Physical Activity, Cardiovascular Fitness, and Insulin Sensitivity Among U.S. Adolescents

The National Health and Nutrition Examination Survey, 1999–2002

GIUSEPPINA IMPERATORE, MD, PHD[1]
YILING J. CHENG, MD, PHD[1]
DESMOND E. WILLIAMS, MD, PHD[1]
JANET FULTON, PHD[2]
EDWARD W. GREGG, PHD[1]

OBJECTIVE — The purpose of this study was to examine the association of physical activity and cardiovascular fitness (CVF) with insulin sensitivity in a nationally representative sample of U.S. youth.

RESEARCH DESIGN AND METHODS — The study included 1,783 U.S. adolescents (11% Mexican American, 14% non-Hispanic black, 63% non-Hispanic white, and 12% other) aged 12–19 years who were examined in the 1999–2002 National Health and Nutrition Examination Survey. Physical activity was assessed by questionnaire and expressed in units of MET hours per week. Predicted maximal oxygen uptake (Vo_{2max}, expressed in milliliters per kilogram of body weight per minute), a measure of CVF, was determined by a submaximal multistage treadmill test. Insulin sensitivity was defined by the Quantitative Insulin Sensitivity Check Index.

RESULTS — Boys were more likely than girls to be highly active ($\geq$30 MET h/week; 51 vs. 37%, $P < 0.001$) and had higher levels of CVF (mean Vo_{2max} 47 vs. 39 $ml \cdot kg^{-1} \cdot min^{-1}$, $P < 0.001$). Sex-specific multiple regression models controlled for age, race/ethnicity, and BMI showed that in boys, high levels of physical activity and high levels of CVF were significantly and positively associated with insulin sensitivity ($\beta = 0.84$, $P < 0.001$ and $\beta = 0.82$, $P = 0.01$, respectively). Among girls, insulin sensitivity was not significantly associated with physical activity or with CVF but was inversely and significantly associated with BMI.

CONCLUSIONS — Increasing physical activity and CVF may have an independent effect of improving insulin sensitivity among boys. For girls, the primary role of physical activity may be in weight maintenance.

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The prevalence of obesity among U.S. adolescents has increased dramatically in recent decades (1). Some reports have suggested that this rise is being accompanied by an increase in type 2 diabetes and in metabolic abnormalities associated with insulin resistance (2–4).

Among adults, physical activity is thought to be a key factor influencing insulin resistance (5) and the future risk of developing type 2 diabetes (6–10). The effect of physical activity on insulin resistance in children may be similar to that observed in adults. However, most of the studies that have investigated this association in children were conducted in overweight children (11–13). Moreover, it is unclear whether the association of physical activity with insulin resistance is independent of adiposity (13–16). In a study including white and African-American children, physical activity was independently associated with insulin sensitivity and secretion (14). Similarly, Schmitz et al. (15) reported a positive association of physical activity with insulin sensitivity assessed by euglycemic-hyperinsulinemic clamp. However, other studies have found no association between either physical activity or fitness and insulin sensitivity (13,16). These discrepancies may be due to differences in the assessment of physical activity and insulin sensitivity or to differences in the relation of physical activity to insulin sensitivity across race/ethnicity or obesity categories. Understanding this relation is important for planning intervention programs to reduce insulin resistance and type 2 diabetes in youth.

Therefore, we investigated, in a representative multiracial sample of U.S. adolescents, whether physical activity levels and fitness are associated with insulin sensitivity and whether these associations are independent of body weight.

RESEARCH DESIGN AND METHODS

— The National Health and Nutrition Examination Survey (NHANES) is a series of cross-sectional health surveys designed to be representative of the U.S. noninstitutionalized population. This report is based on the 1999–2002 NHANES data collection. Detailed descriptions of the design of the survey have been published (17). Each NHANES consists of a home interview followed by a standardized medical examination in a mobile examination center (MEC). During the home interview, data on sociodemographic variables are collected, including race/ethnicity, family income, and education. Participants are then asked to attend the MEC, where they complete additional questionnaires, undergo physical examinations, and provide a blood sample. Half of the participants are randomly assigned to the morning

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From the [1]Division of Diabetes Translation, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia; and the [2]Division of Nutrition and Physical Activity, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia.

Address correspondence and reprint requests to Dr. Giuseppina Imperatore, Division of Diabetes Translation, CDC, 4770 Buford Highway, NE MS-K10, Atlanta, GA 30341. E-mail: gai5@cdc.gov.

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Abbreviations: CVF, cardiovascular fitness; MEC, mobile examination center; NHANES, National Health and Nutrition Examination Survey; QUICKI, Quantitative Insulin Sensitivity Check Index.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

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session of the MEC and are asked to fast overnight. In the 1999–2002 survey, for participants aged 12–19 years, the overall response rate for those interviewed was 89% and for those examined was 86%.

The study received human subject review and approval. Participants were asked to sign separate informed consent documents for the interview and health examination.

Demographics/antropometrics

On the basis of self-report, participants were categorized as non-Hispanic white, non-Hispanic black, or Mexican American; other racial groups were included in the category "other." Weight and height were measured in the MEC and were used to compute BMI (expressed as weight in kilograms divided by the square of height in meters). Of those attending the morning session, 98% had data on weight and height. Participants were classified as overweight or at risk of overweight when their age- and sex-specific BMI percentile was $\geq$95th or $>$85th but $<$95th, respectively (18).

Physical activity assessment

Physical activity was measured by a questionnaire that was administrated during the home interview to individuals aged $\geq$16 years or during the MEC session for those aged 12–15 years. There were no missing data for physical activity. Participants were asked to report the frequency and duration of physical activity during the past month from a list of 37 different activities and were also given the opportunity to report activities not on the list. Activities on the list included school-related involvement, such as physical education, but excluded transportation to and from school. Physical activity was coded and classified according to a standardized coding scheme developed by Ainsworth et al. (19) and was defined as the ratio of work metabolic rate to a standard resting metabolic rate (MET). One MET is equivalent to energy expenditure during seated rest, ~3.5 ml of oxygen consumed $\cdot$ kg^{-1} body weight $\cdot$ min^{-1}. Individuals who did not report any activity were classified as sedentary. In those who reported any physical activity, physical activity was categorized into two groups based on the median of the MET distribution: moderate (MET h/week $>$0 and $<$30 MET h/week) and high ($\geq$30 MET h/week).

Cardiovascular fitness assessment

Cardiovascular fitness (CVF) was determined by using a submaximal exercise test (20) performed at the MEC. On the basis of their sex, age, BMI, and self-reported level of physical activity, the participants were assigned to one of eight treadmill test protocols (additional details available at http://www.cdc.gov/nchs/data/nhanes/cv.pdf). The goal of each protocol was to elicit a heart rate that was ~75% of the age-predicted maximum (estimated as 220 − age) by the end of the test. Heart rate was monitored continuously with an automated monitor. The main outcome was the workload (i.e., grade and speed of the treadmill) attained when the participant reached 75% of predicted maximum heart rate. Workload is expressed in terms of estimated oxygen consumption ($V\text{O}_{2\max}$, expressed as milliliters of O_2 consumed per kilogram of body weight per minute). The use of this submaximal test protocol to predict CVF was previously validated (21). In the present analysis, estimated $V\text{O}_{2\max}$ was further categorized on the basis of sex- and age-specific criteria, and CVF is reported as low, moderate, or high on the basis of the criteria used in the FITNESSGRAM program (22,23).

Of the 1,783 adolescents included in the study, 1,343 underwent the CVF test, and, of those, 1,050 (78%) completed it. The reasons for not completing the CVF test were a technical problem in 276 subjects, meeting stop criteria in 12 subjects, refusal in 1 subject, and other reasons in 4 subjects.

Insulin sensitivity assessment

Of 1,892 individuals aged 12–19 years who attended the morning session and reported fasting for at least 9 h, 1,853 (98%) had measurements of fasting glucose and insulin levels. Of the 1,853, the present analysis includes 1,783 individuals who did not have a diagnosis of diabetes and were not pregnant. All insulin and glucose assays were performed at the Diabetes Diagnostic Laboratory at the University of Missouri, Columbia, Missouri. Fasting plasma glucose was measured enzymatically by the hexokinase method (24). Serum insulin was measured by radioimmunoassay with the double-antibody batch method (24). Details about these laboratory procedures and quality control have been published (24).

We measured insulin sensitivity using the Quantitative Insulin Sensitivity Check Index (QUICKI) calculated as 100/(log fasting insulin in microunits per milliliter + log glucose in milligrams per deciliter) (25). In children, this index of insulin sensitivity has been shown to closely correlate with indexes of insulin sensitivity derived from either clamp studies (26) or frequently sampled intravenous glucose tolerance testing (27).

Statistical methods

Statistical analyses were performed using SAS for Windows software (release 8.02; SAS Institute, Cary, NC) for data management and SUDAAN software (release 8.0.2; Research Triangle Institute, Research Triangle, NC) to obtain point estimates and SEs. All analyses incorporated sampling weights and the complex sample design. Because of non-normal distributions, the following variables underwent log transformation: $V\text{O}_{2\max}$, fasting insulin, fasting glucose, and MET hours per week. Comparisons of physical activity levels and metabolic characteristics between boys and girls were done with unpaired Student's *t* tests and ANOVA. The relations between log(fasting insulin), log(fasting glucose), and QUICKI as dependent variables and MET hours per week and $V\text{O}_{2\max}$ as independent variables were assessed by use of unadjusted Pearson correlations and partial correlations adjusted for age, sex, race/ethnicity, and BMI.

Multiple linear regression analysis was used to examine the association of physical activity and CVF with insulin sensitivity, with adjustment for sex, age, race/ethnicity, and BMI. We examined the potential statistical interaction of physical activity and CVF with age, sex, race/ethnicity, and BMI. Only the interaction term of CVF by sex reached a significance level of $P < 0.05$; therefore, we performed the analyses stratified by sex.

RESULTS — The subjects' mean ± SE age was 15.4 ± 0.1 years, 48% of the participants were females, 37% were other than non-Hispanic white, and 30% were overweight or at risk of overweight (Table 1). Participants who did not perform the CVF test ($n = 801$) were on average heavier (BMI 24.6 ± 6.2 vs. 23.0 ± 5.3 kg/m^2, $P = 0.001$) than those who completed the test. Sex and race distributions were similar to those in the participants who completed the test (girls: 49 vs. 48%, $P = 0.77$; non-Hispanic white: 67 vs. 70%, $P = 0.12$; data not shown).

Boys were more likely than girls to report high levels of physical activity and had higher levels of CVF (Table 2). On

Table 1—*Demographic and anthropometric characteristics of the study participants*

	Total	Boys	Girls
n (%)	1,783	924 (51.8)	859 (48.2)
Age (years)	15.4 ± 0.1	15.5 ± 0.1	15.3 ± 0.1
Age distribution (%)			
12–15 years	50.6 ± 1.7	49.6 ± 2.1	51.7 ± 2.6
16–19 years	49.4 ± 1.7	50.4 ± 2.1	48.3 ± 2.6
Race/ethnicity (%)			
Non-Hispanic white	63.2 ± 2.3	63.8 ± 2.6	62.5 ± 3.1
Non-Hispanic black	14.0 ± 1.9	13.8 ± 2.0	14.1 ± 2.0
Mexican American	10.6 ± 1.4	11.2 ± 1.7	9.9 ± 1.4
Other	12.3 ± 2.0	11.2 ± 2.1	13.5 ± 2.3
BMI percentile	60.3 ± 1.0	59.7 ± 1.4	61.0 ± 1.3
Weight status (%)*			
Normal weight	70.3 ± 1.4	67.7 ± 2.4	73.0 ± 2.2
At risk of overweight	13.5 ± 1.2	14.8 ± 2.2	12.1 ± 1.1
Overweight	16.3 ± 1.1	17.5 ± 1.7	14.9 ± 2.1

Data are *n* (%) or means ± SE. No statistically significant differences between boys and girls were observed for the variables presented. *BMI percentile: normal weight <85th, at risk ≥85th and <95th, overweight ≥95th.

average, girls and boys had similar insulin sensitivity (Table 2). Overall, we observed a small but significant correlation between physical activity and CVF ($r = 0.17$, $P < 0.001$). This was true in boys ($r = 0.12$, $P = 0.04$) but not in girls ($r = 0.08$, $P = 0.17$) (data not shown).

In the overall group (boys and girls combined), physical activity and CVF were positively associated with insulin sensitivity and negatively associated with fasting insulin levels (Table 3). These correlations were much stronger in boys than in girls. After adjustment for age, race/ethnicity, and BMI, the correlations were somewhat weaker but remained significant in boys.

In the multiple regression analyses, in the overall population, with control for sex, age, and race/ethnicity, physical activity was significantly associated with insulin sensitivity (Table 4). Insulin sensitivity levels were 0.69 QUICKI unit higher in highly active adolescents than in their sedentary counterparts ($P = 0.004$), a magnitude of association equivalent to 26% of 1 SD in the overall population (1 SD = 2.66). After control for BMI, the association of physical activity with insulin sensitivity was attenuated by about one quarter: higher levels of physical activity increased insulin sensitivity by 0.48 QUICKI unit ($P = 0.03$). When we stratified the analyses for sex, this association remained significant in boys but not in girls. We also analyzed the data using physical activity in METs as a continuous variable and obtained similar results (β coefficient for a 3 MET increase in boys was 0.01 [$P = 0.032$] and in girls was 0.001 [$P = 0.793$]) (data not shown).

In both boys and girls, BMI level was a strong and independent determinant of insulin sensitivity, even after controlling for age, race/ethnicity, and physical activity. Similar findings were observed for the association between CVF and insulin sensitivity (Table 4). Insulin sensitivity was higher in boys in the high category of CVF than in boys in the low CVF group, independent of BMI. In contrast, in girls, CVF was not significantly associated with insulin sensitivity after adjustment for BMI, which suggests that in girls the association of CVF with insulin sensitivity is mediated by body weight.

Among girls and boys, 27 and 29%, respectively, of insulin sensitivity variability was explained by age, race/ethnicity, BMI, and physical activity. In the model using CVF, these estimates were 28% for girls and 20% for boys (Table 4).

CONCLUSIONS— This is the first study to explore the relation between physical activity or CVF and insulin sensitivity in a large representative sample of U.S. youth. We found that in boys, higher physical activity and CVF were each associated with high insulin sensitivity, independent of BMI. In contrast, in girls, physical activity was not associated with insulin sensitivity and the association between insulin sensitivity and CVF disappeared after controlling for BMI. In both sexes, higher BMI was associated with lower insulin sensitivity.

Physical activity enhances the muscle concentration of the glucose transporter GLUT4 (28), which may be one mechanism by which physical activity improves insulin sensitivity. Physical activity may also improve insulin sensitivity indirectly by inducing weight loss and increasing lean mass. Physical activity also increases cardiovascular fitness, and, as such, the finding of an association of fitness with insulin sensitivity provides additional validation for an effect of physical activity on insulin sensitivity. It is noteworthy, however, that in our population the correlation between physical activity and CVF was small (coefficient = 0.17). Given that fitness is believed to be influenced in part by genetic factors (29,30), independent of physical activity, CVF may be a pheno-

Table 2—*Physical activity, CVF levels, and metabolic characteristics of the study participants*

	Total	Boys	Girls
n (%)	1,783	924 (51.8)	859 (48.2)
Mean physical activity level (MET h/week)	18.9 (16.9–21.1)	23.9 (20.5–27.7)	14.7 (12.6–17.1)†
Physical activity level (%)			
Sedentary (no physical activity)	13.5 ± 0.8	11.1 ± 1.2	16.0 ± 1.5†
Moderate (<30 MET h/week)	42.3 ± 2.4	37.4 ± 2.9	47.6 ± 2.7
High (≥30 MET h/week)	44.2 ± 2.3	51.4 ± 3.0	36.5 ± 2.6
$V_{O_{2\max}}$ ($\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$)*	42.6 (41.7–43.5)	46.6 (45.5–47.6)	38.8 (38.0–39.6)†
CVF level (%)*			
Low	29.5 ± 2.4	28.5 ± 2.7	30.6 ± 2.5
Middle	44.6 ± 1.9	44.3 ± 2.5	44.9 ± 2.5
High	26.0 ± 2.0	27.3 ± 2.3	24.5 ± 3.0
QUICKI	33.6 ± 0.1	33.7 ± 0.1	33.4 ± 0.2
Fasting insulin (pmol/l)	65.4 (62.4–68.4)	62.4 (58.8–65.4)	69.0 (64.8–73.2)‡
Fasting glucose (mmol/l)	5.06 (5.06–5.10)	5.16 (5.15–5.20)	4.94 (4.90–5.00)†

Data are *n* (%), geometric means (95% CI), or means ± SE. *Sample size *n* = 1,050. †$P < 0.001$ girls vs. boys; ‡$P < 0.01$ girls vs. boys.

Table 3—*Unadjusted and adjusted (for age, race/ethnicity, and BMI) Pearson correlations*

	Total		Boys		Girls	
	CVF	Physical activity	CVF	Physical activity	CVF	Physical activity
n	1,050	1,783	559	924	491	859
Unadjusted Pearson correlations						
Insulin sensitivity (QUICKI)	0.21*	0.12†	0.28*	0.17*	0.09	0.04
Fasting insulin (pmol/l)	−0.24*	−0.13*	−0.30*	−0.17*	−0.09	−0.05
Fasting glucose (mmol/l)	0.06	0.02	−0.13*	−0.06	−0.01	0.02
Adjusted Pearson correlations						
Insulin sensitivity (QUICKI)	0.14*	0.11*	0.18*	0.13*	0.04	0.05
Fasting insulin (pmol/l)	−0.17*	−0.12*	−0.21*	−0.13*	−0.04	−0.05
Fasting glucose (mmol/l)	0.08	−0.06	−0.09	−0.01	−0.01	−0.02

CVF is expressed as Vo_{2max} (milliliters per kilogram per minute); physical activity is expressed as MET hours per week Vo_{2max}, MET, fasting glucose, and insulin values were log transformed. $^*P < 0.001$; $^†P < 0.01$.

Table 4—*Multiple linear regression coefficients for the association between physical activity and cardiovascular fitness with insulin sensitivity among U.S. adolescents*

	Total		Boys		Girls	
Dependent variable: QUICKI	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Physical activity						
n	1,783		924		859	
Sex (girls)	−0.27 ± 0.20	−0.41 ± 0.15	—	—	—	—
Age (years)	0.02 ± 0.03	0.01 ± 0.03	−0.05 ± 0.05	−0.07 ± 0.04	0.11 ± 0.03	0.11 ± 0.04†
Race/ethnicity						
Non-Hispanic white	Reference	Reference	Reference	Reference	Reference	Reference
Non-Hispanic black	−0.54 ± 0.21‡	−0.20 ± 0.17	−0.17 ± 0.29	−0.15 ± 0.26	−0.99 ± 0.25†	−0.36 ± 0.23
Mexican American	−0.72 ± 0.16§	−0.46 ± 0.13§	−0.68 ± 0.18§	−0.47 ± 0.15§	−0.79 ± 0.24†	−0.48 ± 0.22*
Other	−0.21 ± 0.25	−0.18 ± 0.19	0.32 ± 0.47	0.16 ± 0.36	−0.82 ± 0.25†	−0.63 ± 0.24*
Weight status*						
Normal weight	–	Reference	–	Reference	–	Reference
At risk of overweight		−1.55 ± 0.19†		−1.59 ± 0.37†		−1.57 ± 0.27†
Overweight		−3.44 ± 0.18†		−3.73 ± 0.25†		−3.03 ± 0.25†
Physical activity						
Sedentary	Reference	Reference	Reference	Reference	Reference	Reference
Moderate	0.22 ± 0.27	0.02 ± 0.25	0.55 ± 0.35	0.18 ± 0.25	−0.03 ± 0.31	−0.09 ± 0.33
High	0.69 ± 0.22§	0.48 ± 0.21*	1.18 ± 0.29†	0.84 ± 0.20†	0.21 ± 0.38	0.12 ± 0.37
R^2	0.03	0.27	0.03	0.29	0.05	0.27
Cardiovascular fitness	*n* = 1,050		*n* = 559		*n* = 491	
n						
Sex (girls)	−0.46 ± 0.23	−0.53 ± 0.20*	—	—	—	—
Age (years)	0.01 ± 0.05	−0.01 ± 0.04	−0.01 ± 0.07	−0.04 ± 0.07	0.05 ± 0.05	0.05 ± 0.05
Race/ethnicity						
Non-Hispanic white	Reference	Reference	Reference	Reference	Reference	Reference
Non-Hispanic black	−0.36 ± 0.18	−0.13 ± 0.17	0.13 ± 0.24	0.04 ± 0.24	−0.96 ± 0.27†	−0.36 ± 0.22
Mexican American	−0.77 ± 0.15†	−0.54 ± 0.14§	−0.57 ± 0.22*	−0.49 ± 0.18*	−1.00 ± 0.25†	−0.60 ± 0.20†
Other	−0.22 ± 0.27	−0.23 ± 0.23	0.56 ± 0.49	0.34 ± 0.47	−0.96 ± 0.34§	−0.78 ± 0.29*
Weight status*						
Normal weight		Reference		Reference		Reference
At risk of overweight		−1.32 ± 0.31†		−1.21 ± 0.41§		−1.36 ± 0.42§
Overweight		−3.19 ± 0.33†		−3.17 ± 0.46†		−3.15 ± 0.32†
Cardiovascular fitness						
Low	Reference	Reference	Reference	Reference	Reference	Reference
Moderate	0.72 ± 0.21§	0.29 ± 0.22	0.89 ± 0.37*	0.41 ± 0.34	0.55 ± 0.25*	0.22 ± 0.24
High	1.05 ± 0.23†	0.65 ± 0.24*	1.27 ± 0.31†	0.82 ± 0.31*	0.74 ± 0.36*	0.44 ± 0.33
R^2	0.05	0.23	0.05	0.20	0.07	0.28

Data are means ± SE. Model 1: adjusted for age, sex, and race/ethnicity; model 2: adjusted for age, sex, race/ethnicity, and BMI. *BMI percentile: normal weight <85th, at risk ≥85th and <95th, overweight ≥95th. $^†P < 0.001$; $^‡P < 0.05$; $^§P < 0.01$.

type for underlying muscle characteristics that favor insulin sensitivity.

Previous cross-sectional studies have reported associations of physical activity and/or CVF with measures of insulin sensitivity, independent of body weight or body fat (14–15,31). A study of white and African-American prepubertal children that used frequently sampled intravenous glucose tolerance tests showed that vigorous physical activity, but not physical fitness, was independently associated with insulin sensitivity (15). Those authors, however, did not perform the analyses separately for boys and girls, in part because of power limitations. Schmitz et al. (15) reported a positive association of physical activity with insulin sensitivity measured by the euglycemic-hyperinsulinemic clamp. In Danish children aged 8 to 10 years, physical activity measured by an accelerometer was inversely associated with fasting insulin (31). In contrast with these data, in a study conducted among 5-year-old Pima Indian children, physical activity levels assessed by doubly labeled water were not independent determinants of insulin sensitivity, after adjustment for either body weight or body fat (16). Similarly, among 5-year-old boys and girls, physical activity intensity levels were not correlated with insulin resistance measured by the homeostasis model (32). Ball et al. (13) found that cardiorespiratory fitness and physical activity in a sample of 8- to 13-year-old overweight Hispanic children, after adjustment for sex, Tanner stage, fat mass, and lean tissue mass, were not independently associated with insulin sensitivity measures.

After controlling for age, race/ethnicity, and BMI, we found no association between physical activity levels or CVF and insulin sensitivity in girls. In the Young Finns study (33), adolescents and young males who participated in one or more physical activities per week had significantly lower serum insulin levels than did those who were inactive. However, similarly to our study, no association was found between physical activity and insulin levels in females. There are at least two possible explanations for our findings. First, the method used to assess physical activity may be less reliable in girls than in boys (34). Second, after control for body fat and physical activity, girls seem to have higher insulin resistance than do boys, even at a very young age (32). Therefore, girls may need higher levels of physical activity to overcome their insulin resistance.

The present study has some limitations. First, QUICKI estimates insulin sensitivity from the mathematical modeling of fasting glucose and fasting insulin concentrations, whereas the gold standard for measuring insulin sensitivity is the euglycemic-hyperinsulinemic clamp. However, the latter method is too invasive and costly and, therefore, is not suitable for large epidemiologic studies. Validation studies of derived indexes of insulin sensitivity in children have reported a strong correlation of QUICKI with insulin sensitivity measured by use of the intravenous glucose tolerance test ($r = 0.89$; $P < 0.01$) (27) or euglycemic clamp ($r = 0.91$, $P < 0.01$) (35).

Second, physical activity was assessed by self-report. This method is influenced by recall bias, a tendency to respond in a socially desirable manner, and misinterpretation of the questionnaire items. In addition, MET estimates were derived from the Ainsworth et al. (19) compendium, which is based on data derived primarily from adults. A similar table of standard values for children or adolescents does not yet exist, and some have suggested that adult MET values may underestimate youth MET estimates by as much as 30% (36). If this underestimate occurred, however, one would expect the error in MET values to be similar for all activities (i.e., ~30% underestimate for all activities presented in the questionnaire). If this were the case, we would expect the error to be constant across age, race/ethnic, and BMI groups.

Third, we included only BMI as a measure of obesity, which does not discriminate between muscle and fat mass. Both body fat mass and distribution are strongly related to insulin sensitivity in children (37). However, in children, BMI correlates with more direct measures of fatness (38). It is, therefore, plausible that if we had included measures of body composition and fat distribution, we would have observed a similar relation between activity and insulin sensitivity.

The results of our study highlight the need to control obesity in adolescents as a measure of improving insulin sensitivity and reducing the risk of type 2 diabetes. Increasing physical activity and CVF may have an independent effect of improving insulin sensitivity among boys. For girls, however, the primary role of physical activity may be in weight maintenance or weight reduction.

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