ARTICLE

Physical Activity Intensity and Cardiometabolic Risk in Youth

Jacqueline Hay, BSc; Katerina Maximova, PhD; Anita Durksen, MSc; Valerie Carson, MSc; Randi Lynn Rinaldi, MSc; Brian Torrance, MSc; Geoff D. C. Ball, PhD; Sumit R. Majumdar, MD; Ronald C. Plotnikoff, PhD; Paul Veugelers, PhD; Normand G. Boulé, PhD; Paul Wozny, MEd; Linda McCargar, PhD; Shauna Downs, MSc; Richard Lewanczuk, MD, PhD; Jonathan McGavock, PhD

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 [$\dot{V}O_{2max}$]).

Results: Body mass index *z* score, waist circumference, and systolic blood pressure decreased and $\dot{V}O_{2max}$ 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.

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Author Affiliations are listed at the end of this article.

IT IS WIDELY ACCEPTED THAT PHYSIcal activity (PA) confers significant health benefits among children and adolescents.[1] Observational and experimental studies have consistently demonstrated that youth who engage in regular moderate to vigorous (MV) PA display lower visceral fat mass,[2,3] lower systolic blood pressure (SBP),[4,5] enhanced vascular function,[6] lower serum triglycerides,[5] and heightened insulin sensitivity.[7,8] Based in large part on these observations, current PA guidelines from various expert groups call for a minimum of 60 minutes of MVPA daily to achieve optimal growth and reduce cardiometabolic risk factors in youth.[9,10] Unfortunately, the data informing these guidelines were based largely on observational studies that relied on self-reported PA, a measure limited because of subjectivity and recall bias.[9]

Recent studies using objective measurements suggest that the association between PA and cardiometabolic risk factors in youth may be more complex than previously believed.[11,12] 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.[2,11,12] Furthermore, sedentary time has become widely recognized as an important determinant of cardiometabolic risk factors in youth, independent of PA levels.[11,13] 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.[2] Second, few investigations distinguished between moderate vs vigorous PA on study end points.[2,4,5] Finally, most studies failed to explore the association between light PA and health outcomes, despite the observation that youth spend most of their time in this form of activity.[14]

In the context of this cross-sectional school-based study, we hypothesized that a negative association would exist between vigorous PA and cardiometabolic risk factors. We also hypothesized that the strength of the association between PA and cardiometabolic risk would be attenuated for light-intensity and moderate-intensity PA. Finally, we hypothesized that the prevalence of overweight status and elevated SBP would be lower in students who accumulated relatively high levels of vigorous PA compared with students who accumulated low levels of vigorous PA.

METHODS

STUDY DESIGN AND POPULATION

This is a cross-sectional analysis of data collected in the first year of the Healthy Hearts Prospective Cohort Study of Physical Activity and Cardiometabolic Health in Youth.[15] The procedures were approved by the biomedical research ethics board at the University of Alberta. Among the 2189 students who participated in a survey conducted in 2008,[15] we recruited a convenience sample of 841 students in grades 5 through 11 (aged 9-17 years) within 8 middle or high schools in the Black Gold School District to wear an accelerometer. Six hundred five of these students returned the accelerometer with sufficient wear time and were included in the study. The school district serves approximately 8900 students within 27 schools from 5 rural and 2 urban communities.

Every school offered a classroom and gymnasium space each spring semester for a 3-day data collection period. All data were collected within the school environment and within a defined window of time that spanned 2 weeks.

MAIN OUTCOME MEASURES

Primary Outcome Measure

The primary outcome measure of interest was body mass index (BMI, calculated as weight in kilograms divided by height in meters squared) *z* score (BMI-*z*). Body mass index was calculated from height and weight obtained with children in their physical education clothing (T-shirt and shorts) and without shoes. Body weight was measured to the nearest 0.1 kg in duplicate using a digital scale that was calibrated each morning (Seca 882 Digital Floor Scale). Height was measured in duplicate to the nearest 0.1 cm using a medical standard stadiometer (Seca Portable Model 214). Absolute BMI values were converted to a *z* score for age in months and sex using Epi Info software.[16] Participants were categorized as healthy weight, overweight, or obese according to the International Obesity Task Force guidelines.[17]

Secondary Outcome Measures

Waist circumference was measured in duplicate at the level of the iliac crest to the nearest 0.5 cm according to guidelines established by McCarthy et al.[18] Blood pressure was assessed in triplicate according to the American Heart Association guidelines for children and adolescents.[19,20] In brief, students laid quietly 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,[15,22] a field test that was validated in large international samples of children across a range of BMI values.[23] 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 required pace. The final stage achieved was used to calculate a rate of maximal oxygen consumption ($\dot{V}O_{2max}$) using a validated regression equation.[22]

EXPOSURES OF INTEREST

Physical activity was measured objectively using waist-mounted 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 specially designed software program (KineSoft).[14,24] 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.[24,25,27] Sequences 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 days 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 minimum 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 to estimate habitual PA.[2,5,28]

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] Children 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 Research) and the Canadian Nutrient File for estimates of daily energy, macronutrient and micronutrient content, and fraction of daily recommended intake. A composite measure of diet quality was quantified according to the recommendations for Eating Well with Canada's Food Guide.[31]

STATISTICAL ANALYSES

Data are presented as means and 95% confidence intervals, unless otherwise stated. All data were tested for normality using the Kolmogorov-Smirnoff test. Nonnormally distributed variables were either log transformed or nonparametric tests were used to test for groupwise differences. Cross-sectional comparisons were initially 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 outcome 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

Table 1. Association Between Vigorous PA and Selected Cardiometabolic Risk Factors in Youth

Variable	Mean (95% CI) Tertile I, Low	Tertile II, Moderate	Tertile III, High	*P* Value
Demographic				
Age, y	12.2 (12.0-12.4)	12.0 (11.8-12.2)	12.2 (11.9-12.4)	.10
Sex, No.				
Male	74	81	91	.32
Female	120	125	111	
Waist circumference, cm	73.1 (71.5-74.7)	70.2 (68.8-71.5)	68.0 (66.7-69.2)	<.001
BMI *z* score	0.67 (0.53-0.80)	0.44 (0.32-0.57)	0.23 (0.11-0.34)	<.001
Overweight/obese, %	33.0	26.7	17.3	.002
High SBP, %	20.2	16.6	8.0	.002
PA data				
Sedentary time, min/d	562 (549-575)	550 (539-561)	539 (529-550)	.03
Light PA, min/d	170 (164-176)	177 (171-183)	185 (179-190)	.003
Moderate PA, min/d	40.5 (38.1-42.8)	53.5 (50.9-56.2)	64.1 (61.1-67.2)	<.001
Vigorous PA, min/d	1.39 (1.31-1.48)	3.59 (3.49-3.70)	8.74 (8.17-9.32)	<.001
Valid duration of wear time, d	4.63 (4.48-4.79)	4.76 (4.61-4.91)	4.71 (4.56-4.86)	.50
Valid duration of wear time, mean min/d	774 (760-787)	784 (772-796)	797 (784-809)	.04
Valid duration of wear time, mean min/weekday	796 (783-810)	807 (795-810)	817 (804-830)	.08
Valid duration of wear time, mean min/weekend d	722 (703-742)	723 (702-744)	736 (713-760)	.61
Dietary pattern				
Diet quality	1.49 (1.38-1.60)	1.58 (1.48-1.69)	1.73 (1.62-1.84)	.01
Sodium intake, mg	2512 (2181-2843)	2463 (2205-2721)	2462 (2199-2724)	.97
Total daily calorie intake, kcal	1838 (1665-2011)	1912 (1743-2081)	1886 (1730-2041)	.82

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); PA, physical activity; SBP, systolic blood pressure.

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-

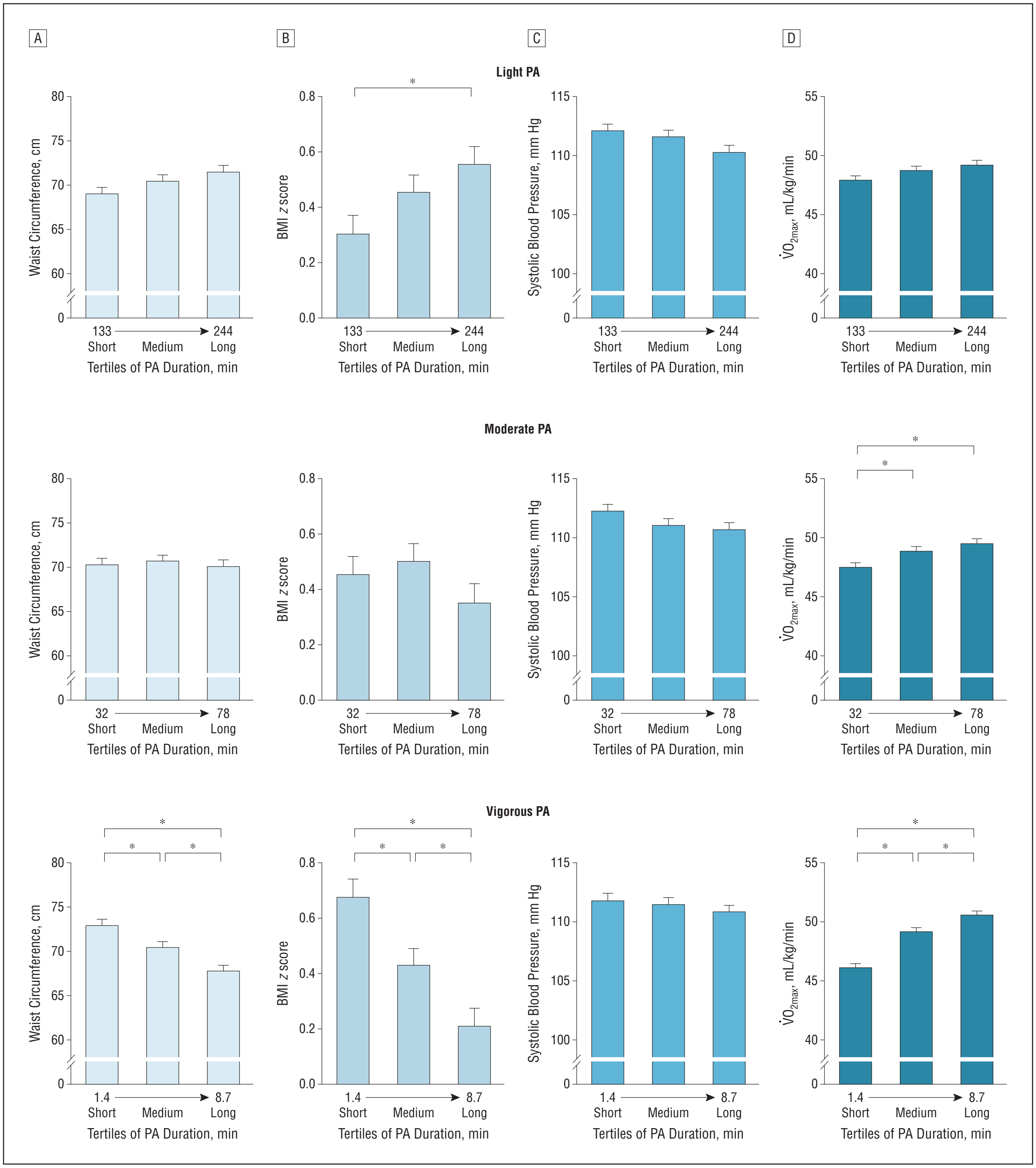

Figure 1. Cardiometabolic risk factors are associated with vigorous but not moderate or light physical activity (PA). Waist circumference (A), body mass index (BMI) *z* score (B), systolic blood pressure (C), and $\dot{V}O_{2max}$ (D) according to tertiles of light, moderate, and vigorous PA. Physical 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.

creased 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).

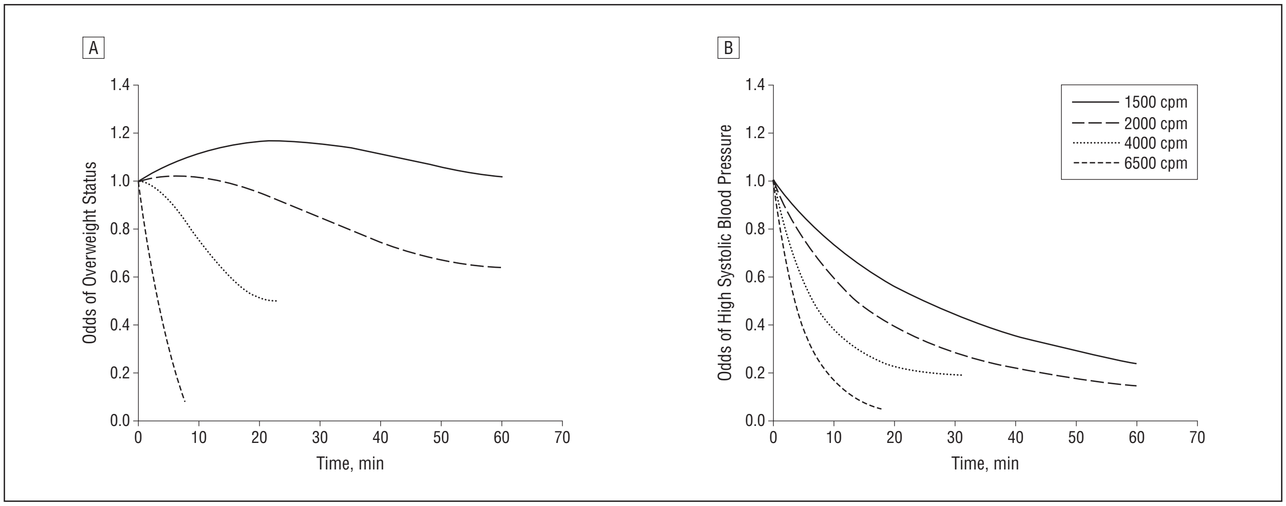

Figure 2. The association between the odds of overweight status and high normal systolic blood pressure across various intensities of physical activity. This graphic representation of the results of a series of logistic regression analyses depicts the slope of the association between the time spent being 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.

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* 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 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 cohort[32,33] and others[11,12,34] extended 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-

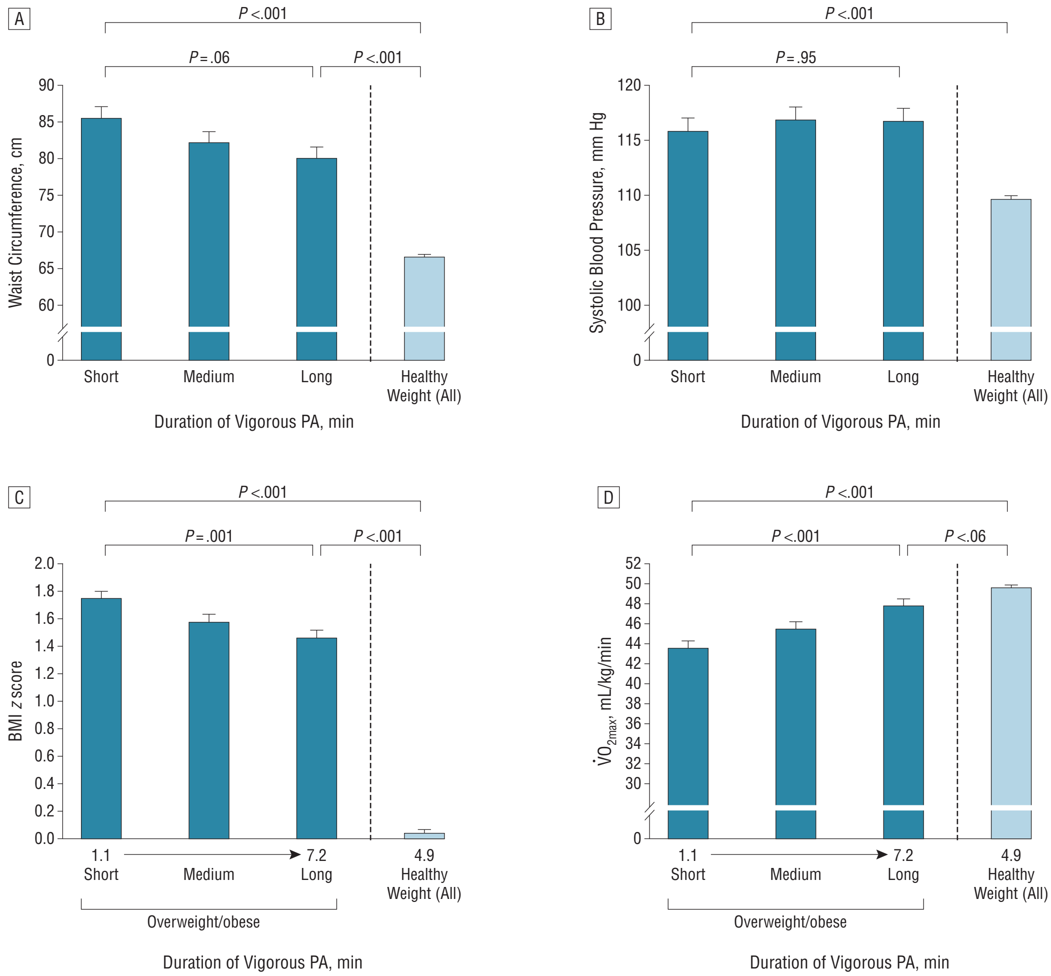

Figure 3. Vigorous physical activity attenuates cardiometabolic risk factor clustering in overweight youth. Values for waist circumference (A), systolic blood pressure (B), body mass index (BMI) *z* score (C), and $\dot{V}O_{2max}$ (D) according to tertiles of vigorous physical activity in overweight students compared with normal-weight students. Physical activity tertiles: short, medium, and long. Means are adjusted for age and sex. Error bars are standard error of the mean. Numbers on the x-axis denote the mean number of minutes spent in that form of physical activity within the particular tertile.

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

	Waist Circumference		BMI *Z* Score		Systolic Blood Pressure		$\dot{V}O_{2max}$	
Variable	**β**	***P* Value**	**β**	***P* Value**	**β**	***P* Value**	**β**	***P* Value**
Age, y	0.33	<.001	−0.03	.66	0.18	.001	−0.04	.52
Sex	0.005	.93	0.04	.44	0.10	.07	0.19	.002
Sedentary time, min/d	0.03	.56	0.05	.35	0.04	.45	0.05	.47
Light PA, min/d	0.14	.02	0.19	.003	−0.02	.73	−0.01	.89
Moderate PA, min/d	0.003	.97	0.04	.56	0.04	.56	0.02	.79
Vigorous PA, min/d	−0.11	.05	−0.15	.009	−0.19	.001	0.17	.007
Diet quality, AU	0.03	.55	−0.02	.74	0.05	.38	0.06	.29

Abbreviations: AU, arbitrary unit; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); PA, physical activity.

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 obesity[36,37] 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 SBP[38] 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 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,[40] 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.[41] 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.[2,11,40] Second, accelerometers do not account for the increased relative intensity experienced by overweight and obese youth at all thresholds of activity.[42] 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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Author Affiliations: Manitoba Institute of Child Health, Department of Pediatrics and Child Health (Mss Hay and Durksen and Dr McGavock) and Department of Kinesiology (Ms Hay), University of Manitoba, Winnipeg; School of Public Health (Drs Maximova and Veugelers) and Departments of Pediatrics, (Dr Ball) Medicine (Drs Majumdar and Lewanczuk), Physical Education and Recreation (Ms Rinaldi and Dr Boulé), and Agricultural, Life, and Environmental Sciences (Dr McCargar), University of Alberta; Ever Active Schools (Mr Torrance), Black Gold School District (Mr Wozny), Edmonton, Alberta; School of Kinesiology and Health Studies, Queen's University, Kingston, Ontario (Ms Carson), Canada; Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Newcastle (Dr Plotnikoff), and Menzies Centre for Health Policy, University of Sydney, Sydney (Ms Downs), Australia.
Correspondence: Jonathan McGavock, PhD, Manitoba Institute of Child Health 510A JBRC-715 McDermot Ave, Winnipeg, Manitoba R3E 3P4, Canada (jmcgavock@mich.ca).
Author Contributions: Dr McGavock had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Majumdar, Plotnikoff, Veugelers, Wozny, Lewanczuk, and McGavock. *Acquisition of data:* Rinaldi, Torrance, Wozny, Downs, and McGavock. *Analysis and interpretation of data:* Hay, Maximova, Durksen, Carson, Ball, Majumdar, Veugelers, Boulé, McCargar, Lewanczuk, and McGavock. *Drafting of the manuscript:* Hay and McGavock. *Critical revision of the manuscript for important intellectual content:* Maximova, Durksen, Carson, Rinaldi, Torrance, Ball, Majumdar, Plotnikoff, Veugelers, Boulé, Wozny, McCargar, Downs, Lewanczuk, and McGavock. *Statistical analysis:* Hay, Maximova, Durksen, Carson, Veugelers, Boulé, and McGavock. *Obtained funding:* Ball, Plotnikoff, Veugelers, Wozny, Lewanczuk, and McGavock. *Administrative, technical, and material support:* Hay, Rinaldi, Torrance, Wozny, Downs, and Lewanczuk. *Study supervision:* Torrance, Boulé, Wozny, McCargar, Lewanczuk, and McGavock.
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Online-Only Material: The eTable is available at http://www.archpediatrics.com.

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