas provide more accurate estimates than do single measurements and indices.[31] FFMI was calculated as the product of BMI and fat free–mass percentage (BMI × [1 − PBF]/100). FMI was calculated as the product of BMI and fat mass percentage (BMI × [PBF/100]).

Data Analysis

Analytic Population

Children aged <10 years are generally judged unable to provide reliable information about their physical activity[32] or dietary behaviors.[33] Therefore, the study sample for the present analysis was restricted to participants who were either aged ≥10 years at entry (Cohorts 2 and 3 entered the study at ages 11 and 14 years, respectively) or attained age 10 years during follow-up assessments (Cohort 1 was aged 8 years at entry and attained age 10 years during follow-up assessments). Data from participants who reliably completed physical activity and dietary assessments when aged ≥10 years were included. Reliability of the physical activity and dietary interviews was determined by the interviewer's assessment of the quality of the information obtained during the interview.

Of the 678 children and adolescents who originally participated in Project HeartBeat!,[15] 472 (70%) were included in the analytic sample. Energy intake, estimated from FFQs, was available for 587 participants (91 missing, invalid, or incomplete FFQs). Physical activity information was available from 576 participants (102 missing, invalid, or incomplete FFQs). Physical activity and dietary information was available for 556 participants. For these, information was missing for height, weight, PBF, BMI, FFMI, or FMI (14 participants) or for pubic-hair staging (70 participants), leaving 472 participants as the analytic sample.

The final data set for this analysis comprised the values for BMI, FMI, FFMI, and the other variables recorded at the same time as the annual assessment of diet and physical activity among the 472 eligible participants. That is, because of dependence on annual observations for those two independent variables (diet and physical activity), the interim observations made at 4-month intervals on other variables were disregarded. Thus, the data examined here are the concurrent measures of all variables on an annual basis over the course of the study. This includes both repeated measures within individuals and between individuals, analyzed in a multilevel approach described below. Data were analyzed in 2008.

Standard statistical analyses were conducted using SPSS, version 9.0. Longitudinal multilevel modeling[34] of the trajectories of BMI, FFMI, and FMI by physical activity, energy intake, and sedentary behavior was conducted using MLwiN software. The MLwiN regression analysis program computes maximum likelihood estimates of the parameters for mixed linear models. Tests of statistical hypotheses were carried out by use of Wald tests (ratio of estimated parameter to its SE) or deviance tests (changes in −2 log [likelihood]). A *p*-value of ≤0.05 was used as the criterion for significance in all statistical testing.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Specifically, in three separate sets of multilevel models, repeated measurements of BMI, FFMI, and FMI were first regressed on physical activity (MVPA, min/day); energy intake (kcal/day); and sedentary behavior (TV viewing, reading, and computer use; min/day), in unadjusted multilevel regression models. The basic model-building strategy consisted of including physical activity, energy intake, and sedentary behavior in Model 1, followed by adding gender, race, and gender×race (Model 2); adding age and gender×age (Model 3); and adding sexual maturation stage (dummy coded) and gender×sexual maturation (Model 4). The primary hypotheses of interest concerned the expected relationships of BMI, FFMI, and FMI with concurrent values of physical activity, energy intake, and sedentary behavior.

Results

Table 1 shows Ms, SDs, and frequency distributions of baseline values for demographic characteristics, physical activity, energy intake, sedentary behavior, BMI, FMI, FFMI, and sexual maturation. Participants' ages averaged 10.4 years for eligible members of Cohort 1, 11.5 years for Cohort 2, and 14.4 years for Cohort 3. Boys and girls were approximately equally distributed in each of the age groups. The widest distribution among cohorts was 46% boys, 54% girls in Cohort 1; the other two cohorts were almost evenly divided between the genders. The proportions of participants at Stage 4 or 5 of pubichair development, as expected, were higher among Cohort 3 participants. Time spent in MVPA (min/day) was lower for girls than for boys at each age. Mean energy intake increased across cohorts among both boys and girls. Sedentary behavior also increased by cohort among both boys and girls. Among boys, mean BMI increased by age level from Cohort 1 to Cohort 3; among girls, mean BMI was lower in Cohort 1 than in Cohort 3, but lowest in Cohort 2. FFMI increased across age levels in both boys and girls from Cohort 1 to Cohort 3. By contrast, FMI increased across age levels in girls, from Cohort 1 to Cohort 3, but declined in boys, from Cohort 1 to Cohort 3.

Partial correlation coefficients, adjusted for age, of BMI, FFMI, FMI with physical activity, energy intake, and sedentary behavior are shown in Table 2. BMI, FFMI, and FMI were correlated with one another; BMI and FMI were most strongly correlated, whereas FFMI and FMI were least strongly correlated. BMI and FMI were negatively correlated with physical activity. Physical activity was positively correlated with energy intake and negatively correlated with sedentary behavior.

Multilevel longitudinal regression models for BMI are shown in Table 3. In Model 1 (unadjusted), sedentary behavior was directly associated, and MVPA was inversely associated, with changes in BMI. Interpretation of the regression coefficient for MVPA indicates that for every 100-minute-per-day increase in MVPA, there was a 0.23 kg/m^2 decrease in BMI among adolescents aged 10–18 years. Gender and race did not appreciably alter the association (Model 2). With the addition of age (Model 3), sedentary behavior and MVPA were no longer significantly associated with changes in BMI. The interaction between gender and race in Model 3 indicated that the estimated effect on BMI was 3.1 (sum of relevant coefficients: −0.1435 + 0.8658 + 2.3855) kg/m^2 higher in black girls than in nonblack boys. With the addition of sexual maturation (Pubic-Stages 2–5) and the interaction between gender and sexual maturation, MVPA remained associated with a

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

decrease in BMI. The interaction between gender and Pubic-Stage 2 in Model 4, for example, indicated that the estimated effect on BMI in girls in Pubic-Stage 2 was 0.21 kg/m^2 higher than in boys in Pubic-Stage 2 and was 0.72 kg/m^2 higher (sum of relevant coefficients: 0.2052 + 0.5176) than in girls in Pubic-Stage 1. In none of the models was energy intake related to BMI.

Multilevel longitudinal regression models for FFMI are shown in Table 4. In Model 1 (unadjusted), and also when the model was adjusted for gender and race/ethnicity (Model 2), energy intake and sedentary behavior were both directly associated with changes in FFMI. When age and then sexual maturation stage were added (Models 3 and 4, respectively), sedentary behavior and energy intake were no longer associated with changes in FFMI. In none of these models was MVPA related to FFMI.

Multilevel longitudinal regression models for FMI are shown in Table 5. Energy intake and MVPA were both inversely associated with changes in FMI in Model 1 (unadjusted) and in Model 2 (adjusted for gender and race). In Models 3 and 4, after further adjustment for age and for sexual maturation, respectively, only the inverse relation between MVPA and changes in FMI remained significant. In none of these models was sedentary behavior related to FMI.

Additional analyses were conducted to examine alternative explanations for the findings. Weekday versus weekend physical activity recall was examined. In this analysis, no significant association was observed between weekday (97% of observations) or weekend day (3%) physical activity recall status on BMI, FFMI, or FMI (data not shown). Alternative measures of sexual maturation were also examined (breast development for girls and genital development for boys). In this analysis, there were no appreciable differences in the coefficients for energy intake, sedentary behavior, or MVPA for BMI (energy intake: −0.071; sedentary behavior: 0.050; MVPA: 0.174); FFMI (energy intake: 0.002; sedentary behavior: 0.033; MVPA: 0.037); or FMI (energy intake: −0.057; sedentary behavior: 0.029; MVPA: −0.134). The coefficients remained nonsignificant for energy intake and for sedentary behavior and were slightly attenuated for MVPA, but they remained significantly associated with BMI and with FMI, as previously observed (Tables 3 and 5).

Discussion

With respect to the three primary independent variables and their relationships to BMI, FFMI, and FMI, the major results of this study are as follows: (1) Energy intake was inversely associated with FMI and directly associated with FFMI in unadjusted models, but it was unrelated to FMI or FFMI in models adjusted for age or sexual maturation and in any model to BMI. (2) Sedentary behavior was unrelated to FMI in any model or to either FFMI or BMI in models adjusted for age or sexual maturation; its association with BMI in unadjusted models was due to its association with FFMI, not FMI. (3) MVPA was inversely related to FMI in all models, even after adjustment for age and sexual maturation, a relationship that was altogether lacking for FFMI but remained, after adjustment for sexual maturation, for BMI (because of FMI and not FFMI). These findings support the hypothesis that greater levels of MVPA are generally beneficially associated with lower values of BMI,

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

in children aged 10–18 years, and they demonstrate that this relationship is specifically attributable to the relationship between MVPA and FMI.

Several previous reports provide a context for interpretation of these findings. The finding that physical activity was beneficially related to the FMI is consistent with other longitudinal studies[8,10,35–39] that have examined the behavioral factors thought to influence relative weight or adiposity in children and adolescents. Most published studies[8,35–37,39] have reported a favorable relationship between physical activity and changes in BMI. It appears that no study has yet examined the relationship of physical activity to changes in the FMI, although a small number of studies[10,38,39] have examined the relationship of physical activity to changes in adiposity.

Two long-term cohort studies of preschool[10] and adolescent children[39] provide an illustration. Among 103 preschool-aged children (M age was 4 years at baseline) followed over 8 years, it has been observed[10] that, compared with the least active children, measured by accelerometry, the most active children had smaller gains in triceps skinfold and the sum of five skinfolds. Among 2287 adolescent girls (aged 9–10 years at baseline) followed for 8 years, a beneficial relationship has been noted[39] between physical activity and the changes in the sum of three skinfolds. The difference in skinfolds between active and inactive girls over the course of the study was 16 mm. Findings from the present analysis, perhaps of less relevance to the individual, lend support to the hypothesis that, independent of energy intake, population participation in MVPA may have beneficial effects on changes in body fatness during adolescence.

In the unadjusted models or those adjusted only for gender and race, there was an inverse relationship between energy intake and FMI and a positive relationship between energy intake and FFMI. Both of these findings run counter to the theory of energy balance, which would predict the opposite relationships of increased energy intake with fat and lean mass, and were therefore unexpected. However, similar findings have been observed in other studies among youth.[40,41] Investigators have proposed at least two explanations.

One explanation is that active children require an increase in energy intake for proper growth and development.[40] An alternative explanation is that overweight adolescents, compared with their normal weight peers, may be more likely to under-report energy intake.[40,41] It is unclear to what degree these (or other) explanations may explain this finding. What is clear, however, is that it is especially difficult to examine the true relationship of energy intake to weight and adiposity in growing children, given the dynamic nature of body size and composition during this life stage. Future investigations should seek to clarify how energy intake relates to body mass and its lean and fat components, examining in particular how factors related to growth, development, and ascertainment bias of body fat components may affect these relationships.

Several longitudinal studies[8,9,35,37,42] have shown that sedentary behavior (usually studied as TV viewing) is directly related to increases in relative weight or adiposity. The current findings showed the same direction of this relationship. Previous studies of sedentary behavior and adiposity have included different combinations of variables in statistical

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

adjustment of results, and it is therefore difficult to compare findings among studies. For example, although most studies do not include adjustment for either physical activity or energy intake,[8,36,37,43] some studies adjust for physical activity alone[9] or for both physical activity and energy intake,[35,42] and these studies do not clearly indicate the specific contribution of sedentary behavior to weight change. A potential alternative explanation for the absence of a significant finding in this regard is that reading and computer use, included in Project HeartBeat! as sedentary behaviors, obscured a true association between TV viewing and adiposity. However, TV viewing alone was not associated with BMI, FFMI, or FMI in this study (results not shown). Comparisons with current patterns of sedentary behavior (e.g., TV viewing) may also be difficult as screen usage has increased over time.[44]

Changes in patterns of adiposity indices during adolescence differ for boys and girls and according to the measure chosen.[27] In Project HeartBeat!, BMI was found to increase in a monotonic fashion with age with little or no gender difference. PBF, however, decreased with age in boys and remained nearly constant with age in girls. The several body measurement–based indices of adiposity are influenced to varying degrees by fat and lean tissue components, as evidenced by the differences in growth patterns. Because BMI is actually dominated by lean mass, relative to the amount of fat mass,[28,45] relationships between BMI and other measures of adiposity should not necessarily be expected to be consistent with one another in the same or different studies. As shown here, findings based on BMI may reflect an underlying association of FMI, an association of FFMI, or countervailing associations of the two. These results underscore the need for caution in interpreting findings for BMI in studies in childhood and adolescence, as well as in practice.

There are unique strengths as well as inherent limitations in the design and methods of Project HeartBeat! as they pertain to the present analysis. Particular strengths address two key weaknesses emphasized in a recent review of longitudinal studies on physical activity, weight, and adiposity in youth.[14] The first major strength is assessment of body composition through inclusion of bioelectric impedance, rather than reliance on weight, height, and other anthropometric variables alone. (Other more ideal methods, such as underwater weighing, were considered impractical because of the size of the study and the required frequency and logistics of examinations.) Second, inclusion of assessments of both dietary behavior and time spent in sedentary and energy-consuming activities permitted evaluation of the contributions of these factors to lean and fat mass, as these vary across the wide age range of 10–18 years.

An important limitation of this study is the ascertainment of measures of physical activity, energy intake, and sedentary behavior not from objective methods such as accelerometry, heart rate monitoring, or direct observation, but from self-report questionnaires and at annual intervals rather than more frequently. However, standard dietary methods were used, as described in greater detail elsewhere.[25] With respect to physical activity, the questionnaire was validated in a previous study[21] (using heart rate and accelerometry as the validation standards) that found correlation coefficients consistent with more recently reviewed validation studies.[46] The methods used precluded ascertainment of energy intake and expenditure for participants aged <10 years, with consequent loss of information for this age group. In addition, the number of black participants, although constituting 20.1% of the total

Author Manuscript

Project HeartBeat! sample, may have been too few for reliable assessment of differences by race/ethnicity. The current findings, therefore, must be interpreted with caution.

Conclusion

These findings from Project HeartBeat! show that time spent in MVPA was inversely and independently associated with adiposity, as measured by the fat mass component of BMI, in children and adolescents aged 10–18 years. Owing to this specific relationship of MVPA with FMI, BMI also was inversely and independently associated with MVPA. By contrast, the lean component (FFMI) of BMI appears to be strongly influenced by intrinsic factors represented by several nonmodifiable characteristics—age, gender, and sexual maturation—so that neither measures of energy intake nor sedentary behavior nor physical activity had detectable effects on this component after adjustment for these variables. The unexpected findings, such as the inverse relationship of energy intake with fat mass and its direct relationship with lean mass, prior to adjustment for age and sexual maturation, underscore the importance of studying broad age groups and including data on age and sexual maturation in seeking to understand the complex relationships among extrinsic factors of nutrition and physical activity and the development of adiposity and other health indicators in childhood and adolescence.

Finally, interpretation of BMI, when measured in research or in clinical practice, should be informed by the understanding that its two distinct components, fat mass and lean mass, may relate differently to external factors that contribute to such adverse health conditions as overweight, high blood pressure, dyslipidemia, and impaired glucose tolerance. Accordingly, devising and evaluating intervention approaches to prevent or reverse these adverse conditions on the basis of BMI should, as a high priority, incorporate measurement of both fat and lean components of BMI specifically and not rely on a BMI calculation alone.

Acknowledgments

The authors acknowledge with gratitude the contribution of time and dedication of each Project HeartBeat! participant and family. The cooperation of the Conroe Independent School District and the generous support of The Woodlands Corporation are deeply appreciated. The Woodlands and Conroe Advisory Committees have assisted greatly in the planning and conduct of this study. We thank Prof. James M. Tanner for helpful advice on the design of the study while he was Visiting Professor at the School of Public Health. The authors also acknowledge the essential contributions of the Project HeartBeat! co-investigators to the design and implementation of this study, including Drs. Nancy Ayers, John T. Bricker, John Kirkland, Claudia Kozinetz, Daniel Oshman, Alexander Roche, and William J. Schull. Senior staff of the project for data management and field center management were Tony Arrey and Marilyn Morrissey, and Candace Ayars and Pamela Folsom, respectively. Dr. Millicent Higgins served as Scientific Program Administrator for the project under Cooperative Agreement U01-HL-41166, National Heart, Lung, and Blood Institute, which provided major funding for the project. Support from the CDC, through the Southwest Center for Prevention Research (U48/CCU609653), and that of Compaq Computer Corporation, is also gratefully acknowledged, as is the University of Texas at Houston, Health Science Center, School of Public Health.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the CDC.

No financial disclosures were reported by the authors of this paper.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

References

1. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among U.S. children, adolescents, and adults, 1999–2002. JAMA. 2004; 291:2847–50. [PubMed: 15199035]
2. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. JAMA. 2006; 295:1549–55. [PubMed: 16595758]
3. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among U.S. children and adolescents, 1999–2000. JAMA. 2002; 288:1728–32. [PubMed: 12365956]
4. Briefel RR, Johnson CL. Secular trends in dietary intake in the United States. Ann Rev Nutr. 2004; 24:401–31. [PubMed: 15189126]
5. Kimm SY, Glynn NW, Kriska AM, et al. Longitudinal changes in physical activity in a biracial cohort during adolescence. Med Sci Sports Exerc. 2000; 32:1445–54. [PubMed: 10949011]
6. LaVoisier, A. Traite elementaire de chimie, presente dans un ordre nouveau et d'apres les decouvertes modernes, 1789. Paris: Chez Cuchet; 1965.
7. Wang YC, Gortmaker SL, Sobol AM, Kuntz KM. Estimating the energy gap among U.S. children: a counterfactual approach. Pediatrics. 2006; 118:e1721–33. [PubMed: 17142497]
8. Jago R, Baranowski T, Baranowski JC, Thompson D, Greaves KA. BMI from 3–6 y of age is predicted by TV viewing and physical activity, not diet. Int J Obes (Lond). 2005; 29:557–64. [PubMed: 15889113]
9. Elgar FJ, Roberts C, Moore L, Tudor-Smith C. Sedentary behaviour, physical activity and weight problems in adolescents in Wales. Public Health. 2005; 119:518–24. [PubMed: 15826893]
10. Moore LL, Gao D, Bradlee ML, et al. Does early physical activity predict body fat change throughout childhood? Prev Med. 2003; 37:10–7. [PubMed: 12799124]
11. Moore LL, Nguyen US, Rothman KJ, Cupples LA, Ellison RC. Preschool physical activity level and change in body fatness in young children. The Framingham Children's Study. Am J Epidemiol. 1995; 142:982–8. [PubMed: 7572980]
12. Maffeis C, Talamini G, Tato L. Influence of diet, physical activity and parents' obesity on children's adiposity: a four-year longitudinal study. Int J Obes Relat Metab Disord. 1998; 22:758–64. [PubMed: 9725635]
13. Jago R, Baranowski T, Yoo S, et al. Relationship between physical activity and diet among African-American girls. Obes Res. 2004; 12S:55S–63S.
14. Must A, Tybor DJ. Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. Int J Obes (Lond). 2005; 29(2S):S84–96. [PubMed: 16385758]
15. Labarthe DR, Nichaman MZ, Harrist RB, Grunbaum JA, Dai S. Development of cardiovascular risk factors from ages 8 to 18 in Project HeartBeat! Study design and patterns of change in plasma total cholesterol concentration. Circulation. 1997; 95:2636–42. [PubMed: 9193432]
16. Grunbaum JA, Labarthe DR, Ayars C, Harrist R, Nichaman MZ. Recruitment and enrollment for Project HeartBeat! Achieving the goals of minority inclusion. Ethn Dis. 1996; 6(3–4):203–12. [PubMed: 9086310]
17. Reynolds EL, Wines JV. Individual differences in physical changes associated with adolescence in girls. Am J Dis Child. 1948; 75:329–50. [PubMed: 18882060]
18. Reynolds EL, Wines JV. Physical changes associated with adolescence in boys. Am J Dis Child. 1951; 82:529–47.
19. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. Arch Dis Child. 1969; 44:291–303. [PubMed: 5785179]
20. Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. Arch Dis Child. 1970; 45:13–23. [PubMed: 5440182]
21. Simons-Morton BG, Taylor WC, Huang IW. Validity of the physical activity interview and Caltrac with preadolescent children. Res Q Exerc Sport. 1994; 65:84–8. [PubMed: 8184216]
22. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000; 32(9S):S498–504. [PubMed: 10993420]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

23. McArdle, WD., Katch, FI., Katch, VL. Exercise physiology: energy, nutrition, and human performance. 2. Philadelphia: Lea & Febiger; 1986.
24. McPherson RS, Nichaman MZ, Kohl HW, Reed DB, Labarthe DR. Intake and food sources of dietary fat among schoolchildren in The Woodlands, Texas. Pediatrics. 1990; 86:520–6. [PubMed: 2216615]
25. Day RS, Fulton JE, Dai S, Mihalopoulos NL, Barradas DT. Nutrient intake, physical activity, and CVD risk factors in children: Project HeartBeat! Am J Prev Med. 2009; 37(1S):S25–S33. [PubMed: 19524152]
26. Lohman, TG., Roche, AF., Martorell, R. Anthropometric standardization reference manual. Champaign IL: Human Kinetics; 1988.
27. Dai S, Labarthe DR, Grunbaum JA, Harrist RB, Mueller WH. Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years. Project HeartBeat! Am J Epidemiol. 2002; 156:720–9. [PubMed: 12370160]
28. Mueller WH, Harrist RB, Doyle SR, Ayars CL, Labarthe DR. Body measurement variability, fatness, and fat-free mass in children 8, 11, and 14 years of age: Project HeartBeat! Am J Human Biol. 1999; 11:69–78. [PubMed: 11533935]
29. Guo SM, Roche AF, Houtkooper L. Fat-free mass in children and young adults predicted from bioelectric impedance and anthropometric variables. Am J Clin Nutr. 1989; 50:435–43. [PubMed: 2773822]
30. Houtkooper LB, Going SB, Lohman TG, Roche AF, Van Loan M. Bioelectrical impedance estimation of fat-free body mass in children and youth: a cross-validation study. J Appl Physiol. 1992; 72:366–73. [PubMed: 1537738]
31. Baumgartner RN, Heymsfield SB, Roche AF. Human body composition and the epidemiology of chronic disease. Obes Res. 1995; 3:73–95.
32. Sallis JF. Self-report measures of children's physical activity. J Sch Health. 1991; 61:215–9. [PubMed: 1943046]
33. McPherson RS, Hoelscher DM, Alexander M, Scanlon KS, Serdula MK. Dietary assessment methods among school-aged children: validity and reliability. Prev Med. 2000; 31:S11–S33.
34. Goldstein, H. Multilevel statistical models. 2. London: Edward Arnold; 1995.
35. Berkey CS, Rockett HR, Gillman MW, Colditz GA. One-year changes in activity and in inactivity among 10- to 15-year-old boys and girls: relationship to change in body mass index. Pediatrics. 2003; 111(4 Pt 1):836–43. [PubMed: 12671121]
36. Burke V, Beilin LJ, Simmer K, et al. Predictors of body mass index and associations with cardiovascular risk factors in Australian children: a prospective cohort study. Int J Obes (Lond). 2005; 29:15–23. [PubMed: 15314630]
37. Gordon-Larsen P, Adair LS, Popkin BM. Ethnic differences in physical activity and inactivity patterns and overweight status. Obes Res. 2002; 10:141–9. [PubMed: 11886936]
38. Kettaneh A, Oppert JM, Heude B, et al. Changes in physical activity explain paradoxical relationship between baseline physical activity and adiposity changes in adolescent girls: the FLVS II study. Int J Obes (Lond). 2005; 29:586–93. [PubMed: 15889117]
39. Kimm SY, Glynn NW, Obarzanek E, et al. Relation between the changes in physical activity and body-mass index during adolescence: a multicentre longitudinal study. Lancet. 2005; 366:301–7. [PubMed: 16039332]
40. Patrick K, Norman GJ, Calfas KJ, et al. Diet, physical activity, and sedentary behaviors as risk factors for overweight in adolescence. Arch Pediatr Adolesc Med. 2004; 158:385–90. [PubMed: 15066880]
41. Bogaert N, Steinbeck KS, Baur LA, Brock K, Bermingham MA. Food, activity and family—environmental vs biochemical predictors of weight gain in children. Eur J Clin Nutr. 2003; 57:1242–9. [PubMed: 14506484]
42. Proctor MH, Moore LL, Gao D, et al. Television viewing and change in body fat from preschool to early adolescence: the Framingham Children's Study. Int J Obes Relat Metab Disord. 2003; 27:827–33. [PubMed: 12821969]
43. Hancox RJ, Milne BJ, Poulton R. Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. Lancet. 2004; 364:257–62. [PubMed: 15262103]

Author Manuscript

44. Rideout, VJ., Roberts, DF., Foehr, UG. Generation M: media in the lives of 8–18 year-olds: executive summary. Menlo Park CA: Henry J. Kaiser Family Foundation; 2005.

45. Dietz WH, Bellizzi MC. Introduction: the use of body mass index to assess obesity in children. Am J Clin Nutr. 1999; 70:123S–5S. [PubMed: 10419414]

46. Kohl HW III, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescents: a review and synthesis. Prev Med. 2000; 31:S54–S76.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 1

Descriptive characteristics assessed at age ≥10 years in 472 participants, Project HeartBeat!, 1991–1995

	Cohort 1 (*n*=212)[a]		Cohort 2 (*n*=151)[b]		Cohort 3 (*n*=109)[c]	
	Boys (*n*=98)	**Girls (*n*=114)**	**Boys (*n*=74)**	**Girls (*n*=77)**	**Boys (*n*=55)**	**Girls (*n*=54)**
Characteristic (M [SD])						
Age (years)	10.4 (0.1)	10.4 (0.1)	11.5 (0.3)	11.5 (0.4)	14.4 (0.1)	14.4 (0.1)
Physical activity (MVPA) (min/day)	84.6 (68.5)	78.0 (81.5)	102.5 (82.0)	51.9 (54.9)	91.1 (73.6)	59.6 (80.3)
Energy intake (kcal/day)	2069.1 (603.7)	1850.7 (709.9)	2340.1 (770.8)	2189.6 (728.6)	2728.3 (910.5)	2249.5 (719.8)
Sedentary behaviors (min/day)[d]	157.0 (125.6)	132.5 (92.2)	154.6 (97.3)	162.2 (116.7)	169.2 (104.8)	161.0 (112.8)
BMI (kg/m^2)	18.6 (3.7)	19.2 (4.2)	19.6 (4.1)	18.6 (3.4)	20.3 (3.2)	21.6 (3.3)
Fat free–mass index (kg/m^2)	14.2 (1.7)	14.1 (2.0)	14.6 (1.9)	13.6 (1.7)	16.4 (1.9)	15.4 (1.4)
Fat mass index (kg/m^2)	4.3 (2.5)	5.1 (2.6)	5.0 (2.8)	5.0 (2.3)	3.9 (2.3)	6.1 (2.2)
Race/ethnicity (*n* [%])						
Nonblack	77 (78.6)	85 (74.6)	61 (82.4)	66 (85.7)	51 (92.7)	50 (92.6)
Gender (*n* [%])	98 (46.2)	114 (53.8)	74 (49.0)	77 (51.0)	55 (50.5)	54 (49.5)
Sexual maturation (*n* [%])						
Pubic-Hair Stage 1	84 (85.7)	66 (57.9)	52 (70.3)	20 (26.0)	2 (3.6)	0 (0)
Pubic-Hair Stage 2	11 (11.2)	35 (30.7)	18 (24.3)	36 (46.8)	10 (18.2)	1 (1.9)
Pubic-Hair Stage 3	3 (3.1)	9 (7.9)	4 (5.4)	13 (16.9)	10 (18.2)	4 (7.4)
Pubic-Hair Stage 4	0 (0)	3 (2.6)	0 (0)	7 (9.1)	24 (43.6)	22 (40.7)
Pubic-Hair Stage 5	0 (0)	1 (0.9)	0 (0)	1 (1.3)	9 (16.4)	27 (50.0)

[a]Cohort 1: children aged ≥10 years at entry or who attained age 10 years during follow-up period

[b]Cohort 2: children aged 11 years at initial assessment

[c]Cohort 3: children aged 14 years at initial assessment

[d]Sedentary behaviors: TV viewing, reading, and computer use

MVPA, moderate-to-vigorous physical activity

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Table 2

Partial correlation coefficients, adjusted for age, between BMI and its components, Project HeartBeat!, 1991–1995

	Fat free-mass index	Fat mass index	MVPA	Energy intake	Sedentary behavior (min/day)[a]
BMI (kg/m^2)	**0.79**[*]	**0.90**[*]	**−0.14**[*]	−0.10	0.04
Fat-free mass index (kg/m^2)	1.00	**0.43**[*]	−0.06	0.01	0.05
Fat mass index (kg/m^2)	**0.43**[*]	1.00	**−0.16**[*]	**−0.16**[*]	0.02
MVPA (min/day)	−0.06	**−0.16**[*]	1.00	**0.14**[*]	**−0.13**[*]
Energy intake (kcal/day)	0.01	**−0.16**[*]	**0.14**[*]	1.00	0.05

[a] Sedentary behavior includes TV viewing, computer use, and reading.

[*] Boldface indicates significance at $p<0.05$.

MVPA, moderate-to-vigorous physical activity

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 3

Multilevel longitudinal models for BMI in 472 participants in Project HeartBeat!, 1991–1995

	BMI (kg/m^2)			
	Model 1 Estimate±SE	Model 2 Estimate±SE	Model 3 Estimate±SE	Model 4 Estimate±SE
Parameter				
Fixed parameters				
Intercept	**20.2332±0.1833** *	**20.0861±0.2769** *	**20.3231±0.2938** *	**19.3467±0.2838** *
Energy intake (1000 kcal/day increments)	−0.0456±0.0806	−0.0350±0.0812	−0.0549±−0.0520	−0.0780±0.0637
Sedentary behavior (100 min/day increments)[a]	**0.0970±0.0424** *	**0.0996±0.0423** *	0.0349±0.0300	0.0552±0.0384
MVPA (100 min/day increments)	**−0.2292±0.0715** *	**−0.2389±0.0747** *	−0.0764±0.0506	**−0.2009±0.0688** *
Gender[b]		−0.2632±0.3844	−0.1435±0.4125	−0.9235±0.4110
Race[c]		0.0054±0.6504	0.8658±0.6524	0.2946±0.6291
Gender×race		**2.8796±0.9182** *	**2.3855±0.8934** *	**2.5105±0.8791** *
Age			**0.6918±0.0599** *	
Gender×age			0.0371±0.0835	
Sexual maturation				
Pubic-Hair Stage 2				**0.5176±0.1886** *
Pubic-Hair Stage 3				**1.1847±0.2322** *
Pubic-Hair Stage 4				**1.2976±0.2212** *
Pubic-Hair Stage 5				**2.1965±0.2214** *
Gender×sexual maturation				
Female×Pubic-Hair Stage 2				0.2052±0.2791
Female×Pubic-Hair Stage 3				0.2922±0.3286
Female×Pubic-Hair Stage 4				**0.9129±0.3238** *
Female×Pubic-Hair Stage 5				0.6091±0.3354

[a] Sedentary behavior includes TV viewing, computer use, and reading.

[b] Gender is coded as 0=male, 1=female.

[c] Race is coded as 0=nonblack, 1=black.

[*] Boldface indicates significance at $p<0.05$.

MVPA, moderate to vigorous physical activity

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 4

Multilevel longitudinal models for fat free–mass index in 472 participants in Project HeartBeat!, 1991–1995

	Fat free-mass index (kg/m^2)			
	Model 1 Estimate±SE	Model 2 Estimate±SE	Model 3 Estimate±SE	Model 4 Estimate±SE
Parameter				
Fixed parameters				
Intercept	**15.1669±0.0872** *	**15.4774±0.1339** *	**15.8114±0.1338** *	**14.4491±0.1303** *
Energy intake (1000 kcal/day increments)	**0.1870±0.0687** *	**0.1675±0.0682** *	0.0100±0.0351	0.0094±0.0412
Sedentary behavior (100 min/day increments)[a]	**0.1017±0.0353** *	**0.0980±0.0352** *	0.0128±0.0207	0.0406±0.0252
MVPA (100 min/day increments)	−0.1066±0.0588	−0.1069±0.0595	−0.0052±0.0340	−0.0368±0.0412
Gender[b]		−0.7913±0.1882	**−0.9214±0.1875** *	**−0.9722±0.1972** *
Race[c]		0.0574±0.3220	0.5816±0.2990	0.2551±0.2816
Gender×race		**0.9262±0.4520** *	**0.9612±0.4119** *	0.6287±0.3877
Age			**0.7956±0.0371** *	
Gender×age			**−0.2098±0.0516** *	
Sexual maturation				
Pubic-Hair Stage 2				**0.6216±0.1211** *
Pubic-Hair Stage 3				**1.8329±0.1516** *
Pubic-Hair Stage 4				**2.3358±0.1427** *
Pubic-Hair Stage 5				**3.2599±0.1407** *
Gender×sexual maturation				
Female×Pubic-Hair Stage 2				−0.1003±0.1784
Female×Pubic-Hair Stage 3				**−0.4317±0.2125** *
Female×Pubic-Hair Stage 4				**−0.4511±0.2058** *
Female×Pubic-Hair Stage 5				**−0.9139±0.2104** *

[a] Sedentary behavior includes TV viewing, computer use, and reading.

[b] Gender is coded as 0=male, 1=female.

[c] Race is coded as 0=nonblack, 1=black.

[*] Boldface indicates significance at $p<0.05$.

MVPA, moderate-to-vigorous physical activity

Author Manuscript

Table 5

Multilevel longitudinal models for fat mass index in 472 participants in Project HeartBeat!, 1991–1995

	Fat mass index (kg/m^2)			
	Model 1 Estimate±SE	**Model 2 Estimate±SE**	**Model 3 Estimate±SE**	**Model 4 Estimate±SE**
Parameter				
Fixed parameters				
Intercept	**4.8739±0.1086** *	**4.4439±0.1667** *	**4.4284±0.1664** *	**4.7940±0.1750** *
Energy intake (1000 kcal/day increments)	**−0.1302±0.0447** *	**−0.1153±0.0448** *	−0.0787±0.0432	−0.0591±0.0430
Sedentary behavior (100 min/day increments)[a]	0.0452±0.0275	0.0487±0.0275	0.0349±0.0257	0.0406±0.0263
MVPA (100 min/day increments)	**−0.1409±0.0463** *	**−0.1215±0.0464** *	**−0.1205±0.0441** *	**−0.1359±0.0466** *
Gender[b]		**0.6836±0.2318** *	**0.7932±0.2285** *	0.1349±0.2551
Race[c]		−0.0292±0.3917	−0.2050±0.3912	−0.1009±0.3880
Gender×race		0.9061±0.5500	**1.0872±0.5519** *	0.9273±0.5454
Age			**−0.1687±0.0414** *	
Gender×age			**0.2774±0.0573** *	
Sexual maturation				
Pubic-Hair Stage 2				−0.1474±0.1258
Pubic-Hair Stage 3				**−0.5620±0.1573** *
Pubic-Hair Stage 4				**−0.9754±0.1484** *
Pubic-Hair Stage 5				**−1.1050±0.1488** *
Gender×sexual maturation				
Female×Pubic-Hair Stage 2				**0.4244±0.1848** *
Female×Pubic-Hair Stage 3				**0.6777±0.2200** *
Female×Pubic-Hair Stage 4				**1.2152±0.2151** *
Female×Pubic-Hair Stage 5				**1.5463±0.2229** *

[a]Sedentary behavior includes TV viewing, computer use, and reading.

[b]Gender is coded as 0=male, 1=female.

[c]Race is coded as 0=nonblack, 1=black.

*Boldface indicates significance at $p<0.05$.

MVPA, moderate-to-vigorous physical activity