Physical Activity Intensity and Cardiometabolic Risk in Youth

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Objective: To determine the association between physical activity (PA) intensities and cardiometabolic risk factors in youth.

Design: Cross-sectional study using data from the 2008 Healthy Hearts Prospective Cohort Study of Physical Activity and Cardiometabolic Health in Youth.

Setting: Rural and urban communities in Alberta, Canada.

Participants: A convenience sample of 605 youth aged 9 to 17 years. Youth were on average aged 12.1 years, 248 were boys (41%), and 157 were overweight or obese (26%).

Main Exposure: Actical accelerometer–measured PA intensity.

Main Outcomes Measures: The primary outcome was body mass index (calculated as weight in kilograms divided by height in meters squared) z score. Secondary outcome measures included waist circumference, systolic blood pressure, and cardiorespiratory fitness (maximal oxygen consumption [VO2max]).

Results: Body mass index z score, waist circumference, and systolic blood pressure decreased and VO2max increased in a dose-response manner across tertiles of vigorous PA (adjusted P < .001). No significant differences in cardiometabolic risk factors were seen across tertiles of moderate or light PA in multivariable analyses. Achieving more than 7 minutes of vigorous PA daily was associated with a reduced adjusted odds ratio of overweight status (0.56; 95% CI, 0.33-0.95) and elevated systolic blood pressure (0.36; 95% CI, 0.16-0.79). The odds of overweight status and elevated blood pressure decreased with increasing time and intensity of PA.

Conclusions: Only vigorous PA was consistently associated with lower levels of waist circumference, body mass index z score, systolic blood pressure, and increased cardiorespiratory fitness in youth. These findings underscore the importance of vigorous PA in guidelines for children and adolescents.


Recent studies using objective measurements suggest that the association between PA and cardiometabolic risk factors in youth may be more complex than previously believed. Population-based studies using accelerometer-derived measures of PA demonstrate that cardiometabolic risk factors are more closely associated with vigorous PA than lower-intensity PA. Furthermore, sedentary time has become widely recognized as an important determinant of cardiometabolic risk factors in youth, independent of PA levels. However, these studies had several limitations that restricted their interpretation into policy. First, past studies and subsequent analyses failed to control for key confounding variables, in particular dietary intake and sedentary time. Second, few investigations distinguished between moderate vs...
vigorously on a portable bed for 5 minutes prior to measurements, 
then sat quietly in an appropriately sized chair with feet flat 
on the ground and arm at the level of the heart. High normal 
SBP was classified as greater than the 90th percentile for age, 
sex, and height.21

Cardiorespiratory fitness was determined using the Leger 
shuttle run,22 a field test that was validated in large interna-
tional samples of children across a range of BMI values.23,24 
The protocol began with each student walking briskly back and forth 
over a 20-m distance. The pace of the run increased by 0.5 km/h 
each minute until the student was unable to run at the re-
quired pace. The final stage achieved was used to calculate 
a rate of maximal oxygen consumption (VO2max) using a vali-
dated regression equation.22

EXPOSURES OF INTEREST

Physical activity was measured objectively using waist-moun-
ted accelerometers during a period of 7 days (Actical, serials B101270-
B101375; Respironics). Raw PA counts were acquired in 15-
second epochs and converted into minutes of PA using a spe-
cially designed software program (KineSoft).21,24 As have others, 
we classified raw counts per minute (cpm) into sedentary time 
(<100 cpm) and light (100-1499 cpm), moderate (1500-6499 
cpm), and vigorous (>6500 cpm) PA intensities.25,26 Sedentary 
time translated to standing or reclining; light activity to walking 
less than 3.2 km/h; moderate activity to walking more than 3.2 
km/h, and jogging is representative of vigorous activity.23,27,28 Se-
quences of consecutive zero counts 60 minutes or longer were 
deemed nonwear and excluded from analyses. Inclusion criteria 
for estimating PA in the final analyses were a minimum of 3 
minutes of wear, with at least 480 registered minutes (8 hours) per day. 
Sensitivity analyses were conducted using a cohort of students 
who achieved 4 days and 8 hours of wear, and the results were 
similar. Therefore, to increase external validity and maximize 
power, we included data from students who provided a mini-
imum of 8 hours of data on at least 3 days in the final analysis. 
Similar criteria have been used in previous cohort studies of youth 

POTENTIAL CONFOUNDING VARIABLES

Dietary intake was assessed using a validated web-based 24-
hour recall instrument (Web-Survey of Physical Activity and 
Nutrition).29 We previously validated and used this tool to study 
dietary patterns among school-aged children in Alberta.29,30 Chil-
dren were prompted to list everything they had to eat and drink 
during the previous 24 hours. The food record was analyzed 
using Food Processor SQL for Windows version 7.9 (ESHA Re-
search) and the Canadian Nutrient File for estimates of daily 
energy, macronutrient and micronutrient content, and frac-
tion of daily recommended intake. A composite measure of diet 
quality was quantified according to the recommendations for 
Eating Well with Canada’s Food Guide.13

STATISTICAL ANALYSES

Data are presented as means and 95% confidence intervals, un-
less otherwise stated. All data were tested for normality using the 
Kolmogorov-Smirnov test. Nonnormally distributed variables were 
either log transformed or nonparametric tests were used to test 
groupwise differences. Cross-sectional comparisons were ini-
tially performed using standard independent t tests and Mann-
Whitney U tests, as appropriate. Generalized linear regressions 
were used to test for differences in the demographic and out-
come measures across tertiles of PA while controlling for age, sex, 
and sedentary time. Multiple comparisons were adjusted for with 
a Bonferroni correction. Multiple logistic regression tests were used
to determine the odds of overweight status and elevated SBP across PA tertiles after adjusting for sedentary time and PA intensities. Multiple linear regression analyses were performed to test for independent continuous associations between cardiometabolic risk factors and intensities of PA. Based on eigenvalues, we did not observe any statistically significant collinearity between PA intensities; therefore, we included them as independent variables in regression analyses. Additional logistic regression tests were used to determine the odds of overweight status and high normal SBP according to graded intensities of PA (1500-6500 cpm). All odds ratios were adjusted for age, sex, sedentary behavior, and diet quality. All data were analyzed using SPSS version 19 (SPSS Inc). A P < .05 was considered statistically significant.

RESULTS

PARTICIPANT DEMOGRAPHICS

Data from the 605 students included in our study sample are provided in the eTable (http://www.archpediatrics.com). Compared with those who provided a valid accelerometer file, those who did not were (1) more likely to be boys (P = .005), (2) less likely to be sedentary (505 vs 554 minutes, P < .001), and (3) achieved greater levels of daily MVPA (62.8 vs 57.1 minutes, P = .04). No differences in BMI-z or waist circumference were noted between those who provided valid data compared with those who did not.

Students spent 69.6% of their accelerometer wear time in sedentary behavior, 22.9% in light PA, 6.8% in moderate PA, and 0.6% in vigorous PA (eTable). Compared with girls, boys spent a greater proportion of their time in light (24% vs 22%, P < .001) and moderate PA (7.4% vs 6.4%, P < .001) and less time in sedentary behavior (67.9% vs 70.9%, P = .007). No interaction effect was observed between sex and PA for any of the outcome measures; therefore, boys and girls were pooled for all analyses. Three separate analyses were run to test for differences in the outcome variables according to tertiles of PA intensity.

PA INTENSITY AND CARDIOMETABOLIC RISK IN YOUTH

Participant characteristics for the primary analyses are restricted to tertiles of vigorous PA in Table 1. No differences in age, sex, minutes of accelerometer wear time, or valid days of data were noted across tertiles of vigorous PA (Table 1). After adjusting for age, sex, sedentary time, and BMI-z where applicable, students in the highest tertile of vigorous PA (mean [SD], 8.7 [1.5] min/d) compared with those in the lowest tertile of vigorous PA (mean [SD], 1.4 [0.4] min/d) displayed lower BMI-z (0.2 vs 0.7, P < .001), lower waist circumference (68 cm vs 73 cm, P < .001), and higher cardiorespiratory fitness (51 mL/kg/min vs 46 mL/kg/min, P < .001) (Figure 1). No statistically significant difference in SBP was seen after adjusting for BMI-z (111 mm Hg vs 112 mm Hg, P = .74). Body mass index z score increased across tertiles of light PA, and fitness increased across tertiles of moderate PA (Figure 1). No other notable associations were made between the outcome variables and tertiles of light or moderate PA.

In a separate series of logistic regressions, we found that the odds of being overweight declined with in-
increased time greater than 2000 cpm, while the odds of high normal SBP declined with increased time greater than 1500 cpm (Figure 2). The slope of the association became steeper with increased intensity for both end points. For example, 50% reduced odds of being overweight were achieved with less than 10 minutes of greater than 6500 cpm of PA, 20 to 25 minutes of greater than 4000 cpm, and more than 60 minutes of greater than 2000 cpm. The same risk reduction for high normal SBP would be achieved with less than 5 minutes of greater than 6500 cpm of PA, less than 10 minutes of greater than 4000 cpm, approximately 15 minutes of greater than 2000 cpm, and more than 25 minutes of greater than 1500 cpm.

Rates of overweight status/obesity and high normal SBP declined in a dose-response manner across tertiles of vigorous PA (Table 1; $P = .002$ and $P = .002$, respectively).

Figure 1. Cardiometabolic risk factors are associated with vigorous but not moderate or light physical activity (PA). Waist circumference (A), body mass index (BMI) $z$ score (B), systolic blood pressure (C), and VO$_{2max}$ (D) according to tertiles of light, moderate, and vigorous PA. Physical activity tertiles: short, medium, and long. Means are adjusted for age, sex, sedentary time, and BMI $z$ score, where applicable. Error bars are standard error of the mean. * $P < .05$. Numbers on the x-axis denote the mean number of minutes spent in that form of PA within the particular tertile.
Compared with students in the lowest tertile of vigorous PA, the odds of overweight status/obesity and high normal SBP were reduced by 57% (odds ratio, 0.43; 95% CI, 0.27-0.68) and 64% (odds ratio, 0.36; 95% CI, 0.19-0.66), respectively, in youth within the upper tertile of vigorous PA. Rates of overweight status/obesity and high normal SBP did not differ across tertiles of light PA.

PA INTENSITY AND CARDIOMETABOLIC RISK IN OVERWEIGHT YOUTH

We repeated all analyses within the subgroup of overweight and obese youth (n = 156; Figure 3). Among overweight youth, waist circumference and BMI-

z

were decreased, while fitness levels increased in a dose-response manner across vigorous PA tertiles, after adjusting for confounders (Figure 3). However, the degree of adiposity and fitness levels seen in the highest tertile of overweight youth were still significantly different from healthy-weight youth (Figure 3).

Results from the multivariate linear regression analyses are presented in Table 2. After adjusting for all confounders, only vigorous PA was independently associated with all cardiometabolic risk factors.

COMMENT

This cross-sectional study of PA and cardiometabolic risk factors revealed 4 novel findings, while confirming previously published research.2,4,5,8 First, measures of cardiometabolic risk declined in a dose-dependent manner with increasing vigorous PA but not with increasing light or moderate PA. Second, the odds of elevated SBP and overweight status declined in a dose-dependent manner only with increasing time spent in vigorous PA. Third, a minimal intensity threshold existed above which the risk of overweight status (>2000 cpm) and high normal SBP (>1500 cpm) began to decline with increasing time spent being physically active. Finally, among overweight youth, measures of adiposity decrease and fitness levels increased with increasing vigorous PA. The key finding from these analyses is that the independent associations observed between vigorous PA and cardiometabolic risk factors were noted across a narrow range of PA duration (approximately 7 minutes). In contrast, no differences in cardiometabolic risk factors were noted despite large differences in light PA (approximately 110 min/d) and moderate PA (approximately 46 min/d). These findings provide novel insight into the value of vigorous PA as a determinant of cardiometabolic risk in adolescents. These data strongly support the importance of including vigorous PA targets within current PA guidelines for youth.

In a landmark paper by the European Youth Heart Study Group, cardiometabolic risk factor clustering (SBP, insulin resistance, serum lipoprotein profile, and adiposity) declined in a dose-response manner, with increasing time spent in MVPA (>2000 cpm).2 Follow-up studies from this same cohort11,33 and others11,12,34 extend these findings, demonstrating that vigorous PA is a robust predictor of waist circumference, BMI-

z

and body fat. Our data extend these observations in several ways. First, after adjusting for all PA intensities, we found that vigorous PA was the single best predictor of measures of adiposity. Second, we found that the odds of being overweight/obese were significantly reduced across tertiles of vigorous but not moderate PA. Third, we found that vigorous PA is also the most robust PA intensity associated with cardiorespiratory fitness. Finally, the dose-response increase in cardiorespiratory fitness and declines in waist circumference and BMI-

z

were observed within the cohort of overweight and obese youth, suggesting the benefits of vigorous PA can be achieved among this high-risk group. While experimental trials are needed to confirm these observations, they suggest that vigorous PA confers greater protection from overweight status/obesity than lower intensity activity in youth.

Interestingly, in contrast to some studies, sedentary time was not associated with cardiometabolic risk fac-

Figure 2. The association between the odds of overweight status and high normal systolic blood pressure across various intensities of physical activity. This graphic representation of the results of a series of logistic regression analyses depicts the slope of the association between the time spent being physically active at various accelerometer cutpoints (ie, physical activity intensities) and the odds of overweight status (A) and high normal systolic blood pressure (B). cpm indicates counts per minute.
tor clustering in youth after adjusting for all intensities of PA. Previous studies have documented modest associations between sedentary behavior and adiposity.11,35 Stronger associations are noted in observational and experimental trials of screen time and the risk for obesity36,37 and high normal SBP. 38 The discrepancy between our study and others may be the inclusion of light PA in the analysis, which may be closely associated with sedentary time considering the cutpoints for stratification. Of note, previous studies that measured sedentary time with accelerometers did not observe associations with SBP38 or cardiometabolic risk.13

Although no consensus has been reached regarding the thresholds of PA intensity in youth,39 previous studies have validated the thresholds of intensity with energy expenditure.25,26 To our knowledge, no study has

Table 2. Continuous Association Between Minutes Spent at PA Intensities and Selected Cardiometabolic Risk Factors

<table>
<thead>
<tr>
<th>Variable</th>
<th>Waist Circumference</th>
<th>BMI Z Score</th>
<th>Systolic Blood Pressure</th>
<th>VO2max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>P Value</td>
<td>β</td>
<td>P Value</td>
</tr>
<tr>
<td>Age, y</td>
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<td>.&lt;.001</td>
<td>−0.03</td>
<td>.66</td>
</tr>
<tr>
<td>Sex</td>
<td>0.005</td>
<td>.93</td>
<td>0.04</td>
<td>.44</td>
</tr>
<tr>
<td>Sedentary time, min/d</td>
<td>0.03</td>
<td>.56</td>
<td>0.05</td>
<td>.35</td>
</tr>
<tr>
<td>Light PA, min/d</td>
<td>0.14</td>
<td>.02</td>
<td>0.19</td>
<td>.003</td>
</tr>
<tr>
<td>Moderate PA, min/d</td>
<td>0.003</td>
<td>.97</td>
<td>0.04</td>
<td>.56</td>
</tr>
<tr>
<td>Vigorous PA, min/d</td>
<td>−0.11</td>
<td>.05</td>
<td>−0.15</td>
<td>.009</td>
</tr>
<tr>
<td>Diet quality, AU</td>
<td>0.03</td>
<td>.65</td>
<td>−0.02</td>
<td>.74</td>
</tr>
</tbody>
</table>

Abbreviations: AU, arbitrary unit; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); PA, physical activity.
compared the association between cutpoints (ie, intensity) of PA and the risk for cardiometabolic outcomes in youth. The results presented in Figure 2 were created in an attempt to resolve this issue and determine an appropriate dose (duration and intensity) of PA associated with reduced odds for specific cardiometabolic end points. Similar to other dose-response studies, we found that the odds of overweight status and high normal SBP declined with both increasing time and intensity of PA. Interestingly, the minimal intensity threshold associated with reduced odds of being overweight (>2000 cpm) was significantly higher than that for high normal SBP (>1500 cpm). Additional studies with larger sample sizes are required to determine a more precise threshold for achieving a reduction in cardiometabolic outcomes in youth.

The study offers several strengths, including the high-resolution (15-second epochs) objective measurement of PA. Shorter epoch durations prevented the misclassification of PA intensity and were in accordance with current best practice recommendations. Further strengths included the addition of dietary information, the direct comparison of various intensities of PA, and the subgroup analyses within a cohort of overweight youth. Despite these strengths, there were some limitations. First, the cross-sectional nature of the study precluded the determination of a direction or a causal nature of these associations. Cross-sectional studies are efficient and frequently used to test hypotheses that focus on the dose-response association between PA and health outcomes. Second, accelerometers do not account for the increased relative intensity experienced by overweight and obese youth at all thresholds of activity. To overcome this limitation, we conducted subgroup analyses restricted to overweight or obese students and found that the associations with vigorous PA extended to this group of youth. We did not assess puberty and were unable to control for differences in maturation between the groups. Lastly, the ethnic diversity was limited within this cohort from urban and rural Canada, limiting the generalizability of these findings. However, limited ethnic diversity minimizes ethnic stratification, thereby increasing the internal validity of this study.

In conclusion, vigorous PA is superior to light and moderate PA for attenuating cardiometabolic risk factors in youth. These data support the concept that vigorous types of PA should be encouraged to reduce cardiometabolic risk factors in youth. The current targets for PA in youth may need to be reexamined, and the inclusion of specific targets for vigorous PA emphasized.

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Online-Only Material: The eTable is available at http://www.archpediatrics.com.

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