Physical Activity Interacts With Adiposity in Determining Cardiometabolic Risk in Adolescents

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Background: Moderate-to-vigorous physical activity (MVPA) has been negatively associated with cardiometabolic risk. We sought to determine if MVPA interacts with body-mass index (BMI) and waist circumference (WC) in determining cardiometabolic risk in adolescents. Methods: This cross-sectional study included cardiometabolic risk (blood pressure [BP], nonfasting lipids) screening and a 7-day recall physical activity questionnaire in 4,104 adolescents (51% male; mean age: 14.6 ± 0.5 years old). WC- and BMI- percentiles were used to define anthropometric categories (including obese adolescents: ³90th WC, ³85th BMI). Results: Obesity in adolescents was associated with lower levels of high-density lipoprotein (HDL cholesterol (Estimate [EST]: -0.28(0.07) mmol/L, p < .001) and higher non-HDL cholesterol (EST: +0.38(0.14) mmol/L, p = .008). Each additional day with ³20 min of MVPA was associated with lower non-HDL cholesterol (EST: -0.014(0.005) mmol/L/days/week, p = .003), independent of anthropometric category. Each additional day with ³20 min of MVPA was associated with an increased odds ratio (OR) for higher BP category in obese adolescents (OR: 1.055, 95% CI: 1.028–1.084, p < .001) and a lower odds ratio for higher BP category in

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presumably-muscular adolescents (OR: 0.968, 95% CI: 0.934–0.989, \( p = .005 \)).

Conclusions: An increase in MVPA was associated with an increased likelihood for higher BP category in obese adolescents. The dose-response relationship between physical activity and cardiometabolic risk needs to be evaluated in adolescents of varying anthropometry categories.

Childhood overweight and obesity have been strongly associated with several cardiometabolic risk factors. A significant proportion of adolescents (>20%) have more than one cardiometabolic risk factor (17), including elevated central adiposity, dyslipidemia, hypertension, insulin resistance, and/or type 2 diabetes (3). Physical inactivity and screen-related sedentary behaviors acquired during childhood often track into adulthood, accelerating the development of cardiovascular disease (11,15,19). Therefore, adolescence may be an important period for identifying and implementing lifestyle interventions in those at risk for cardiovascular disease. Combined body mass index (BMI) and waist circumference (WC) assessment have been documented in several clinical studies (13,23,35,36). Studies of adolescents have revealed that the combined use of BMI and WC may better specify adiposity and cardiometabolic risk, including in determining risk of high blood pressure, high triglyceride levels, high insulin levels, and metabolic syndrome (13,23).

The purpose of this study was to determine the extent to which physical activity and sedentary behavior may interact in the association between increasing adiposity and cardiometabolic risk in adolescents. We hypothesized that overweight and obese adolescents would have greater cardiometabolic risk than nonobese adolescents (including lower high density lipoprotein (HDL), higher non-HDL, and higher blood pressure category), but that this would be improved for those with increased levels of physical activity and decreased levels of screen-related sedentary behavior.

Methods

Study Participants

Our cross-sectional study recruited grade 9 students (2009–2010; 4,884 students were approached) to universally screen for cardiometabolic risk in both urban and rural populations in southern Ontario, as part of a larger school-based educational and screening initiative (Heart Niagara, Healthy Heart Schools’ Program, Niagara, Ontario, Canada). Universal screening was employed as a process in which a large majority of the student cohort was assessed to identify population trends and those at increased cardiovascular health risk. Program and representative participant characteristics have been described previously (17). This study was approved by the Research Ethics Boards of the Niagara Catholic District School Board and the District School Board of Niagara. All participants provided informed assent along with parental consent. All measurements, including anthropometry, blood pressure, and blood sampling, were performed by the same research study nurse.

Measurements

**Anthropometry.** Standard height, weight, and waist circumference measurements were determined (measured with light clothing). WC measurement was based on
National Health and Nutrition Examination Survey (NHANES) methods (23,24). Age- and sex-specific WC and BMI percentiles (9,10) were used to categorize participants into 5 anthropometric categories: presumably-muscular (<70th WC; ≥85th BMI), normal weight (<70th WC; <85th BMI), borderline normal weight (≥70th-89th WC; <85th BMI), overweight (≥70–89th WC; ≥85th BMI), and obese (≥90th WC; ≥85th BMI).

**Blood Pressure.** Blood pressure was evaluated using a BpTRU blood pressure monitor (BpTRU, Coquitlman, Canada) in a standardized manner (right arm, seated), according to the recommendations of the Fourth Report on Diagnosis, Evaluation, and Treatment of High Blood Pressure (31). A research nurse determined the appropriate sized blood pressure cuff for the participants upper right arm using standard conventions. In particular, a BP cuff must have an inflatable bladder width that is at least 40% of the arm circumference at the midpoint of the arm (31). The systolic and diastolic blood pressure readings were converted to age-, sex-, and height-specific percentiles, and then were used to categorize each subject as prehypertensive (90th-<95th percentile), stage 1 hypertensive (≥95th-<99th percentile), or stage 2 hypertensive (≥99th percentile) (31). Adolescents with initial blood pressure readings of <95th percentile were not reevaluated (i.e., single measure). Adolescents with initial blood pressure levels ≥95th percentile had the measurements repeated (i.e., duplicate measure). A calculated average of six automated blood pressure readings (taken at one-minute intervals) was recorded if the second measurement was also ≥95th percentile.

**Lipid Assessment.** A nonfasting, finger-stick blood sampling (capillary sample) was used to assess total and high-density lipoprotein (HDL in millimoles/Liter, [mmol/L]) cholesterol levels using the Cholestech LDX System with TC-HDL cassettes (Cholestech, Inverness Medical Innovations, Ottawa, Canada). Optics quality control was performed to ensure accurate readings after each set-up. Cassette quality control was performed after each new lot of cassettes was received.

**Physical Activity and Sedentary Behavior Questionnaire.** Participants completed a lifestyle questionnaire, including a 7-day recall of the number of days where a period of (i) mild, (ii) moderate-to-vigorous, and/or (iii) muscle-strengthening physical activity were performed (i.e., ≥320 min/day; Table 1). Each physical activity intensity and mode was assessed independently. A composite score reflecting overall physical activity was also calculated based on the sum of all physical activity-related questions. Higher overall scores were reflective of a greater number of days per week where a period of physical activity was performed. Screen-related sedentary behavior, including (i) television viewing, (ii) video game use, and (iii) computer use, was also probed in the questionnaire (Table 1). A composite score was computed based on the sum of all screen-related sedentary behavior questions. Higher overall scores were reflective of greater screen-related sedentary behavior, reported as hours/day.

**Data Analysis.** Descriptive statistics were performed to determine participant characteristics based on the 5 predefined anthropometry categories. Multivariable linear or ordinal logistic regression models, with a maximum likelihood algorithm to determine parameter estimates, evaluated the association between cardiometabolic risk variables and lifestyle factors (including physical activity and screen-related
Table 1 Questionnaire-Based Assessment of Physical Activity and Sedentary Behavior

<table>
<thead>
<tr>
<th>Activity Variable</th>
<th>Questionnaire Item</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Physical Activity</td>
<td>“On how many of the past 7 days did you take part in physical activity or exercise for at least 30 minutes where your heart did not beat fast or you did not breathe hard…”</td>
<td>• Fast walking, slow bicycling, skating, pushing a lawn mower, or mopping floors</td>
</tr>
<tr>
<td>Moderate-to-Vigorous Physical Activity</td>
<td>“On how many of the past 7 days did you exercise or take part in physical activity that made your heart beat fast and made you breathe hard for at least 20 minutes?”</td>
<td>• Basketball, soccer, running, rugby, jogging, fast dancing, swimming laps, tennis, fast bicycling, or similar aerobic activities</td>
</tr>
<tr>
<td>Muscle Strengthening Physical Activity</td>
<td>“On how many of the past 7 days did you do exercises to strengthen or tone your muscles?”</td>
<td>• Push-ups, sit-ups, or weight lifting</td>
</tr>
<tr>
<td>Sedentary Behavior</td>
<td>“How many hours per day do you usually watch TV or video movies away from school?”</td>
<td>• Internet, instant messaging, homework on computer</td>
</tr>
<tr>
<td></td>
<td>“How many hours per day do you usually spend on the computer away from school?”</td>
<td>• Video game or arcade</td>
</tr>
<tr>
<td></td>
<td>“How many hours per day do you usually spend playing video games…”</td>
<td></td>
</tr>
</tbody>
</table>

sedentary behavior) based on the 5 predefined anthropometry categories. All data were reported as mean ± SD, parameter estimates (EST) with standard error, or odds ratio (OR) with 95% confidence interval (CI), where appropriate. All statistical analyses were performed using SAS version 9.1 (SAS Institute, Cary, North Carolina) and alpha was set at 0.05.

Results

Participant Characteristics

Our cross-sectional study universally screened for cardiovascular risk in 4,104 grade 9 student participants (84% recruited, 51% male, mean age: 14.58 ± 0.52 years old), which included approximately 10% presumably-muscular, 15% overweight, and 10% obese students. Participant characteristics, including BMI, physical activity levels, screen-related sedentary behavior, lipid values, and blood pressure category, are shown by anthropometric category in Table 2. A majority of participants had 1 blood pressure reading, as per our protocol. Following our criteria for blood pressure, 0.3% of participants had 6 blood pressure readings taken. 3.7% of participants were unable to have an accurate blood pressure reading taken.
<table>
<thead>
<tr>
<th>Presumably-muscular</th>
<th>Normal</th>
<th>Borderline Normal</th>
<th>Over-weight</th>
<th>Obese</th>
<th>p-value (between all categories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;70th WC, ≥85th BMI</td>
<td>&lt;70th WC, &lt;85th BMI</td>
<td>≥70–89th WC, &lt;85th BMI</td>
<td>≥70–89th WC, ≥85th BMI</td>
<td>≥90th WC, ≥85th BMI</td>
<td></td>
</tr>
<tr>
<td>n, (% male)</td>
<td>392 (47% a,c,d)</td>
<td>2544 (49%)</td>
<td>92 (50%)</td>
<td>577 (58% a)</td>
<td>380 (61% a)</td>
</tr>
<tr>
<td>BMI (kilograms/meters²)</td>
<td>22.8 ± 3.4 a,b,c,d</td>
<td>19.8 ± 1.7</td>
<td>21.7 ± 1.0 a</td>
<td>26.1 ± 2.4 a,b,c</td>
<td>31.4 ± 4.2 a,b</td>
</tr>
<tr>
<td>WC (centimetres)</td>
<td>74 ± 6 a,b,c,d</td>
<td>70 ± 5</td>
<td>83 ± 2 a</td>
<td>86 ± 4 a,b,c</td>
<td>101 ± 8 a,b</td>
</tr>
<tr>
<td>Mild Physical Activity (days/week)</td>
<td>3.8 ± 2.4 c</td>
<td>3.5 ± 2.3</td>
<td>3.6 ± 2.3</td>
<td>3.7 ± 2.3 c</td>
<td>3.2 ± 2.2 a</td>
</tr>
<tr>
<td>Moderate-to-Vigorous Physical Activity (days/week)</td>
<td>4.7 ± 2.0 c</td>
<td>4.4 ± 2.1</td>
<td>4.1 ± 2.2</td>
<td>4.5 ± 1.9 c</td>
<td>4.1 ± 2.0 a</td>
</tr>
<tr>
<td>Strength Physical Activity (days/week)</td>
<td>3.1 ± 2.1 c</td>
<td>2.9 ± 2.1</td>
<td>2.9 ± 2.3</td>
<td>3.0 ± 2.1 c</td>
<td>2.6 ± 2.1 a</td>
</tr>
<tr>
<td>Overall Physical Activity (days/week)</td>
<td>11.6 ± 4.8 a,c</td>
<td>10.8 ± 4.8</td>
<td>10.7 ± 5.1</td>
<td>11.2 ± 4.7 c</td>
<td>9.7 ± 4.4 a</td>
</tr>
<tr>
<td>Overall Screen Time (hours/day)</td>
<td>5.6 ± 3.0 c</td>
<td>5.5 ± 3.0</td>
<td>5.4 ± 2.3</td>
<td>5.8 ± 2.8 a,c</td>
<td>6.7 ± 3.2 a,b</td>
</tr>
<tr>
<td>Systolic Blood Pressure (Millimeters of Mercury)</td>
<td>106 ± 11 a,c,d</td>
<td>103 ± 10</td>
<td>107 ± 10 a</td>
<td>109 ± 10 b,c</td>
<td>114 ± 10 a,b</td>
</tr>
<tr>
<td>Diastolic Blood Pressure (Millimeters of Mercury)</td>
<td>66 ± 8 c,d</td>
<td>65 ± 8</td>
<td>66 ± 7</td>
<td>67 ± 8 a,c</td>
<td>70 ± 9 a,b</td>
</tr>
<tr>
<td>Total Cholesterol (Millimoles/Liter)</td>
<td>3.87 ± 0.73 c,d</td>
<td>3.80 ± 0.72</td>
<td>3.83 ± 0.63</td>
<td>3.98 ± 0.81 a</td>
<td>4.07 ± 0.79 a,b</td>
</tr>
<tr>
<td>High Density Lipoprotein Cholesterol (HDL; Millimoles/Liter)</td>
<td>1.21 ± 0.32 a,c,d</td>
<td>1.28 ± 0.32</td>
<td>1.25 ± 0.35</td>
<td>1.12 ± 0.32 a,b,c</td>
<td>0.99 ± 0.26 a,b</td>
</tr>
<tr>
<td>Non-HDL Cholesterol (Millimoles/Liter)</td>
<td>2.66 ± 0.69 a,c,d</td>
<td>2.52 ± 0.66</td>
<td>2.58 ± 0.65</td>
<td>2.85 ± 0.83 a,b,c</td>
<td>3.08 ± 0.78 a,b</td>
</tr>
</tbody>
</table>

All data are reported as mean ± SD. BMI = body mass index, WC = waist circumference, overall physical activity = sum of mild and moderate-to-vigorous physical activity and strength physical activity, overall screen time = sum of television viewing, video games, and computer use. Pairwise comparisons with significance indicated as follows: a = p < 0.05 vs. Normal; b = p < 0.05 vs. Borderline normal; c = p < 0.05 vs. Obese; d = p < 0.05 vs. Overweight.
HDL and non-HDL Cholesterol

Overweight and obesity in adolescents were associated with higher non-HDL cholesterol (EST: +0.32(0.13) mmol/L, \( p = .013 \); +0.38(0.14) mmol/L, \( p = .008 \)) and lower HDL cholesterol (EST: -0.17(0.06) mmol/L, \( p = .005 \); -0.28(0.07) mmol/L, \( p < .001 \)), respectively. Anthropometric associations with either HDL or non-HDL cholesterol were not observed in normal, borderline normal, or presumably-muscular adolescents.

Physical Activity

Each additional day with a period of overall, moderate-to-vigorous (Figure 1), and strengthening physical activity (\( \geq 20 \) min/day), was associated with lower non-HDL cholesterol (EST: -0.012(0.003) mmol/L/days/week, \( p < .001 \); EST: -0.014(0.005) mmol/L/days/week, \( p = .003 \); EST: -0.021(0.008) mmol/L/days/week, \( p = .006 \)), respectively. These findings were independent of anthropometric category. The relationship between the number of days with a period of moderate-to-vigorous physical activity and BP category is shown in Figure 2. Each additional day with a period of moderate-to-vigorous physical activity (\( \geq 20 \) min/day) was also associated with an increased odds ratio for higher BP category in obese adolescents (OR: 1.055, 95% CI: 1.028–1.084, \( p < .001 \)) and a lower odds ratio for higher BP category in presumably-muscular adolescents (OR: 0.968, 95% CI: 0.934–0.989, \( p = .005 \)). Each additional day with a period of moderate-to-vigorous physical activity was not associated with changes in BP category in normal, borderline normal, or overweight adolescents.

![Figure 1 — Association of Moderate-to-Vigorous Physical Activity (~20 minutes per day) and Non-HDL Cholesterol in Adolescents. Data represented as mean (square) ± SD (error bars) and trend line of the relationship between physical activity and non-HDL cholesterol (dotted line).](image-url)
In obese adolescents only, each additional hour of screen-related sedentary behavior was associated with lower HDL cholesterol (EST: -0.014(0.006) mmol/L/hour, \( p = .026 \)), but not non-HDL cholesterol (EST: 0.012(0.014) mmol/L/hour, \( p = .384 \)), or odds of a higher BP category (OR: 0.995, 95% CI: 0.977–1.013, \( p = .920 \)).

Discussion

Overweight and obese adolescents often exhibit greater cardiometabolic risk, which tracks into adulthood, thereby accelerating the risk of premature cardiovascular disease (11,15,19). Our cross-sectional study enabled the universal screening of cardiometabolic risk in a large sample of healthy adolescents. Notably, our study cohort had similar anthropometric category percentages, including the percentage
of overweight and obese adolescents, to the Canadian Health Measures Survey cohort (8,34).

**Association of Anthropometry and Cardiometabolic Risk in Adolescents**

Overweight and obese categories were associated with higher non-HDL cholesterol, and lower HDL cholesterol, using BMI- and WC-percentiles to categorize anthropometry. BMI assessments (4,27,28) have previously limited our understanding of the relationship between adiposity and cardiometabolic risk in adolescents. BMI imperfectly indicates central adiposity and may not accurately reflect body composition in physically active adolescents who have increased muscle mass (2). In comparison, WC is a strong predictor of cardiometabolic risk in adolescents (25,30). Combined BMI and WC assessments may hold greater clinical relevance in the determination of adiposity and cardiometabolic risk (13,23). In particular, Janssen et al. (13) reported that adolescents in the high-BMI, high-WC category were twice as likely to have high triglyceride levels, high insulin levels, and the metabolic syndrome, compared with those in the high-BMI, low-WC group.

**Physical Activity Interacts With Anthropometry in the Association With Non-HDL Cholesterol in Adolescents**

Physical activity has shown to be effective in improving cholesterol levels in adolescents (22). We have determined that higher overall physical activity is associated with lower non-HDL cholesterol, independent of anthropometry category. Our finding reinforces previous reports that physical activity during adolescence may have a significant influence on blood lipid values, rather than adiposity alone (22). Universal screening for physical activity may be important in determining cardiometabolic risk as older adolescents progress into adulthood.

**Physical Activity Interacts With Anthropometry in the Association With Blood Pressure Category**

Our study has determined that higher overall physical activity level is associated with a higher blood pressure category among obese adolescents and a lower blood pressure category among presumably-muscular adolescents. Our findings suggest that blood pressure reactivity in response to physical activity may differ depending on adiposity. While the underlying physiological mechanisms were not explored in the current study, it is possible that the physical activity stimuli in the presumably-muscular adolescent group exceeded the physical activity criteria (i.e., physical activity duration of 20–30 min) probed in the current study. Obese adolescents may have also been subject to a reporting bias, whereby physical activity levels were over-estimated. The shorter physical activity levels probed may also have been an insufficient stimulus to attenuate the increased arterial stiffness, endothelial dysfunction, insulin resistance, and sympathetic nervous system activation that is commonly associated with adiposity-related blood pressure increases (33). Obese adolescents are known to experience a greater systolic blood pressure response during acute exercise (6,7). A review by Torrance et al. (33) indicates that 40 min
of moderate-to-vigorous aerobic physical activity (3–5 days per week) is needed to improve blood pressure in obese adolescents (33). Sufficient physical activity stimuli appear to improve cardiometabolic risk in adolescence, but further studies are required to examine our interesting finding of higher blood pressure in physically active obese adolescents.

**Determining the Physical Activity and Cardiometabolic Risk Dose-Response Relationship**

Physical activity plays an important role in the prevention of obesity and cardiometabolic risk (26). The current recommendation for children and adolescents is 60–90 min of moderate-to-vigorous physical activity on a daily basis (32). To better characterize physical activity participation, our study examined a lower duration physical activity threshold (i.e., 20–30 min) in conjunction with mild-to-vigorous physical activity intensities. Higher physical activity intensity has also been emphasized more recently to improve cardiometabolic risk and reduce total and central adiposity (20). Further studies are required to determine the independent effect of physical activity duration and intensity on cardiometabolic risk (14,26).

**Sedentary Behavior Is Associated With HDL Cholesterol Levels in Adolescents**

The American Academy of Pediatrics has recommended that children minimize screen-related sedentary behaviors to less than 120 min daily (1). Participants’ reported levels of sedentary behavior significantly exceeded this recommendation. Within the obese cohort, higher reported levels of sedentary behavior were associated with lower HDL cholesterol level. However, there was no interaction between screen-related sedentary behavior, anthropometry, and either blood pressure category or non-HDL cholesterol values. As unhealthy sedentary behaviors are established early in life (12,36), and increase twofold (about 25–46%) from infancy to adolescence (5,16,21,29), there are important population-based cardiometabolic risk implications.

**Limitations**

The following limitations should be considered when interpreting these results. While the large adolescent sample size confers an important advantage in the universal surveillance of cardiometabolic risk factors, the cross-sectional study design limits causality to be inferred. The direct assessment of adiposity and fasting lipid profile measurements, as well as more than one BP measurement in healthy adolescents (i.e., those students with an initial normal BP measurement; 96%), were precluded due to time constraints associated with the large population examined in a school setting. Nonetheless, nonfasting lipid values have also been linked to increased cardiometabolic risk profile in other large population-based cohorts (18). Blood pressure measures were taken in a classroom setting to accommodate the large sample size; therefore, reported blood pressure may not be reflective of a true resting state. Nonetheless, a standardized method (31) for blood pressure assessment allowed for between-subject comparison. The large study population also favored
use of self-reported questionnaires and precluded the direct assessment of physical activity and sedentary behavior; thus, potentially leading to a reporting bias. The examples of physical activity and sedentary behavior in the lifestyle questionnaire were not all encompassing, given current technological trends. Cell phone and/or smart phone use was not specifically mentioned in the questionnaire for screen time behaviors and should be explored in future studies. Ultimately, our findings have demonstrated significant trends in distinct anthropometric categories between physical activity and cardiometabolic risk. Accelerometer use may provide greater objectivity in determining physical activity levels in future studies.

Conclusions

The relationship between adiposity and blood pressure category shows interaction with physical activity level among both obese and presumably-muscular adolescents. Future longitudinal studies are required to clearly determine these relationships with an emphasis on establishing (i) evidence-based physical activity dose-response recommendations, the inclusion of (ii) long-term, follow-up studies, and (iii) treatment of cardiometabolic risk profile in obese adolescents.

References


