

Associations between physical activity, body fat, and insulin resistance (homeostasis model assessment) in adolescents: the European Youth Heart Study^{1–3}

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ABSTRACT

Background: More and better data are needed to understand the action of physical activity (PA) on insulin resistance and the concomitant relation with body fat in adolescence.

Objective: We examined the relation between total PA and intensity levels with insulin resistance under special consideration of waist circumference and skinfold thickness.

Design: This was a cross-sectional study of 613 adolescents (352 girls, 261 boys) with a mean (\pm SD) age of 15.5 ± 0.5 y from Sweden and Estonia. Total, low, moderate, and vigorous PA was measured by accelerometry. Body fat estimators included waist circumference and the sum of 5 skinfold thicknesses. Fasting insulin and glucose were measured, and insulin resistance was calculated according to the homeostasis model assessment (HOMA). Linear regression analysis and analysis of covariance were used to determine the association between PA and insulin resistance while considering body fat. All estimates were adjusted for sex, country, pubertal status, and indicators of body fat when applicable.

Results: Total, moderate, and vigorous PA were inversely correlated with HOMA. Body fat estimators were positively correlated with HOMA. Significant contrasts in HOMA concentrations were seen when comparing the lower 2 tertiles with the upper tertile of PA indicators. Repeating the analysis with body fat estimators showed significant contrasts in HOMA concentrations when comparing the lower tertiles with the upper tertile.

Conclusion: In view of an increase in obesity in young people, the results accentuate the role of PA in sustaining metabolic balance in adolescence and the potential benefit of an increase of time spent at higher PA levels for youth with relatively elevated amounts of body fat. *Am J Clin Nutr* 2008;87:586–92.

KEY WORDS Insulin resistance, metabolic syndrome, diabetes, physical activity, epidemiology

INTRODUCTION

The past decade has witnessed a significant rise in the prevalence of insulin resistance among adolescents in both developing and industrialized countries (1, 2). Obesity seems to be the single most important cause of peripheral insulin resistance in young people (3). Total obesity and more central obesity in particular (4–6) were reported to be associated with metabolic risk factors, such as elevated blood pressure, hypercholesterolemia, hypertriglycerinemia, and insulin resistance in both older and younger persons (7–9).

The development of type 2 diabetes is a continuous process in time, and longitudinal studies indicate that obesity during childhood and adolescence is closely correlated to markers of insulin resistance later in life (9). Therefore, a greater in-depth knowledge of the factors affecting insulin resistance in younger age groups is of necessity in the development of effective prevention programs.

Although obesity is positively associated with insulin resistance, it was reported that physical activity (PA) is both inversely correlated with markers of insulin resistance (10, 11) and indicators of body fat (12, 13). Many studies investigating the association between PA and insulin resistance were done in overweight and obese subjects (14–17). Inasmuch, it remains of interest to elucidate the association between PA and insulin resistance in leaner persons.

Studies investigating the relation between PA and insulin resistance are often confined to questionnaire-based inquiries (18, 19). These questionnaires depend on the accuracy of recalling activities and give a less-refined account of PA than do more objective methods such as accelerometry, which were shown to provide adequate measures for PA in children and adolescents (20).

It is also of a public health interest to better understand the relative importance of total PA and the intensity levels of PA in respect to insulin resistance and body fat. The measurement of body fat and its distribution need to be, for practical purposes, both cost effective and reliable. As such, waist circumference is

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a preferred marker of central obesity in population studies because it measures visceral and subcutaneous fat in the abdominal region and hence total central fatness (5, 21), whereas skinfold thickness was shown to be a reliable indicator of body fat (21–23). Therefore, the aim of this study was to examine the relation between total PA and intensity levels with insulin resistance under special consideration of waist circumference and skinfold thickness. This becomes of special interest when considering the effect that amendable lifestyle factors may have on a person's health and well-being.

SUBJECTS AND METHODS

Subjects

In total, 613 adolescents (352 girls and 261 boys), mean (\pm SD) age of 15.5 ± 0.5 y, belonging to the Estonian and Swedish part of the European Youth Heart Study, were used in this analysis. Study design, selection criteria, and sample calculations were reported elsewhere (24, 25).

The local ethical committees approved the study protocols (Örebro City Council case no. 680/98, Huddinge University Hospital case no. 474/98, and Tartu University no. 49/30/1997). The subjects and their families received written information about the purpose and the content of the study. Written informed consent was obtained from all the participants.

Physical activity

PA was measured with an activity monitor (MTI model WAM 7164; Manufacturing Technology Inc, Shalimar, FL; formerly known as Computer Science and Applications Inc) during 4 consecutive days (2 weekdays and at least 1 weekend day) and can provide a valid estimation of PA (26). The small device ($4.5 \times 3.5 \times 1.0$ cm, 43 g) was initialized, and the data were downloaded through a computer interface having no external controls that could be manipulated. The device was attached with an elastic waistband on the right hip and was to be worn during the entire day except for activities that could damage it such as showering and swimming. At least 3 d of recording, with a minimum of 10 h registration/d, was set as an inclusion criterion. A measure of average PA intensity (henceforth called total PA) was expressed as the sum of recorded counts per epoch (1 min) divided by total daily registered time. Activity intensity levels were determined by applying the age-specific energy expenditure prediction formula by Freedson et al (27–29) with metabolic equivalent (MET) = $2.757 + (0.0015 \times \text{counts per minute}) - [0.08957 \times \text{age (in y)}] - [0.000038 \times \text{counts per minute} \times \text{age (in y)}]$. MET cutoff values for moderate and vigorous PA were based on limits published by Trost et al (30). Cutoff points for PA intensity levels were set at MET rates corresponding to low PA of <1.5 MET, moderate PA of $3 \leq 6$ MET, moderate and vigorous PA of ≥ 3 MET, and vigorous PA of >6 MET. Each minute over the specific cutoff was summarized in the corresponding intensity level group. Time spent in low PA was defined as the sum of time per day in which counts per minute were <100 and would correspond to <1.5 MET (31). All accelerometers were calibrated by a manufacturer-supplied calibrator. Validation studies examining the accelerometer used in this study and the construction of summary variables for intensity of movement suggest that it is a valid and reliable measure of children's PA (32, 33).

Physical examination

Body mass index (BMI; in kg/m^2) was calculated. Skinfold thicknesses and waist circumference were used as markers of body fat. Both have the advantage of being relatively simple to measure and being also well correlated with metabolic risk factors (5, 6, 21–23). Skinfold thickness was measured with a Harpenden caliper (Baty International, Burgess Hill, United Kingdom) at the biceps, triceps, subscapular, suprailiac, and triceps surae areas on the left side of the body according to the criteria described by Lohman et al (34). All measurements were taken twice and in rotation, and the mean was calculated. If the difference between the 2 measurements was >2 mm, a third measurement was taken and the 2 closest measurements were averaged. The sum of the 5 skinfold thicknesses was used as an indicator of comparative subcutaneous body fat (35, 36).

Waist circumference (in cm), being used as a marker of central body fat, was measured with a metal anthropometric tape midway between the lower rib margin and the iliac crest, at the end of gentle expiration. The measurements were taken twice, and the mean of the 2 values was used for further calculations. Waist-to-height ratio was also calculated. For the purpose of comparing the data with previous publications, the subjects were also categorized as nonoverweight, overweight, and obese, applying the cutoff points suggested by Cole et al (37).

Identification of pubertal development was assessed according to Tanner (38) by a researcher of the same sex as the subject. Breast development in girls and genital development in boys were used for pubertal classification.

Blood samples

Blood samples were taken by venipuncture after an overnight fast with the subject in the supine position; the blood was collected in vacuum tubes (Vacuette; Greiner International, Düsseldorf, Germany). The fasting state was verbally confirmed by the subject before blood sampling. Serum concentrations of insulin and glucose were measured by standardized methods. A detailed description of the blood analysis was reported by Wennlöf et al (39).

In this study homeostasis model assessment (HOMA) was calculated with the HOMA2 computer model (HOMA CALCULATOR, version 2.2; Diabetes Trials Unit, Oxford Centre for Diabetes, Endocrinology and Medicine, Oxford, United Kingdom) (40, 41). HOMA models β cell function and insulin resistance from fasting insulin and glucose concentrations and was compared with a number of well-validated methods (41, 42).

Statistical analysis

To achieve normality in the residuals, HOMA, fasting insulin, and glucose were logarithmically transformed. Sex differences were assessed by analysis of variance and by the chi-square test for nominal data and corrected for mass significance according to Bonferroni Holm (43). Spearman's correlation coefficients were reported for markers of insulin resistance and body fat.

Linear regression analysis was used to measure the relation between markers of insulin resistance and PA intensity levels after controlling for sex, country, pubertal status, and markers of body fat (waist circumference and skinfold thickness). Waist circumference and skinfold thickness were centered by subtracting their respective mean for the regression analysis. Interaction effects between PA intensity levels and markers of body fat and



TABLE 1Descriptive characteristics of the study sample¹

	All (n = 613)	Girls (n = 352)	Boys (n = 261)	P for sex ²
Age (y)	15.5 ± 0.5 (15.5, 15.6) ³	15.5 ± 0.5 (15.4, 15.5)	15.6 ± 0.5 (15.5, 15.6)	NS
Height (cm)	169 ± 8 (169, 170)	165 ± 6 (165, 166)	175 ± 8 (174, 176)	<0.05
Weight (kg)	58.9 ± 10.1 (58.1, 59.7)	56.0 ± 8.7 (55.1, 56.9)	62.9 ± 10.5 (61.6, 64.2)	<0.05
BMI (kg/m ²)	20.5 ± 2.7 (20.3, 20.7)	21.0 ± 3.0 (20.2, 20.8)	20.5 ± 2.7 (20.2, 20.8)	NS
Waist circumference (cm)	69.4 ± 6.7 (68.8, 69.9)	67.1 ± 5.9 (66.4, 67.7)	72.5 ± 6.5 (71.7, 73.3)	<0.05
Sum of 5 skinfold thicknesses (mm)	51.6 ± 21.6 (49.9, 53.3)	60.7 ± 20.5 (58.5, 62.8)	39.4 ± 16.7 (37.4, 41.5)	<0.05
Weight (%)				NS
Nonoverweight	90	91	89	
Overweight	9	9	9	
Obese	1	1	2	
Insulin (mU/L)	10.3 ± 4.6 (9.9, 10.7)	11.0 ± 4.8 (10.5, 11.5)	9.3 ± 4.2 (8.8, 9.8)	<0.05
Glucose (mmol/L)	5.1 ± 0.4 (5.0, 5.1)	5.0 ± 0.4 (4.9, 5.0)	5.2 ± 0.4 (5.1, 5.2)	<0.05
HOMA	1.4 ± 0.6 (1.3, 1.4)	1.5 ± 0.6 (1.4, 1.5)	1.3 ± 0.6 (1.2, 1.3)	<0.05
Total PA (counts · min ⁻¹ · d ⁻¹)	529 ± 212 (512, 546)	476 ± 169 (459, 494)	601 ± 242 (571, 630)	<0.05
Low PA (min/d)	414 ± 86 (407, 421)	426 ± 73 (418, 434)	399 ± 99 (386, 411)	<0.05
Moderate PA (min/d)	64 ± 33 (61, 66)	58 ± 27 (55, 60)	72 ± 38 (68, 77)	<0.05
Moderate and vigorous PA (min/d)	76 ± 40 (73, 79)	67 ± 32 (63, 70)	88 ± 46 (83, 94)	<0.05
Vigorous PA (min/d)	12 ± 13 (11, 13)	9 ± 10 (8, 10)	16 ± 15 (14, 18)	<0.05
Pubertal status (%)				<0.05
I	0	0	0	
II	2	1	2	
III	11	11	12	
IV	36	45	24	
V	50	43	60	

¹ HOMA, homeostasis model assessment; PA, physical activity.² Assessed by ANOVA and by chi-square test for nominal data and corrected for mass significance according to Bonferroni Holm (43).³ $\bar{x} \pm SD$; CI in parentheses (all such values).

between sex and PA intensity levels were tested by inserting product terms for the relevant variables. Regression analysis was repeated on all of the dependent variables (HOMA, insulin, and glucose) for each of the PA intensity levels (low, moderate, moderate and vigorous, vigorous, and total PA).

Analysis of covariance (ANCOVA) was used in testing differences of logarithmically transformed HOMA concentrations stratified by tertiles of PA intensity (total, moderate, and vigorous PA) and tertiles of body fat indicators by skinfold thickness and waist circumference. Nonoverweight and overweight or obesity according to the cutoffs published by Cole et al (37) were compared. Adjustments were made for sex, county, and pubertal status. Bonferroni's adjustments for multiple comparisons were used to examine the contrasts between the tertiles.

Further analysis was performed by adjusting also for age, height, or BMI in both the regression analyses and the ANCOVA. Analysis was performed with the statistical software

packages SPSS 15.0 (SPSS Inc, Chicago, IL) with the level of significance set at 0.05.

RESULTS

The descriptive characteristics of the study sample, including a comparison between the sexes, are shown in **Table 1**. Bivariate correlation analysis showed strong correlations between waist circumference and skinfold thickness with BMI. All markers of insulin resistance were significantly correlated to each other. Waist circumference and BMI were significantly correlated to HOMA, insulin, and glucose. Skinfold thickness was significantly correlated with HOMA and insulin (**Table 2**).

The statistics of the regression models that used HOMA, insulin, and glucose as dependent variable are depicted in **Table 3**. Each model was controlled for sex, country, pubertal status, and

TABLE 2Spearman's correlation coefficient *r* between insulin resistance markers and markers of body fat¹

	Skinfold thickness	WHR	BMI	HOMA	Insulin	Glucose
Waist circumference	0.501 ²	0.389 ²	0.878 ²	0.495 ²	0.495 ²	0.144 ²
Skinfold thickness		0.362 ²	0.684 ²	0.395 ²	0.401 ²	-0.025
WHR			0.390 ²	-0.011	-0.013	0.020
BMI				0.513 ²	0.516 ²	0.082 ²
HOMA					0.998 ²	0.346 ²
Insulin						0.316 ²

¹ HOMA, homeostasis model assessment; WHR, waist-to-height ratio.² Significant at the 0.01 level (2-tailed test).

TABLE 3
Associations between markers of insulin resistance and physical activity (PA) intensity¹

	β	SE	<i>b</i>	<i>P</i>	<i>R</i> ²	sr
HOMA²						
Low PA	0.00020	0.00019	0.040	0.305	0.173	0.038
Moderate PA	-0.00140	0.00050	-0.107	0.005	0.182	-0.103
Moderate and vigorous PA	-0.00153	0.00041	-0.141	<0.001	0.190	-0.135
Vigorous PA	-0.00531	0.00127	-0.159	<0.001	0.195	-0.153
Total PA	-0.00031	0.00008	-0.149	<0.001	0.192	-0.141
Insulin²						
Low PA	0.00020	0.00019	0.040	0.306	0.181	0.038
Moderate PA	-0.00142	0.00050	-0.109	0.004	0.197	-0.105
Moderate and vigorous PA	-0.00154	0.00041	-0.143	<0.001	0.205	-0.137
Vigorous PA	-0.00526	0.00126	-0.158	<0.001	0.209	-0.152
Total PA	-0.00031	0.00008	-0.150	<0.001	0.205	-0.137
Glucose²						
Low PA	0.00003	0.00004	0.029	0.479	0.080	0.028
Moderate PA	-0.00020	0.00009	-0.088	0.029	0.086	-0.085
Moderate and vigorous PA	-0.00023	0.00008	-0.122	0.003	0.093	-0.117
Vigorous PA	-0.00087	0.00024	-0.147	<0.001	0.099	-0.141
Total PA	-0.00004	0.00001	-0.121	0.003	0.092	-0.115

¹ HOMA, homeostasis model assessment. Standard error (SE), nonstandardized regression coefficient (β), standardized regression coefficient (*b*), standardized coefficients of determination (*R*²), and semipartial correlations (sr) examined separately the association of each PA intensity with markers of insulin resistance after control for sex, country, pubertal status, and waist circumference.

² Data were ln transformed.

waist circumference. All the PA intensity values (total, moderate, moderate and vigorous, and vigorous PA) with the exception of low PA were significantly and inversely correlated to the outcome variables HOMA, insulin, and glucose. Repeating the analysis with skinfold thickness instead of waist circumference as a predictor in the regression analysis did not change the outcome. The results also remained unaltered when adding BMI or body height as confounders in the regression equation (data not shown). Stratifying the analysis by sex did not alter the results for the outcome variables HOMA and insulin, whereas PA intensity values remained significantly associated with glucose only in boys. Including an interaction term in each model constituted by the product of waist circumference and the respective PA intensity value showed that there was a significant interaction between vigorous PA and waist circumference with HOMA and also with insulin as outcome variables. In the regression analysis with HOMA as an outcome variable, the standardized β coefficients were vigorous PA ($\beta_1 = -0.143, P < 0.001$), waist circumference ($\beta_2 = 0.417, P < 0.001$), vigorous PA \times waist circumference ($\beta_3 = -0.138, P = 0.001$). With insulin as outcome variable, the standardized β coefficients were vigorous PA ($\beta_1 = -0.142, P < 0.001$), waist circumference ($\beta_2 = 0.420, P < 0.001$), vigorous PA \times waist circumference ($\beta_3 = -0.137, P = 0.006$). Repeating the regression analysis with skinfold thickness and waist-to-height ratios as further indicators of body fat yielded similar results (data not shown).

When differentiating PA and body fat markers into groups of tertiles, ANCOVA showed significant main effects for PA and body fat markers as represented in **Table 4**. No significant interaction effect between tertiles of body fat markers and PA intensity tertiles was reached. Significant contrasts in HOMA concentrations were seen when comparing the lowest tertile with the upper tertiles of PA intensity levels and also when comparing the middle with the upper tertiles of total and vigorous PA (**Figure 1**).

Repeating the analysis with tertiles of body fat estimators showed significant contrasts in HOMA concentrations when comparing the lowest and middle tertiles with the upper tertiles of body fat estimators (**Figure 2**). Analysis with tertiles of BMI showed similar results (data not shown). When differentiating nonoverweight from overweight or obesity by the cutoff points published by Cole et al (37), ANCOVA showed a significant main effect for weight on HOMA with mean square = 7.597, *R*² = 0.162, and *P* < 0.001 (Figure 2).

TABLE 4
Main effects of physical activity (PA) and body fat marker tertiles on homeostasis model assessment with ANCOVA to adjust for sex, country, and pubertal status¹

	Sum of squares	Mean square	<i>P</i>	<i>R</i> ²
Model 1A				
Total PA	1.945	0.973	0.003	
SF	3.420	1.710	<0.001	0.15
Model 1B				
Moderate PA	1.487	0.744	0.011	
SF	3.6155	1.808	<0.001	0.15
Model 1C				
Vigorous PA	1.300	0.650	0.021	
SF	3.056	1.528	<0.001	0.14
Model 2A				
Total PA	2.671	1.336	<0.001	
WC	4.701	2.350	<0.001	0.16
Model 2B				
Moderate PA	1.690	0.845	0.006	
WC	4.769	2.384	<0.001	0.16
Model 2C				
Vigorous PA	1.517	0.758	0.010	
WC	4.312	2.156	<0.001	0.16

¹ SF, skinfold thickness; WC, waist circumference.

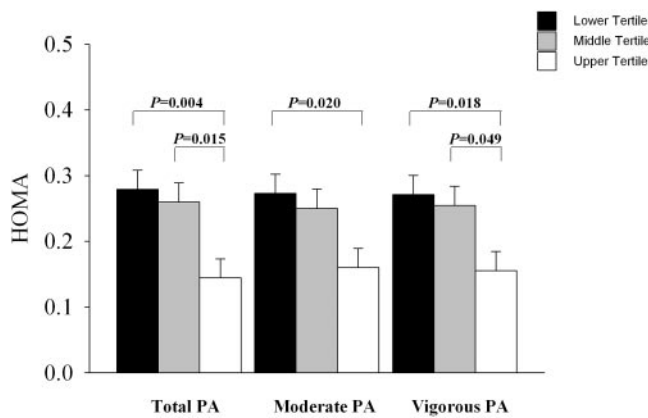


FIGURE 1. ANCOVA was used in testing differences in logarithmically transformed homeostasis model assessment (HOMA) concentrations stratified by tertiles of physical activity (PA) intensity (total, moderate, and vigorous PA). Adjustments were made for sex, country, and pubertal status. Bonferroni's adjustments for multiple comparisons were used to examine the contrasts between the tertiles. Mean values are shown with error bars representing SE. *P* values represent significant contrasts between HOMA concentrations. *n* = 204 or 205 per tertile.

Additional adjustments for BMI when applicable or for body height did not alter the outcomes in any of the analyses (data not shown). All tertile ranges used in the analysis, including their mean and CI, are shown in **Table 5**.

DISCUSSION

Previous studies were ambivalent on the issue of whether the association between PA and insulin resistance is independent of adiposity (14–17). Some of the discrepancies could be caused by differing assessment methods in measuring PA and insulin resistance. The use of questionnaires to assess PA instead of accelerometers might lead to diverse results, which might be the

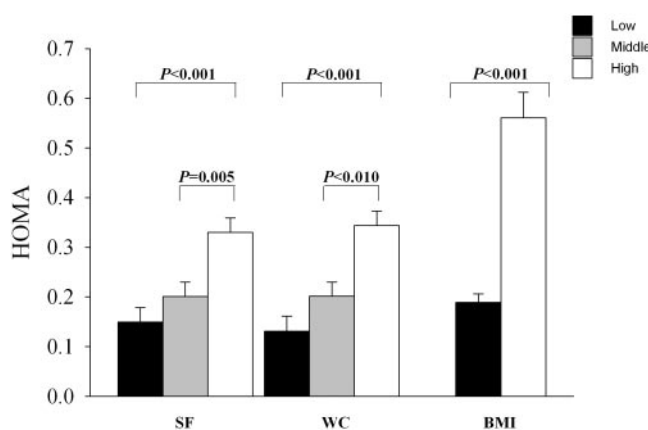


FIGURE 2. ANCOVA was used in testing differences in logarithmically transformed homeostasis model assessment (HOMA) concentrations stratified by tertiles of body fat estimators (*n* = 204 or 205 per tertile): skinfold thickness (SF) and waist circumference (WC). Nonoverweight BMI (in kg/m²; *n* = 551) and overweight or obesity BMI (*n* = 62) according to the cutoff points published by Cole et al (37) were compared with the use of ANCOVA. Adjustments were made for sex, country, and pubertal status in all analyses. Bonferroni's adjustments for multiple comparisons were used to examine the contrasts between the tertiles. Mean values are shown with error bars representing SE. *P* values represent significant contrasts between HOMA concentrations.

TABLE 5

Tertile ranges, means, and CIs of physical activity (PA) intensity, waist circumference, and sum of 5 skinfold thicknesses

	Range	Mean	CI
Moderate PA (min/d)			
Low	0 to <46	33	32, 34
Middle	46 to <71	58	57, 89
High	71 to 215	101	97, 105
Vigorous PA (min/d)			
Low	0 to <4	2	1, 2
Middle	4 to <13	8	8, 8
High	13 to 93	26	25, 28
Total PA (counts · min ⁻¹ · d ⁻¹)			
Low	151 to <416	324	315, 333
Middle	416 to <581	494	487, 500
High	581 to 1496	770	747, 792
Waist circumference (cm)			
Low	55 to <66	63	63, 63
Middle	66 to <71	69	68, 69
High	71 to 109	77	76, 77
5 Skinfold thicknesses (mm)			
Low	20 to <39	31	31, 32
Middle	39 to <56	48	47, 48
High	56 to 124	76	73, 79

cause of failing to see an independent association between PA and markers of insulin in previous studies (14, 15). Differences seen in the relation between PA and insulin resistance could also be a consequence of analyzing different amounts and distribution of body fat.

The results of the current study show that there is a significant inverse relation between PA and insulin resistance and a positive relation between markers of body fat and insulin resistance in adolescents. When comparing the contrasts between PA tertiles on HOMA concentrations, the results indicate that principally higher levels of PA intensity and longer times spent at moderate and vigorous PA may have a positive effect on insulin resistance in adolescents. At the same time the results show the particular relation between higher amounts of body fat and insulin resistance when considering the significant contrasts that were seen between the highest tertile of body fat markers with the lower 2 tertiles, whereas there was no significant difference seen between the lowest and the middle tertiles. This relation is even more marked when comparing nonoverweight and overweight or obese adolescents in which case the HOMA concentrations are almost tripled in the overweight or obese group.

Inasmuch, the results may indicate that the inverse association between PA and insulin resistance may not always be detectable when comparing leaner persons. Concurrently, the results may also suggest that an increase of time spent at vigorous PA might be of singular benefit for adolescents with higher amounts of body fat.

A question that has been raised in the past is whether insulin resistance response to PA is similar in girls and boys. A recent study that used questionnaire-derived PA data and quantitative insulin sensitivity check index found an inverse association between PA and insulin resistance only in adolescent boys after controlling for BMI (16). Because the differing results could have been caused by the use of diverse markers of insulin resistance, we repeated the analysis with the use of the quantitative

insulin sensitivity check index as a replacement for HOMA, yet the outcomes remained unchanged. The differing results could be caused by the dissimilar methods used in assessing PA that could explain why studies that used accelerometry confirm our findings (10).

In our study sample, PA remained independently associated with HOMA in both sexes even after controlling for pubertal maturity, BMI, and waist circumference or skinfold thickness. This finding becomes even more relevant when considering that BMI, waist circumference, and skinfold thickness are strongly correlated and that all 3 measures are considered markers of body fat (21). As indicated in previous studies (10), our results confirm the finding that the association between PA and glucose concentrations is not always equivocal in the sexes, insofar as in our study the inverse relation between PA and glucose was only significant in girls.

It is known that regular PA influences insulin action on skeletal muscle glucose and fat metabolism (44). The mechanisms by which PA may decrease insulin resistance are not yet fully explored (45, 46). It was shown that vigorous PA results in physiologic adaptations of skeletal muscle cells in adults. Some of the physiologic adaptations include an increase in capillary supply to skeletal muscles (47), an increase in the activities of enzymes of the mitochondrial electron transport chain, and a concomitant increase in mitochondrial volume and density (48). In addition, an increased substrate use (49) with a decrease of carbohydrate oxidation and an increased muscle glucose transport might play a role (50). Indirectly, regular PA may act by increasing lean body mass and concomitantly reducing body fat (12).

In view of the increased importance that is given to the role of body fat and in particular central body fat in metabolic disease (51), our results indicate the relative importance of PA during adolescence when symptoms of insulin resistance might not yet be manifest. This becomes more pressing when considering the epidemic increase of obesity in young people (1).

A limitation of the study is the cross-sectional design, which implies that the direction of the causality cannot be determined. Furthermore, the standard for measuring insulin resistance or sensitivity is the euglycemic insulin glucose clamp method (52, 53). Yet its invasive nature, cost, and protocol make it difficult to implement in population studies. HOMA models β cell function and insulin resistance from fasting insulin and glucose concentrations and has as such been adapted as a validated global measure of changes in insulin resistance (41, 54, 55). At the same time the study was strengthened by the relatively large study population and accessibility to PA measurements by accelerometers in contrast to PA questionnaires.

Perspectively, our results are in agreement with previous findings from accelerometry data that show that total PA is inversely associated with markers of insulin resistance (10). Nevertheless, there is a need to differentiate. In subjects with relatively low body fat, one might fail to elucidate a significant association between PA and markers of insulin resistance. At the same time the results indicate that adolescents with higher amounts of body fat might profit most from increased time spent at vigorous PA levels and an overall increase of total PA.

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