Insulin and Weight Status in Adolescents: Independent Effects of Intensity of Physical Activity and Peak Aerobic Power

Daniela A. Rubin, Robert G. McMurray, and Joanne S. Harrell

Differences in insulin concentrations between normal weight or overweight adolescents (n = 437) were determined depending on their habitual physical activity (PA) and aerobic power (pVO$_{2\text{max}}$). tertiles were computed for PA (survey) and pVO$_{2\text{max}}$ (submaximal predicted cycle test). Independent of their weight, adolescents in the upper 2 tertiles for vigorous PA had lower insulin concentrations than those in the bottom tertile (p < .05). Adolescents in the top tertile for pVO$_{2\text{max}}$, expressed per kg fat-free mass also had lower insulin concentrations than those in the medium and bottom tertiles (p = .002). In youth, vigorous physical activity and aerobic power are associated with fasting insulin independent of weight status.

Puberty is associated with increased insulin resistance (IR) and increased insulin concentrations (28), with girls being more insulin resistant than boys (25,10). Body-fat mass contributes to this increased IR (30). Fat mass alone, however, does not seem to fully explain this puberty-induced increase in IR (25). Two other factors that have been associated with IR are physical activity levels and cardiorespiratory fitness (14,31).

The decline in physical activity levels during mid- to late puberty (23) might contribute to the increased IR. Two studies showed a positive association between total habitual physical activity and insulin sensitivity in adolescents (31) and in prepubertal youth (18). Two other studies failed to show such an association in overweight youth (4) or a positive association between moderate to vigorous physical activity and insulin sensitivity in normal weight youth (18). In these previous studies, differences in the methodology used, the intensity of the physical activity, or the participant's weight status possibly explain these inconsistent findings.

Most studies in youth suggested that increased aerobic power is also associated with decreased fasting insulin concentrations (13,14,22), although some studies disagreed (16,17). This association between aerobic power and insulin was particularly true when aerobic power was expressed in units of milliliters oxygen per kilogram body mass per minute: mL⁻¹·kg⁻¹·min⁻¹ (13,14); this association disap-
peared, however, when controlling for body fat (4,13). Thus, expressing aerobic power in units that eliminate fat content, such as mL O₂ per kilogram fat-free mass (FFM), presents an alternative way to study this association if normal weight and overweight youth are to be studied.

In adolescents, the influence of obesity and gender on the associations between habitual physical activity and aerobic power and insulin has not been extensively studied (14). The association between insulin and habitual physical activity might be different not only because of amount of physical activity but also because of the intensity (18). Moreover, the association between aerobic power and insulin might differ depending on the units used to express aerobic power. Thus, the purpose of this study was to examine the relationship between the amount of habitual physical activity and the level of aerobic power and insulin concentrations as an indicator of IR in both boys and girls, independent of their being normal weight or overweight.

**Methods**

**Participants**

Participants were 437 children and adolescents (236 girls and 201 boys) who were selected from approximately 1,400 participants in the study on cardiovascular health in children between the years 2000 and 2003. The adolescents selected had to be in midpuberty, that is, in Tanner developmental Stages 2-4 (27). The ethnic breakdown of the participants was 228 African American (52.2%), 2 Asian (0.5%), 182 White (41.6%), 6 Native American (1.4%), and 19 other (4.2%) youth. Forty-five percent of the youth were classified as overweight with body-mass index (BMI) ≥85th percentile and 55% were classified as normal weight with BMIs <85th percentile. The sample was comparable to previous data published in other cohorts of the CHIC study (21).

**Overall Procedures**

All measurements took place in the school setting. Blood samples were collected on all participants after an overnight fast. Height, body mass, skinfolds, and the cycle-ergometry tests to predict maximal aerobic power were completed within 3 days of blood sampling. The pubertal development questionnaire and the physical activity checklist were completed in small groups under the supervision of a trained research assistant.

**Physical Measures**

Height was measured to the nearest 0.1 cm using a stadiometer (Perspective Enterprises, Kalamazoo, MI), and body mass was obtained in kilograms (nearest 0.1 kg) using a calibrated balance-beam scale (Detecto Scales, Brooklyn, NY). All height and body-mass measurements were conducted with participants dressed in shorts and T-shirt and without shoes. BMI was computed by dividing body mass (kg) by height (m) squared. The adolescents were categorized as at risk for overweight or overweight if they had a BMI ≥85th sex-age-specific percentile based on the year
2000 growth charts from the Centers for Disease Control (5). Adolescents with BMIs <85th percentile were categorized as normal weight.

Triceps and subscapular skinfolds were measured using Lange skinfold calipers (Cambridge Scientific Instruments, Cambridge, MD), following procedures described by the National Health and Nutrition Examination Survey (26). Skinfolds were measured in triplicate and the average used as the result. The sum of the triceps and subscapular skinfolds was used to calculate percentage of body fat using gender-, race-, and pubertal-stage-specific equations from Slaughter et al. (32). FFM (kg) was calculated from percentage of FFM: [(100 - body fat %) × 0.011] × kg.

Peak aerobic power (pVO\textsubscript{2peak}) was predicted from the previously validated PWC\textsubscript{170} cycle-ergometry test, which has a correlation coefficient of $r = .807$ with VO\textsubscript{2peak} obtained through a treadmill exercise test (22). For this study, pVO\textsubscript{2peak} was expressed both in mL of oxygen per kilogram of body mass per minute (mL\textsuperscript{-1}·kg\textsuperscript{-1}·min\textsuperscript{-1}) and in mL of oxygen per kilogram of fat-free mass per min (mL\textsuperscript{-1}·kg\textsubscript{FFM}·min\textsuperscript{-1}). The latter unit was used to explore the relationship between peak aerobic power and insulin without the confounding effect of fat mass.

Estimates of habitual physical activity (PA) were obtained from a PA checklist that had a test–retest correlation coefficient of $r = .70$ (11). Youth were asked to check how often during a week they participated, for at least 15 min, in 32 different leisure physical activities. Possible answers ranged from never to daily (Scores 0–6). The total habitual PA score was computed based on the MET intensity of the activity (2) times the number of reported sessions per week. Moderate to vigorous physical activity (MVPA) was determined by totaling the sessions per week of activities that had intensity levels ≥3.8 metabolic equivalents (METs) (2). The vigorous PA score was determined similar to the MVPA score but using only activities with intensity ≥6 METs.

Tanner stage was determined using the pubertal developmental scale (1–5), a questionnaire that assessed puberty based on growth spurt in height, pubic hair development, skin changes in both boys and girls, facial hair growth and voice change in boys only, and breast development and menarche in girls (27). This tool had internal consistency coefficients ranging from .68 to .83, and its validity has been evaluated using correlations between the PDS and physician ratings from direct observation ($r = .61–.63$) and from the PDS and self-ratings from Tanner stage ($r = .72–.80$) (27).

**Blood Sampling and Biochemical Analyses**

Blood samples were obtained after a verified overnight (12-hr) fast, between 7 and 8 a.m., using the sterile venipuncture technique. Blood samples were collected in tubes containing EDTA and immediately centrifuged at 4 °C to obtain plasma. Once plasma was obtained, it was kept on dry ice and shipped to its storage location where it was kept frozen at −70 °C until analyzed. Glucose concentrations were determined utilizing the hexokinase oxidase method. Plasma insulin concentrations were determined by radioimmunoassay procedures using commercially available kits. (Linco Laboratory, St. Charles, MD). The insulin assay had a coefficient of variation of 8.0%. Fasting insulin concentrations were used as a surrogate for IR, the higher the fasting insulin, the higher the IR as validated by Gunger et al. (12).
Statistical Procedures

Descriptive statistics (M and SD) were computed for the body composition and exercise variables by gender and weight status. Weight status was categorized as overweight (BMI ≥85th percentile) and normal weight (BMI <85th percentile). BMI was used for classification rather than skinfolds because the cut points are more universally accepted. Independent-samples t tests were used to determine differences between girls and boys and between normal weight and overweight adolescents. Because there is no published standard for the PA survey instrument, amounts of reported PA (sessions/week) were categorized into high, moderate, and low, according to gender-specific tertiles. This categorization was conducted for total habitual physical activity (TPA), moderate to vigorous physical activity (MVPA, activities of ≥3.8 METs), and vigorous physical activity (VPA, activities of ≥6 METs).

To determine differences in insulin based on physical activity, separate ANCOVAs were conducted for TPA, MVPA, and VPA. Ethnicity and gender were included as covariates because insulin appears to differ among ethnic groups (13) and between genders (10,25). Each of the ANCOVAs used three levels of PA (top vs. medium vs. bottom tertile) and two levels of weight status (normal weight vs. overweight). If there were differences in insulin based on levels of PA but not weight status, an ANCOVA controlling for ethnicity, gender, and sum of skinfolds (as a surrogate marker for adiposity) was conducted. If gender was a significant covariate in the first analysis, ANCOVAs—controlling for ethnicity and skinfolds—was conducted separately for each gender. Post hoc testing of main and interaction effects were completed using pairwise t tests with Bonferroni adjustments.

Similar ANCOVA analyses were completed to determine if there were differences in fasting insulin between the levels of aerobic power. Gender-specific tertiles were also used for aerobic power because there are no universal norms for aerobic power in children. Analyses were conducted independently for aerobic power expressed in mL·kg⁻¹·min⁻¹ and in mL·kgbodymass⁻¹·min⁻¹. All statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS) for Windows, version 9.0 (Chicago, IL).

Results

Subjects' Characteristics

Participating girls and boys had similar height, body mass, and BMI, but the girls had greater percentages of body fat and less FFM than boys (see Table 1). Girls also had higher insulin concentrations than boys (p < .001). Compared with the normal weight group, the overweight girls and boys were taller, had a greater body mass, a greater BMI, a larger percentage of body fat, and higher insulin concentrations (p < .001). White adolescents had lower insulin concentrations than did African American adolescents (118.8 ± 48.6 vs. 127.1 ± 96.5 pmol/L, p < .001).

Girls and boys had similar reported amounts of TPA and MVPA (p > .317), but the boys reported higher amounts of VPA (p < .001). Girls’ pVO₂peak expressed either by body mass or FFM were lower than for the boys (p < .001 for both). There were no differences in reported TPA (p = .421), MVPA (p = .356), or VPA (p = .396) between normal and overweight adolescents. Overweight adolescents had
lower \( p\text{VO}_{2\text{max}} \), expressed either per kg body mass (\( p < .001 \)) or per kg FFM (\( p < .001 \)), than the normal weight adolescents.

As presented in Table 2, there were no differences in insulin concentrations between the tertiles of TPA (\( p = .808 \)) or MVPA (\( p = .421 \)). Adolescents in the upper two tertiles for VPA (≥5.5 sessions/week or ≥82 min/week) had lower insulin concentrations than adolescents in the bottom tertile (\( p ≤ .008 \)). These results were independent of weight status, gender, or ethnicity (\( p > .144 \)). Gender-specific analyses showed that the girls in the upper two tertiles of VPA had lower insulin

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Characteristics (( M ± SD )) of Body Composition and Exercise Variables in Girls and Boys Based on Their Weight Status (WS = Normal Weight vs. Overweight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Girls</strong> (( n = 129 ))</td>
</tr>
<tr>
<td>Age</td>
<td>11.8 ± 0.7</td>
</tr>
<tr>
<td>Height</td>
<td>153.7 ± 6.7</td>
</tr>
<tr>
<td>Weight</td>
<td>44.7 ± 19.2</td>
</tr>
<tr>
<td>Body mass index</td>
<td>18.8 ± 1.8</td>
</tr>
<tr>
<td>Body fat%</td>
<td>18.7 ± 4.6</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>36.1 ± 4.2</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>4.94 ± 0.37</td>
</tr>
<tr>
<td>Insulin (pmol/L)</td>
<td>93.8 ± 52.1</td>
</tr>
<tr>
<td>TPA (arbitrary score)</td>
<td>192.3 ± 103.4</td>
</tr>
<tr>
<td>MVPA (sessions/week)</td>
<td>23.4 ± 15.8</td>
</tr>
<tr>
<td>VPA (sessions/week)</td>
<td>9.8 ± 7.4</td>
</tr>
<tr>
<td>( p\text{VO}_{2\text{max}} ) (mL( \cdot ) kg( ^{-1} ) \cdot min( ^{-1} ))</td>
<td>37.8 ± 9.0</td>
</tr>
<tr>
<td>( p\text{VO}_{2\text{max}} ) (mL( \cdot ) kg( ^{-1} ) \cdot min( ^{-1} ))</td>
<td>46.4 ± 10.2</td>
</tr>
</tbody>
</table>

Note: TPA = total physical activity; MVPA = moderate to vigorous physical activity; VPA = vigorous physical activity; \( p\text{VO}_{2\text{max}} \) = predicted maximal aerobic power.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Insulin Concentrations by Tertiles of Total (TPA), Moderate to Vigorous (MVPA), and Vigorous (VPA) Physical Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Total PA insulin</strong> (pmol/L) ( M ± SE )</td>
</tr>
<tr>
<td></td>
<td><strong>Unadjusted</strong></td>
</tr>
<tr>
<td>Tertiles of PA</td>
<td></td>
</tr>
<tr>
<td>bottom</td>
<td>113.9 ± 6.9</td>
</tr>
<tr>
<td>medium</td>
<td>109.7 ± 6.3</td>
</tr>
<tr>
<td>top</td>
<td>106.9 ± 6.25</td>
</tr>
<tr>
<td>( P )</td>
<td>0.768</td>
</tr>
</tbody>
</table>

\( ^{*} \) Adjusted for race/ethnicity and gender. \( ^{*} \) Overall \( P \) value for 1-way ANOVA. \( ^{*} \) Overall \( P \) value for 1-way ANCOVA.
concentrations than girls in the bottom tertile ($p \leq .003$), also independent of their weight status (Figure 1). Conversely, in boys there were no differences ($p = .277$) in insulin concentrations across the three tertiles of VPA (Figure 1).

Adolescents in the upper two tertiles for $p$VO$_{2max}$ (mL$^{-1} \cdot$ kg$^{-1} \cdot$ min$^{-1}$) had lower insulin concentrations than those in the bottom tertile ($p < .05$) regardless of gender or ethnicity. Girls and boys in the top tertile for $p$VO$_{2max}$ also had lower insulin concentrations than those in the bottom tertile ($p < .011$). The interaction between tertiles of $p$VO$_{2max}$ and weight status in insulin concentrations was significant ($p = .020$; Figure 2). Separate ANCOVAs conducted in normal weight
Figure 2 — Top graph: fasting insulin concentrations (M ± SD) of all youth presented by tertiles of peak aerobic power (pVO_{2\text{max}}) in mL⁻¹·kg⁻¹·min⁻¹ (p < .001 for main effect of pVO_{2\text{max}}, p < .001 for main effect of weight status, p = .020 for interaction between pVO_{2\text{max}} and weight status). Main effect of pVO_{2\text{max}} in overweight adolescents (p < .001), but not in normal weight (p = .158). Bottom graph: fasting insulin concentrations (M ± SD) of all youth presented by tertiles of peak aerobic power in mL⁻¹·kg_{FFM}⁻¹·min⁻¹ (p = .001 for bottom vs. top tertile main effect of pVO_{2\text{max}} mL⁻¹·kg_{FFM}⁻¹·min⁻¹).

and overweight adolescents controlling for gender and ethnicity showed a main effect of pVO_{2\text{max}} in overweight adolescents (p < .001) but not in normal weight adolescents (p = .158).

When aerobic power was expressed in mL⁻¹·kg_{BMI}⁻¹·min⁻¹ (pVO_{2\text{max}}_{\text{BMI}}), there were also significant differences in insulin concentrations across the three tertiles of aerobic power (p = .002; Figure 2). Regardless of gender, adolescents in the top tertile for pVO_{2\text{max}}_{\text{FFM}} had lower insulin concentrations than those in the bottom tertile (99.3 ± 72.9 pmol/L vs. 127.1 ± 93.1 pmol/L, p = .001).
Discussion

This study found that fasting insulin concentrations in adolescents did not vary with amounts of habitual TPA or MVPA. Conversely, adolescents who reported ≥5.5 sessions/week or ~82 min/week of VPA had 27% lower insulin concentrations than those who reported lower amounts of VPA. The study also found that in overweight adolescents, higher levels of peak aerobic power expressed in mL·kg⁻¹·min⁻¹ (≥298.8 mL·kg⁻¹·min⁻¹) were associated with lower insulin concentrations. All adolescents in the top tertile for aerobic power expressed per unit of FFM had lower insulin concentrations than those in the medium and bottom tertiles.

To date, there is no consensus about the relationship between PA and weight status in youth. The adolescents in this study, regardless of weight status, reported similar amounts of TPA, MVPA, and VPA, therefore suggesting the lack of an association between PA levels and weight status. In support of our findings, Andersen et al. showed that differing levels of VPA had no effect on the BMI of 8- to 16-year-old girls (3). Other studies, however, have shown higher levels of physical activity in normal weight than overweight youth (8,20). The surrogates of adiposity (BMI vs. percent of body fat) or the measurement of PA (heart-rate monitoring or accelerometry vs. reported) might have contributed to the inconsistencies between the findings in the current study and others (8,20).

Neither TPA nor MVPA was significantly associated with fasting insulin concentrations, suggesting that leisure activities of intensities lower than 6 METs might not be as important as higher intensity activities for sustaining low insulin concentrations. Two mechanisms linking PA with low insulin concentrations are decreased body fat and increased muscle insulin sensitivity. The adolescents in the current study who had lower insulin concentrations reported ≥55 sessions of VPA per week. Because this amount of VPA is within the range of minutes previously reported to positively influence body fat in youth, it is possible to speculate that VPA is linked with low insulin concentrations in these youth because of their low body fat (1,6,8). Adolescents in the top and medium tertiles of VPA, however, had lower insulin concentrations than those reporting ≤55 sessions per week, independent of their weight status and adiposity levels (sum of skinfolds as surrogate). Thus, these results indicate that VPA is associated with reduced insulin concentrations independent of the relationship between body fat and insulin. Because neither TPA nor MVPA was significant, we suggest that the intensity and the amount of the PA might be key factors for determining differences in fasting insulin in youth, possibly because of muscle adaptations resulting from habitual activity or exercise training (15).

Analyses conducted separately by gender showed that insulin concentrations differed by tertiles of VPA in the girls but not in the boys. Similar to other studies in youth (3,6), the girls in this study had greater percentages of body fat, participated in less VPA, and had higher insulin concentrations than boys. Thus, it is not surprising that the association between high VPA and lower insulin concentrations was more evident in the girls than in the boys. The threshold for positive adaptations in insulin because of PA might differ based on initial insulin concentrations. Supporting this speculation, data from McMurray et al. (21) showed that decreases in insulin concentrations after an 8-week PA intervention were more evident in youth who were in the third and fourth quartiles for insulin levels (fasting insulin >131.6 pmol/L). In contrast, the mean insulin for boys in this study was 93.8 ±
73.6 versus 124.3 ± 81.3 pmol/L for the girls. To plan effective interventions for decreasing insulin or to provide more accurate PA recommendations, further studies are needed to determine the amount and intensity of PA that decreases insulin depending on initial body fat levels, insulin concentrations, or gender.

The girls in this study with pVO_{2max} ≥38 mL·kg^{-1}·min^{-1} and the boys with pVO_{2max} ≥45.5 had the lowest insulin concentrations. These results agree with previous data by McMurray et al. (21) and Gutin et al. (14). In comparison, when aerobic power was expressed in mL·kg_{FFM}^{-1}·min^{-1}, insulin concentrations were also approximately 25% lower in adolescents who had a mean aerobic power of ≥49.1 mL·kg_{FFM}^{-1}·min^{-1} (which corresponded with the highest tertile). These results using mL·kg_{FFM}^{-1}·min^{-1} do not support the premise that the association between aerobic power and insulin concentrations depends exclusively on fat mass but indicate that it depends on FFM. This appears logical because muscle mass is the major contributor to glucose metabolism (15). The effect of exercise on IR might be multifactorial, and exercise intervention should target improvements in aerobic power, as well as decreasing fat mass and increasing muscle mass, if the objective is to decrease insulin concentrations.

Key strengths of the current study are the large sample size with similar representation of female and male, as well as normal weight and overweight adolescents. Because all adolescents were at midpuberty, possibly extreme differences in pubertal status did not interfere with findings. In contrast, the study has limitations related to the methods used to determine PA and aerobic power: The questionnaire used to assess PA has been validated (11); it estimated, however, the amount of habitual PA, not activity performed within the previous 48 hr before blood sampling, which could have influenced the fasting insulin concentrations (24). In addition, the estimate of habitual PA is likely influenced by perceptions of weight (9,33). Categorizing youth into tertiles of PA also presents a limitation, but this type of categorization has been used by others to examine PA and health outcomes (19,29). Although pVO_{2max} values were within the expected values for adolescents (7,23), peak aerobic power was predicted instead of directly measured. Similar to the PA measure, there are no universal cut points for aerobic power for children, so our results should be taken as a trend rather than as an absolute threshold.

The conclusions from this study are based on cross-sectional data using fasting insulin as an indicator of insulin resistance. Fasting insulin has been highly correlated with insulin resistance (r = .92) in adolescents (12). In this study, the use of indexes such as HOMA or Quicki did not add any extra information because our results using fasting insulin or HOMA were the same, concurring with findings from Gutin et al. (14). Although the use of fasting insulin limits our conclusions, conducting large-sample studies in youth using euglycemic clamps is not feasible.

In this study, adolescents who reported higher amounts of VPA (≥5.5 sessions/week or 82 min/week) and higher aerobic power had lower fasting insulin concentrations, indicating less IR. In addition, insulin concentrations (and therefore IR) were related to both fat mass and lean body mass. Combining our findings of VPA and aerobic power, we suggest that activities of an intensity that increases aerobic fitness might be most important for sustaining normal insulin concentrations. Future studies should determine the exact dose of exercise (intensity and duration) needed to decrease insulin concentrations in adolescents of normal weight, as well as overweight adolescents, of different genders.
Acknowledgments

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References


