Activity, Dietary Intake, and Weight Changes in a Longitudinal Study of Preadolescent and Adolescent Boys and Girls

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ABSTRACT. *Objective.* **To examine the role of physical activity, inactivity, and dietary patterns on annual weight changes among preadolescents and adolescents, taking growth and development into account.**

Study Design. **We studied a cohort of 6149 girls and 4620 boys from all over the United States who were 9 to 14 years old in 1996. All returned questionnaires in the fall of 1996 and a year later in 1997. Each child provided his or her current height and weight and a detailed assessment of typical past-year dietary intakes, physical activities, and recreational inactivities (TV, videos/VCR, and video/computer games).**

Methods. **Our hypotheses were that physical activity and dietary fiber intake are negatively correlated with annual changes in adiposity and that recreational inactivity (TV/videos/games), caloric intake, and dietary fat intake are positively correlated with annual changes in adiposity. Separately for boys and girls, we performed regression analysis of 1-year change in body mass index (BMI; kg/m²). All hypothesized factors were in the model simultaneously with several adjustment factors.**

Results. **Larger increases in BMI from 1996 to 1997 were among girls who reported higher caloric intakes (.0061 ± .0026 kg/m² per 100 kcal/day; β ± standard error), less physical activity (−.0284 ± .0142 kg/m²/hour/day) and more time with TV/videos/games (.0372 ± .0106 kg/m²/hour/day) during the year between the 2 BMI assessments. Larger BMI increases were among boys who reported more time with TV/videos/games (.0384 ± .0101) during the year. For both boys and girls, a larger rise in caloric intake from 1996 to 1997 predicted larger BMI increases (girls: .0059 ± .0027 kg/m² per increase of 100 kcal/day; boys: .0082 ± .0030). No significant associations were noted for energy-adjusted dietary fat or fiber.**

Conclusions. **For both boys and girls, a 1-year increase in BMI was larger in those who reported more time with TV/videos/games during the year between the 2 BMI measurements, and in those who reported that their caloric intakes increased more from 1 year to the next. Larger year-to-year increases in BMI were also seen among girls who reported higher caloric intakes and less physical activity during the year between the 2 BMI measurements. Although the magnitudes of these estimated effects were small, their cumulative effects, year after year during adolescence, would produce substantial gains in body weight. Strategies to prevent excessive caloric intakes, to decrease time with TV/videos/games, and to increase physical activity would be promising as a means to prevent obesity.** *Pediatrics* **2000;105(4). URL: http://www.pediatrics.org/cgi/content/full/105/4/e56;** ***physical activity, gym class, inactivity, television, videos, video/computer games, energy intake, dietary fat, dietary fiber, body mass index, adiposity, obesity, weight change, preadolescence, adolescence, longitudinal.***

ABBREVIATIONS. BMI, body mass index; SD, standard deviation; FFQ, youth and adolescent food frequency questionnaire; MET, metabolic equivalent.

From 1980 to 1990, the prevalence of obesity in children and adolescents in the United States approximately doubled,[1] following a steady increase in adiposity during earlier decades.[2–4] This rapid increase suggests the role of environmental rather than genetic factors,[5] although an interaction between genes and environment could be occurring.[5,6]

Childhood and adolescent obesity have been linked to higher all-cause mortality in adulthood,[7–9] as well as childhood hyperlipidemia, glucose intolerance, cholelithiasis, and hypertension.[10,11] Associations between adolescent blood pressure, cholesterol, and body mass index (BMI) have been reported,[3,12–14] and longitudinal change in BMI was accompanied by (same direction) change in blood pressure.[14] Others found strong associations between childhood body fatness and plasma lipids/blood pressures that were not explained by fitness.[15]

In addition to the physical health consequences, both immediate and long-term, obesity has psychosocial effects and substantial economic costs.[16,17] College acceptance rates are lower for obese applicants,[18] and obese women face more obstacles in the workplace.[19]

The tracking of adiposity in childhood is quite strong.[20,21] One third of obese preschool children become obese adults, as do half of obese school-aged children.[22] Remission rates are low (<1% per year) and decline with age.[22] As summarized by Klesges et al,[23] because of obesity's persistence into adulthood, its resistence to treatment, and its health consequences, it is critical to understand the determinants

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of adiposity in children to learn how to prevent the childhood onset of obesity. Although the cause of obesity is complex and multifactorial, including genetic factors, environmental factors are clearly important in its development. Excess body weight results from energy intake in excess of expenditure. However, energy intake must exceed energy output in the growing child, particularly during those periods of most rapid adolescent growth.[5]

Adolescence is a time when independence is established, and dietary and activity patterns may be adopted that are followed for many years. Thus, it has great influence on adult fatness and chronic disease experiences decades later. Because both behaviors and adiposity track into adulthood, it is important to assess the roles of modifiable behaviors (diet, physical activity, and inactivity) on adolescent adiposity.

We describe a prospective longitudinal study of adolescent weight change over a 1-year follow-up. We limit consideration here to associations among (primarily recreational) physical activity, gym class participation, recreational inactivity (TV, videos, and video/computer games), dietary intakes (total energy, dietary fat, and fiber), and adiposity changes in adolescent and preadolescent boys and girls. We undertook the following analysis, on population data collected from youth, to address our longitudinal hypothesis: dietary intakes, physical activities, and inactivities occurring over a year are associated with changes in body fatness during that year.

METHODS

Population

Established in the fall of 1996, the ongoing Growing Up Today Study consists of 16 882 children, residing in 50 states, who are offspring of Nurses' Health Study II participants.[24] The Growing Up Today Study was designed to assess prospectively the determinants of adolescent weight changes, including dietary intake, physical activity, and inactivity.

Letters were sent in 1996 to mothers of children, in the 9- to 14-year age range, explaining the goals of the new study and requesting consent for their children to participate. Approximately 18 526 mothers returned the consent form, providing the name, age, gender, and mailing address of 26 765 children. Introductory letters and gender-specific questionnaires were then mailed directly to children whose mothers had granted consent. These letters assured potential participants that the information they provided would be confidential. The baseline (1996) sample included 9039 girls (68% response rate) and 7843 boys (58% response rate) who returned completed questionnaires, thereby assenting to participate. Some of these respondents were outside the 9- to 14-year age range at the time of questionnaire completion, leaving us with 8980 girls and 7791 boys at baseline. A year later (fall 1997), they were mailed follow-up questionnaires to update all information. These were returned by 7299 girls and 5653 boys. The sample for analysis, to be described later, is smaller because of exclusions and missing values on 1 or more important variables.

Measures

Adiposity

We assessed adiposity by computing BMI (BMI = weight/height^2 [kg/m^2]) from the heights and weights reported by the children in 1996 and 1997. Our questionnaire provided specific instructions for measuring height and weight but suggested asking someone to help. Annual change in adiposity was measured by 1-year change in BMI, $BMI_{1997} - BMI_{1996}$, adjusted for the time lag (not always exactly 12 months) between the 2 returned questionnaires. Shannon et al[25] reported high validity of self-reported heights and weights in sixth graders (boys' weight: $r = .90$, height: $r = .74$; girls' weight: $r = .84$, height: $r = .62$). Preliminary results from pilot studies among girls 10 to 17 years old suggested even higher validity ($r = .98$ for weight, $r = .73$ for height, and $r = .89$ for BMI). Data from Strauss[26] showed that self-reported heights and weights were extremely reliable for studying issues related to obesity in children 12 to 16 years old.

We excluded any height that was >3 standard deviations (SDs) beyond the gender- and age-specific mean height (1996: 41 girls and 59 boys; 1997: 17 girls and 17 boys), and consecutive annual heights if height declined by >1 inch or increased by >8 inches (mean change + 3 SD) between 1996 and 1997 (125 girls and 73 boys). We excluded any BMI <12 kg/m^2 as a biological lower limit (clinical opinion), and any BMI >3 SD beyond the gender- and age-specific mean (in the log scale, because the distribution of BMI was skewed toward larger values; 1996: 87 girls and 56 boys; 1997: 56 girls and 51 boys). Consecutive BMIs were excluded if they produced an annual change >3 SD beyond the mean change (not log scale because BMI changes were not skewed; 77 girls and 37 boys).

Dietary Intakes

Members of our group designed a self-administered, semiquantitative food frequency questionnaire (FFQ) specifically for older children and adolescents that is inexpensive and easy to administer to large populations.[27] This FFQ for youth and adolescents has been shown to be valid ($r = .54$ for comparing the FFQ with 3 24-hour recalls[28]) and reproducible.[27] This is similar in performance to the FFQ in adults.[27]

The FFQ included questions regarding usual frequency of intake of 132 specific food items over the past year. Questions differentiated fat content of relevant food items (milk and other dairy products, fried food, salad dressing, and fat and skin on meat). Using nutrient composition databases, assuming food portion sizes specific to our age range and each child's reported intake of each food, we estimated total caloric intake (kcal/day), total fat intake (g/day) and total Association of Official Analytical Chemists dietary fiber intake (g/day). Fat and fiber intakes were then energy-adjusted using the method of Willett.[29] We excluded as implausible energy intakes <500 kcal/day or >5000 kcal/day (1996: 35 girls and 53 boys; 1997: 26 girls and 45 boys).

Physical Activity

We developed a physical activity questionnaire, specifically for youth, that asked them to recall the typical amount of time spent, over the past year, in various activities and team sports. Questions included, for 17 separate sports and other activities (like hard work outdoors and walking), how many hours per week they typically did them (outside of gym class in school). From each child's responses, we computed his or her hours of physical activity (outside of gym class) per week. Assessments of this instrument found that estimates of total physical activity were moderately reproducible ($r = .49$ for girls; $r = .53$ for boys) and were reasonably correlated with cardiorespiratory fitness (total activity hours with time to complete 1-mile run: $r = -.23$ for girls; $r = -.27$ for boys), thus providing evidence of validity.[30–32]

We were unable to ascertain details of varying intensity (within sport), or duration per session of activity, which may be related to obesity.[33] However, we assigned a metabolic equivalent (MET), based on a compendium by Ainsworth et al,[34] to individual sports/activities and estimated a total MET per week for each child.

The children reported separately on the number of gym or physical education classes in school they were currently participating in per week.

We excluded from analyses those estimates of activity that exceeded 40 hours/week (1996: 398 girls and 537 boys; 1997: 223 girls and 312 boys).

TV/Videos/Games

Another series of questions were designed to measure weekly hours of recreational inactivity. For watching TV and videos (VCR) and for time spent playing video/computer games, children reported for each their typical hours per day, separately for weekdays and weekends. From this information, we computed each child's total hours per week. Totals of >80 hours per week were excluded as unreliable (1996: 57 girls and 164 boys; 1997: 34 girls and 89 boys).

Other Measures

Children also reported at baseline their race/ethnic group by marking all that apply (6 choices available). We assigned each child to a race/ethnic group following US Census definitions, except we retained Asians as a separate group rather than pooled with other).[1,35] In 1996 and 1997, children reported their Tanner maturation stage (5 categories for stage of pubic hair development) and whether girls' menstrual periods had yet begun. Self-ratings of sexual maturity in adolescent girls have been validated.[36] For girls, we derived a menstrual history variable having 3 categories: premenarche in both 1996 and 1997, periods began between 1996 and 1997, and postmenarche at baseline. We computed each child's age from his or her birthdate and the date when the questionnaire was returned to us.

Sample for Analysis

Beyond the exclusions outlined in the above sections, there were some missing data on the factors of primary interest (activity, inactivity, and diet) and also on covariates adjusted for in the analysis (Tanner stage, menarche status, and race). This left us with 6149 girls and 4620 boys providing data for the analysis of change in BMI from 1996 to 1997.

Statistical Analysis

All analyses were performed separately by gender. We compared the baseline (1996) values, of those children who returned with those who did not return the 1997 questionnaire, to assess the potential for bias in our sample for the analysis of 1-year change in BMI.

To estimate the effects of diet, activity, and inactivity on annual changes in adiposity, we used linear regression models with 1-year change in BMI as the continuous outcome variable; it was approximately normally distributed. All models controlled for race/ethnic group, baseline BMI, annual change in height (to adjust for the increased energy needs of the growing child[5]), menstrual history in girls, Tanner stage, and age, to adjust for changes in BMI that occur because of growth and maturation.[37–43]

The 6 factors of primary interest, which we entered simultaneously in all models, were total energy intake, fat intake (energy-adjusted), fiber intake (energy-adjusted), number of gym classes per week in school, hours of physical activity, and hours of TV/videos/games. To assess the timing of these factors, relative to their effects on BMI change from 1996 to 1997, we fit 4 separate versions of the model. One model used diet and activity during the year before the first BMI (recalled in 1996), whereas another used diet and activity during the year between the 2 BMIs (recalled in 1997). A third model used the means over 2 years of each diet and activity variable, and a fourth model used the year-to-year change in diet and activity.

It is possible that the most relevant period may be different for each factor. For example, the best predictors of change in BMI from 1996 to 1997 could conceivably be a change in activity from 1 year to the next, the number of gym classes per week reported in the fall of 1996, and caloric intake in the year between the 2 BMIs. As an exploratory analysis of this issue, we used stepwise regression, including as potential predictors all 6 variables recorded in the fall of 1996, in 1997, their 2-year means, and changes from 1996 to 1997. We further allowed METs per week (1996 METs, 1997 METs, mean METs, and change in METs) to enter these stepwise models.

Because each child provided to this analysis only 1 annual change in BMI, ordinary linear regression models were appropriate. However, we refit the models, taking into account correlations among the small numbers of siblings of the same gender, to confirm that estimates were not materially different. We used generalized estimating equations[44] and SAS Proc Genmod (SAS Institute, Cary, NC)[45] to take these correlations into account. We also confirmed that our assumption of linear associations between annual BMI changes and the diet and activity variables were reasonable by replicating our analysis using quintile categories for each factor.

RESULTS

In our cohort, 94.7% were white (not Hispanic), .9% were black (not Hispanic), 1.5% were Hispanic, 1.5% Asian, and 1.4% other (including Native American). This reflects the minority representation of their mothers who are all nurses and participants in the Nurses' Health Study II.[24] Table 1 presents baseline gender- and age-specific summaries of anthropometric measurements and the 6 factors of interest, for 8980 girls and 7791 boys. At baseline, .3% of 9-year-old girls had begun menstrual cycles, 2.4% of 10-year-olds, 11.6% of 11-year-olds, 36.5% of 12-year-olds, 69.4% of 13-year-olds, and 89.4% of 14-year-old girls.

Using the baseline (1996) data, we compared those children who did not return questionnaires in 1997 with those who did, to assess possible follow-up bias. The 2 groups were comparable on 1996 BMI (age-adjusted), total energy intake, dietary fat intake, dietary fiber intake, and number of gym classes per week. Thus, there do not seem to be biases related to dietary intakes or adiposity. However, those not returning the 1997 questionnnaire were older (girls: 12.20 vs 11.98, $P < .05$; boys: 12.18 vs 11.86, $P < .05$), were more physically active (girls: by .11 hours/day [age-adjusted], $P < .05$; boys: by .06 hours/day [age-

TABLE 1. Baseline Values for Growing Up Today Study Participants: Age-Specific Means (SDs)

Age Years	Height (in)	Weight (lbs)	BMI kg/m²	Energy kcal/Day	Fat g/Day	Fiber g/Day	Activity Hours/Day	TV/Games Hours/Day	Gym Number/Week
Girls (n = 8980)									
9	53.96 (2.72)	72.70 (14.92)	17.47 (2.84)	2106 (636)	70.4 (10.4)	16.4 (4.1)	1.65 (1.03)	3.42 (1.94)	2.1 (1.1)
10	56.08 (3.17)	81.12 (18.18)	18.02 (3.10)	2048 (642)	70.0 (10.8)	16.4 (4.3)	1.80 (1.11)	3.49 (1.99)	2.1 (1.1)
11	58.83 (3.26)	91.66 (20.33)	18.48 (3.06)	2034 (643)	69.7 (11.1)	16.4 (4.1)	2.01 (1.19)	3.65 (2.07)	2.5 (1.4)
12	61.53 (3.06)	104.82 (22.07)	19.36 (3.26)	2050 (665)	68.9 (11.2)	16.5 (4.5)	2.29 (1.28)	3.86 (2.14)	2.9 (1.6)
13	63.46 (2.76)	115.33 (22.27)	20.05 (3.17)	2072 (676)	68.1 (11.6)	16.4 (4.2)	2.47 (1.34)	3.80 (2.15)	3.0 (1.6)
14	64.41 (2.59)	121.35 (21.32)	20.52 (3.09)	2089 (641)	66.5 (12.0)	16.8 (4.6)	2.58 (1.36)	3.55 (2.17)	3.1 (1.8)
Boys (n = 7791)									
9	54.74 (2.85)	76.16 (16.33)	17.77 (2.90)	2299 (630)	78.6 (11.2)	17.8 (4.4)	2.14 (1.26)	4.15 (2.10)	2.1 (1.1)
10	56.45 (2.91)	83.37 (18.32)	18.28 (3.10)	2253 (657)	78.6 (11.3)	17.7 (4.7)	2.29 (1.25)	4.39 (2.27)	2.2 (1.1)
11	58.66 (3.00)	92.60 (20.49)	18.79 (3.17)	2284 (741)	78.6 (11.4)	17.5 (4.6)	2.47 (1.26)	4.45 (2.33)	2.5 (1.4)
12	61.37 (3.35)	105.27 (24.06)	19.50 (3.30)	2290 (733)	78.8 (11.7)	17.0 (4.3)	2.62 (1.33)	4.62 (2.38)	2.9 (1.6)
13	64.23 (3.50)	118.89 (27.03)	20.11 (3.42)	2335 (762)	78.9 (11.9)	17.0 (4.5)	2.79 (1.34)	4.80 (2.38)	3.1 (1.6)
14	67.17 (3.54)	134.37 (26.95)	20.82 (3.22)	2405 (784)	78.0 (11.3)	16.9 (4.2)	2.71 (1.32)	4.75 (2.43)	3.0 (1.8)

* Fat and fiber were both energy-adjusted. Sample sizes, for age 9 years: 1029 girls and 933 boys; age 10 years: 1698 girls and 1528 boys; age 11 years: 1730 girls and 1608 boys; age 12 years: 1671 girls and 1396 boys; age 13 years: 1497 girls and 1282 boys; age 14 years: 1355 girls and 1044 boys.

adjusted]; $P = .06$), and spent more time with TV/videos/games (girls and boys: by .3 hours/day [age-adjusted], $P < .05$), but these differences were small.

Figure 1 presents the mean annual changes (+1 SD) in BMI (kg/m^2) by baseline age group. Girls who were 11 years old at baseline, and boys who were 12 years old, had the largest mean annual increase in BMI. Regarding growth and development, the largest mean increase in height occurred in girls who were 10 years old, and in boys 12 years old, at baseline. Onset of menses occurred most frequently in girls 12 years old at baseline.

Table 2 shows the linear regression model coefficients for predicting 1-year change in BMI (from 1996 to 1997), adjusting for race, menarche history (girls), annual height growth, baseline BMI, age, and Tanner stage. The model on the far right of Table 2 corresponds to the test of our longitudinal hypothesis (1-year change in BMI is associated with the child's diet and activity between the 2 BMI measurements). Annual BMI increases were higher in girls with higher caloric intakes (BMI increased by .0061 kg/m^2 per 100 kcal/day; $P < .02$), more hours of TV/videos/games (BMI increased by .0372 kg/m^2/hour/day; $P < .001$), and fewer hours of activity (BMI decreased by .0284 kg/m^2/hour/day of activity; $P < .05$) during the year between the 2 BMI measurements. Energy-adjusted fat and fiber intakes and number of gym classes per week were not predictive.

Variations on our hypothesized model appear in the first 3 columns of Table 2. The first model tests whether diet and activity before measurement of the initial BMI are associated with subsequent change in BMI. The second model looks at the means over 2 years of each diet and activity variable, and the third model looks at year-to-year change in each diet and activity variable. For girls, estimates from these other 3 models suggested weaker effects than the model that evaluated our hypothesis. However, a larger increase in caloric intake (from the year before the initial BMI to the year after; column 3) was associated (.0059 kg/m^2 per 1-year increase of 100 kcal/day; $P < .03$) with a larger increase in BMI, and an increase in physical activity (from the year before the initial BMI to the year after) was marginally associated (−.0262 kg/m^2/hour/day increase in activity; $P = .054$) with an annual BMI decline. Although the 4 model R^2 are very close together, the model corresponding to our hypothesis (right column in Table 2) had the highest $R^2 = .19$.

For boys, the model corresponding to our longitudinal hypothesis (Table 2, boys, right column; model $R^2 = .17$) showed that annual BMI increases were higher among boys who, in the year between the 2 BMIs, spent more time with TV/videos/games (.0384 kg/m^2/daily hour; $P < .0001$) and, marginally, had less physical activity (−.0261 kg/m^2/hour of activity; $P = .094$). Caloric intake, energy-adjusted fat and fiber intakes (during the year between the 2 BMI measurements), and number of gym classes per week (at time of second BMI measurement) were not associated ($P > .10$) with change in BMI.

As in girls, a larger rise in caloric intake from 1 year to the next was associated with a larger increase in BMI (.0082 kg/m^2/100 kcal/day increase, $P < .01$; Table 2, boys, column 3). In the first model (column 1), more gym class time reported for the 1996–1997 school-year was associated with smaller BMI increases from 1996 to 1997 (.03 kg/m^2 decline in BMI per additional gym class each week; $P < .03$). But an increase in number of weekly gym classes (from fall 1996 to fall 1997) was associated with an increase in BMI for boys (Table 2 column 3).

To illustrate the magnitude of the estimated effects of diet and activity, we hold constant (in the model on the far right of Table 2) the adjustment variables and the remaining 5 factors. Figure 2 shows the expected annual change in BMI for girls and boys with extreme values (10th percentile and 90th percentile) of each factor. Although the significant effects were each in the directions we hypothesized, their magnitudes appear relatively small. But if these

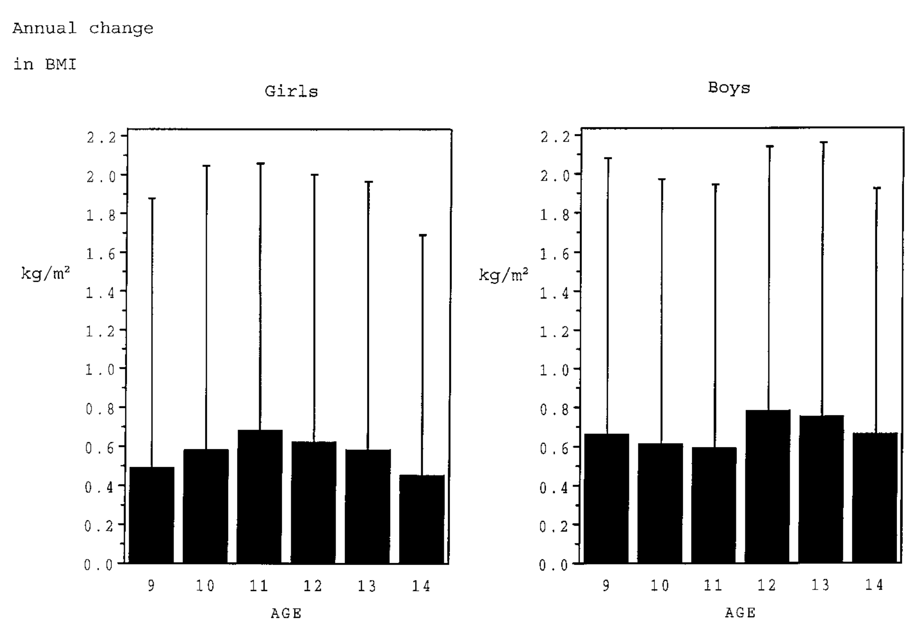


Fig 1. Mean annual change (+1 SD) in BMI (kg/m^2) by age at baseline.

TABLE 2. Linear Regression Model Coefficients, With Standard Errors and *P* Values for Predicting One-Year Change in BMI (kg/m^2) in Girls and Boys

Factor	One-Year Change in BMI Predicted by Diet and Activity							
	In Year Before Initial BMI		Mean Over Two Years		Year-to-Year Change		In the Year Between the Two BMIs	
	β (Standard Error [β])	*P*	β (Standard Error [β])	*P*	β (Standard Error [β])	*P*	β (Standard Error [β])	*P*
Girls								
Calories (100 kcal/d)	+.0028 (.0026)	.293	+.0056 (.0029)	.053	+.0059 (.0027)	.028	.0061 (.0026)	.016
Fat (g/d)	+.0012 (.0015)	.421	+.0011 (.0018)	.537	+.0004 (.0016)	.792	+.0008 (.0016)	.632
Fiber (g/d)	+.0023 (.0041)	.577	+.0026 (.0048)	.582	−.0031 (.0043)	.465	+.0011 (.0043)	.799
Gym classes (number/wk)	−.0056 (.0111)	.615	−.0082 (.0123)	.508	−.0088 (.0094)	.352	−.0067 (.0098)	.496
Activity (excluding gym, h/d)	−.0100 (.0137)	.469	−.0229 (.0157)	.144	−.0262 (.0136)	.054	−.0284 (.0142)	.046
TV/video/games (h/d)	+.0193 (.0081)	.018	+.0380 (.0106)	.001	+.0053 (.0083)	.526	+.0372 (.0106)	.001
Boys								
Calories (100 kcal/d)	−.0038 (.0028)	.178	+.0013 (.0031)	.661	+.0082 (.0030)	.006	.0032 (.0028)	.249
Fat (g/d)	−.0018 (.0018)	.296	−.0017 (.0019)	.377	+.0010 (.0018)	.577	−.0015 (.0017)	.375
Fiber (g/d)	−.0059 (.0045)	.186	−.0045 (.0051)	.373	+.0025 (.0049)	.610	−.0046 (.0047)	.320
Gym classes (number/wk)	−.0300 (.0133)	.025	−.0031 (.0147)	.830	+.0407 (.0119)	.001	+.0185 (.0121)	.128
Activity (excluding gym, h/d)	−.0090 (.0151)	.550	−.0188 (.0170)	.267	−.0113 (.0149)	.448	−.0261 (.0156)	.094
TV/videos/games (h/d)	+.0265 (.0085)	.002	+.0425 (.0104)	.001	−.0019 (.0086)	.830	+.0384 (.0101)	.001

* The 6 factors above were in the model simultaneously along with race, menarche history (girls), annual height growth, baseline BMI, age, and Tanner stage. Fat and fiber were energy-adjusted. Gym class measures participation at the time of BMI measurement, not past year.

effects are repeated year after year (.2 kg/m^2 increase in BMI per year for TV/videos/games), they cumulate to clinically significant effects on adiposity (1 kg/m^2 after 5 years).

We next performed an exploratory stepwise analysis that included all the adjustment variables but allowed the data to suggest which time period for each of the dietary and activity variables best predicted 1-year change in BMI. We further allowed the inclusion of METs to reflect the intensities of the various physical activities. For girls, the factors that were selected by the algorithm were the same 3 that were significant in the Table 2 model on the right: calories, activity, and TV/videos/games between the 2 BMI measurements. For boys, higher mean (over 2years) hours of TV/videos/games, gym class participation that increased more from the first to the second year, and caloric intake that increased more from the first to the second year predicted larger increases in BMI. Boys with higher METs during the year between the 2 BMIs had marginally smaller (P = .06) increases in BMI.

To see if there was effect modification by age, we used interaction terms that indicated younger (9 to 11 years old) or older (12 to 14 years old) age at baseline. In younger girls, the effects on change in adiposity by activity (−.0755 ± .0209), TV/videos/games (.0747 ± .0150), and gym class (−.0451 ± .0182) were all significantly stronger than in the older girls. Among boys under 12 years old, those with more physical activity in the year between the BMI measurements had smaller annual increases in BMI (−.0746 ± .0212).

DISCUSSION

Currently, there are few effective treatments to reduce weight and maintain the loss among overweight individuals. Therefore, intentional weight losses are rarely sustained. The Council on Scientific Affairs from the American Medical Association supports prevention as the treatment of choice for adults. For weight loss, they support a nutritionally balanced, low-energy diet while increasing energy expenditure through regular physical exercise.[46] Similar recommendations have been put forth for children.[47] But modifying dietary, activity, and inactivity patterns is difficult after lifelong habits are established. Even with only 1 year of follow-up on our cohort, we note that year-to-year activity and inactivity are more stable in the older girls than the younger girls; thus, their habits are already becoming established.

Our ongoing longitudinal study of >10 000 boys and girls from all over the United States showed that boys and girls who spent more time viewing television and videos and playing video/computer games during a year had larger increases in BMI, as did those who increased their caloric intake more from the previous year. For girls, physical activity and caloric intakes during the year were also associated with change in BMI. For younger boys, physical activity between the BMI measurements was inversely associated with change in BMI. There was some evidence, for boys and younger girls, that more frequent gym classes in school were associated with smaller increases in BMI, but this evidence should be viewed with caution because of the potential for bias because gym class is optional for some students. Finally, we found no evidence that energy-adjusted fat or fiber intakes were associated with changes in BMI, for either girls or boys.

Although our assessment of body fatness, using only height and weight, was crude, more reliable body composition techniques[33] were not feasible in a large cohort of self-reporting children. Detailed studies of indices that use weight and height suggested that BMI is the better measure of adiposity at all childhood ages.[48–53] We needed a measure that has a high correlation with body fatness, more importantly than a low correlation with height. A frequent criti-

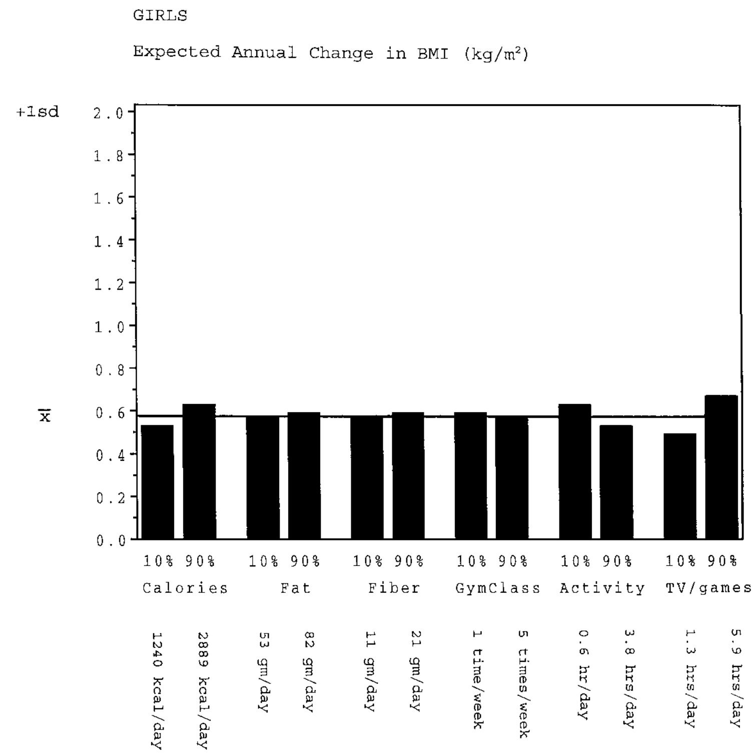
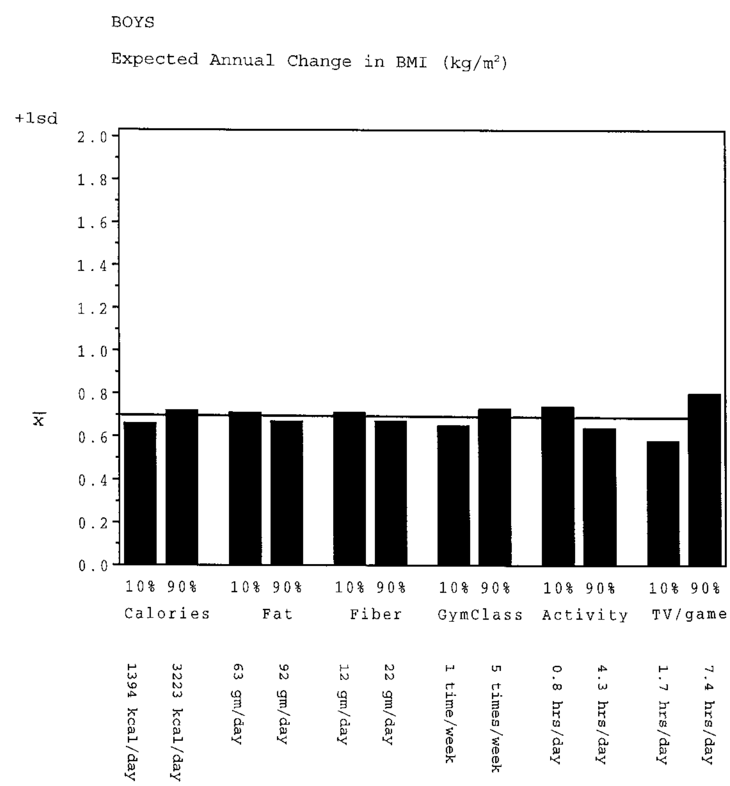


Fig 2. The expected annual change in BMI for children with extreme values (10th percentile and 90th percentile of the distribution) of each factor, with all other variables held constant, derived using the models on the far right of Table 2.



cism of BMI is that it is correlated with height, but body fatness (by more reliable techniques) is positively correlated with height.[10,51,54]

Our analysis of annual change in BMI, a continuous variable, had the advantage of avoiding arbitrary cut-points to define obesity. Thus, we have avoided misclassification of obesity that would arise if there were systematic bias in self-reported height or weight.[55] And we have examined relative weight loss and gain within the whole range of adiposity, from very underweight to very overweight.

Measuring dietary intakes of children is very difficult and fraught with problems.[33] By 10 years old, children are able to give accurate dietary information and are well aware of the foods they have eaten.[56] Rockett et al[28] presented evidence that the accuracy of our FFQ did not vary according to the BMI or age of the child. Food frequency questionnaires provide enough accuracy in studies of adolescents to permit individual diets to be related to subsequent health outcomes.[57] We focused our analysis on total energy intake and (energy-adjusted) dietary fat and fiber intakes because of evidence that they have special roles in obesity. At mealtime, fat is less satiating than carbohydrate,[58–60] and dietary fat is stored more efficiently than carbohydrate or protein.[61] In contrast, a high fiber diet should be greater in volume and more satiating at mealtime.[58] In the United States, diets high in fat tend to be low in fruits and vegetables and complex carbohydrates.[62]

Most physical activity in children takes place in organized programs outside of school.[63] Our instrument assesses mostly recreational activity rather than approximating total energy expenditure. Recreational activity and inactivity patterns are modifiable and could be the object of public health policies.[64]

Our findings are consistent with a growing body of evidence that among children and adolescents, physical activity and inactivity (particularly TV viewing) are associated with body fatness.[2,23,38,63,65–74] Data collection in some of these studies occured even before the advent of VCRs and video/computer games in the home—inactivities that now contribute significantly to our children's lifestyles. But the positive association between TV viewing and adiposity has not been confirmed by all studies.[36,75] The role of inactivity in obesity may be even beyond the fewer calories expended; television advertising tends to push foods that are energy-dense and nutrient-poor.[58] Children request foods that are more frequently advertised on TV, and TV viewing is correlated with caloric intake.[76]

In a 3-year longitudinal study of obesity in 146 preschool children, Klesges et al[23] found that high dietary fat intake (total fat energy) was associated with greater increase in BMI. Increasing caloric intake by as little as 150 calories per day above the number of calories needed for weight maintenance would result in a substantial weight gain over a year.[5] Efficiency of metabolism of energy intake varies among individuals. There are no significant differences in the metabolic requirements of lean and obese individuals to maintain their body weight,[5] but a formerly obese adult requires fewer calories to maintain body weight than a never-obese person of the same body weight.[77] Perhaps these findings apply to children also.

Other investigators review behavioral, social, and environmental factors that influence energy intake and expenditure and physical activity.[58,78]

A major strength of our analysis was the longitudinal design, which allowed us to study changes over 1 year in adiposity. A cross-sectional study of BMI measured at 1 time-point would be limited because excess adiposity in a child may be attributable to the effects of poor dietary and activity patterns cumulating over years before data collection. A limitation of our study was the necessity to collect data on children and adolescents by self-report on mail-return questionnaires. With our very large cohort, alternatives were not feasible. We considered our model R^2 (for predicting annual changes in BMI) approaching .20 quite good, considering that BMI change is a composite of 4 measurements (heights and weights each measured twice), self-reported by children. This represents a correlation of .44 between the model-predicted changes in BMI and the observed changes.

The results of this study provide evidence that, in older children and adolescents, energy intake, physical activity, and recreational inactivity are associated with changes in body fatness, but that dietary fat and fiber are not (aside from their energy content). Attempts by pediatricians to modify each of several factors a little, rather than modifying a single factor (activity, TV/videos/games, or energy intake) a lot, might be more successful in individual patients. To prevent excessive annual increases in body fatness in children, public health strategies to reduce recreational inactivity (TV, videos, and video/computer games), to increase recreational physical activity, and to reduce excess caloric intake may be promising.

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Activity, Dietary Intake, and Weight Changes in a Longitudinal Study of Preadolescent and Adolescent Boys and Girls

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