
Available from: 10.1002/oby.20698

Accessed from: http://hdl.handle.net/1959.13/1045740
Volumes and bouts of sedentary behavior and physical activity: Associations with cardio-metabolic health in obese children

Dylan P. Cliff, PhD\textsuperscript{a}, Rachel A. Jones, PhD\textsuperscript{a}, Tracy L. Burrows, PhD\textsuperscript{b}, Philip J. Morgan, PhD\textsuperscript{c}, Clare E. Collins PhD FDAA\textsuperscript{b}, Louise A. Baur, PhD FRACP\textsuperscript{d}, Anthony D. Okely, EdD\textsuperscript{a}.

\textsuperscript{a}Interdisciplinary Educational Research Institute, Faculty of Social Sciences, School of Education, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia, 2522

\textsuperscript{b}Priority Research Centre in Physical Activity and Nutrition, School of Health Sciences, Faculty of Health and Medicine, University of Newcastle, University Drv, Callaghan, NSW, Australia, 2308

\textsuperscript{c}Priority Research Centre in Physical Activity and Nutrition, Faculty of Education & Arts, University of Newcastle, University Drv, Callaghan, NSW, Australia, 2308

\textsuperscript{d}University of Sydney Discipline of Paediatrics and Child Health, The Children’s Hospital at Westmead, Locked Bag 4001, Westmead, NSW, Australia, 2145

Keywords: accelerometry; cardiovascular risk; exercise; life styles; sitting

Running head: Child sedentariness and metabolic health

Financial Disclosures and Conflicts of Interests. No authors have any financial disclosures or conflicts of interest to report. Recruitment and data collection were completed as part of a National Health and Medical Research Council (NHMRC) project grant (ID 354101). Dylan Cliff is funded by a National Heart Foundation of Australia Postdoctoral Research Fellowship (PH 11S 6025). Anthony Okely is funded by a National Heart...
Foundation of Australia Career Development Award. Clare Collins is funded by a NHMRC Career Development Award. This was the funders’ sole contribution to the study.

**Corresponding Author:**

Dylan P. Cliff, PhD

Interdisciplinary Educational Research Institute

School of Education

University of Wollongong

Northfields Ave, Wollongong NSW 2522 Australia

Ph: +61 2 4221 5929   Fax: +61 2 4221 3892

E-mail: dylanc@uow.edu.au

**Manuscript word count:** 3497

**Abstract word count:** 195

**Tables:** 4

**Figures:** 1
What is already known about this subject?

- Obesity in childhood is associated with an adverse cardio-metabolic risk factor profile.
- The total volume of moderate-to-vigorous physical activity is associated with individual and clustered cardio-metabolic health in children, irrespective of the pattern of accumulation.
- Independent of moderate-to-vigorous physical activity and adiposity, the total volume and pattern of sedentary behavior are associated with cardio-metabolic risk factors in adults, but evidence among children is unclear.

What does this study add?

- Among overweight and obese children, the total volume of moderate-to-vigorous physical activity was more strongly associated with clustered cardio-metabolic risk than the total volume of sedentary behavior.
- Independent of the total volume of moderate-to-vigorous physical activity and waist circumference, the total volume of sedentary behavior was associated with HDL cholesterol levels in overweight and obese children.
- Overweight and obese children in the highest quartile of daily 30min bouts of sedentary behavior had lower HDL cholesterol than those in the lowest quartile, independent of waist circumference and the total volumes of moderate-to-vigorous physical activity and sedentary behavior.
Abstract

Objective: To examine associations of volumes and bouts of sedentary behavior (SED) and moderate-to-vigorous physical activity (MVPA) with individual and clustered cardio-metabolic outcomes in overweight/obese children. Design and Methods: Cross-sectional data from 120 overweight/obese children (8.3±1.1y, 62% girls, 74% obese) with SED and MVPA assessed using accelerometry. Children were categorised into quartiles of mean bouts.day⁻¹ of SED (10, 20, and 30min) and MVPA (5, 10, and 15min). Associations with triglycerides, HDL cholesterol, glucose, insulin, systolic/diastolic blood pressure, and clustered cardio-metabolic risk (cMet) were examined using linear regression, adjusted for confounders. Results: Independent of MVPA, SED volume was inversely associated with HDL cholesterol ($\beta$ [95% CI] =-0.29 [-0.52, -0.05]). MVPA volume was inversely associated with diastolic blood pressure, independent of SED ($\beta$=-0.22 [-0.44, -0.001]), and cMet ($\beta$=-0.19 [-0.36, -0.01]) although not after adjustment for SED ($\beta$=-0.14 [-0.33, 0.06]). Independent of MVPA and SED volumes, participants in the highest quartile of 30min bouts.day⁻¹ of SED had 12% lower HDL cholesterol than those in the lowest quartile ($d$=0.53, $p$=0.046, $p_{\text{trend}}$=0.11). Conclusions: In addition to increasing MVPA, targeting reduced SED and limiting bouts of SED to <30min may contribute to improved HDL cholesterol levels and cardio-metabolic health in overweight/obese children.
Introduction

Childhood obesity is associated with numerous health consequences, of which cardio-metabolic risk factors for cardiovascular disease and type 2 diabetes mellitus, are of major concern for future population health (1). Identification of the modifiable behaviors associated with cardio-metabolic health in childhood is critical to chronic disease prevention.

One established risk factor of poor metabolic health in children is insufficient moderate-to-vigorous physical activity (MVPA) (2-4). Fewer studies have investigated the potentially harmful effects of high levels of sedentariness. Sedentary behaviors are defined as any waking behavior characterized by an energy expenditure $\leq 1.5$ metabolic equivalents (METs; 1 MET = rest) while in a sitting or reclining posture (5). Distinct from insufficient MVPA, excessive sedentariness has emerged as a unique determinant of cardio-metabolic health in adults (6). It is possible that engaging in $\geq 60 \text{ min.d}^{-1}$ of MVPA, the dose specified in physical activity recommendations for children (7), might be insufficient to protect children from the potential adverse health consequences of excessive sedentary time throughout the remainder of their day.

It is, however, unclear whether the overall volume of sedentary time is associated with cardio-metabolic health among young people, after accounting for MVPA. While some evidence supports such an association (8-10), several studies have reported that objectively measured sedentary time was not cross-sectionally associated with cardio-metabolic risk factors in children and adolescents independent of MVPA (3, 4, 11). The associations between sedentary behavior, MVPA and health outcomes may be influenced by the patterns in which the total volume of these behaviors is accumulated, although very little evidence is available in children. In adults, breaking up prolonged bouts of sedentary behavior is associated with a favorable cardio-metabolic profile (12-14). Among young people, however, two studies have reported that breaks in or bouts of sedentary behavior were not associated
with cardio-metabolic health outcomes, independent of MVPA (11, 15). In contrast, after accounting for the total volume of MVPA, young people who accumulated more daily bouts of MVPA (≥10min) had lower odds of obesity compared to those who accumulated fewer or no bouts (16). Notably, findings were not consistent for other cardio-metabolic outcomes, such as cholesterol and systolic blood pressure (17).

Adverse metabolic profiles in overweight and obese (referred to hereafter as overweight/obese) children are concerning because cardio-metabolic risk factors track (18), and predict development of the metabolic syndrome, type 2 diabetes mellitus, and premature death in adulthood (19, 20). As such, understanding the modifiable behaviors associated with cardio-metabolic health in overweight/obese children is particularly important. The purpose of this study was to examine associations of volumes and bouts of objectively measured sedentary behavior and MVPA with individual and clustered cardio-metabolic health outcomes in overweight/obese children.

**Methods and Procedures**

**Participants**

Overweight/obese children were recruited as part of the multi-site Hunter Illawarra Kids Challenge Using Parent Support (HIKCUPS) trial (U.S. National Centre for Clinical Trials Registry - NCT00107692) (21-23). Baseline data collected from April 2005 to April 2006 were used for the current analyses. Participants were recruited from communities surrounding the Universities of Wollongong and Newcastle, New South Wales, Australia, using a number of methods (21). Eligibility criteria included the child being overweight/obese (24), aged 5.5-9.9 years, pre-pubertal (Tanner Stage I) and generally healthy (21). Children with extreme obesity (BMI z-score >4.0), known syndromal causes of obesity, medications known to be associated with weight gain, chronic illness, who had started puberty (parent reported –
Tanner staging) or significant dietary restriction were excluded. Of the 165 participants recruited, 120 had complete data and were included in the current analyses (missing blood data: n=13; missing activity data: n=22; missing data on confounders: n=10). Missing data were random with respect to age, sex, and waist circumference z-score. The Human Research Ethics Committees at both sites approved the study protocol. Written informed assent and consent were obtained from children and parents, respectively.

**Volume and bouts of sedentary behavior and physical activity**

Sedentary behavior and physical activity were measured during waking hours over 8 days using a uniaxial hip-mounted accelerometer (Actigraph 7164, LLC, Fort Walton Beach, FL) as previously described (25). Accelerometers recorded activity counts in 60-second epochs. Data were reduced using MeterPlus version 4.2 (San Diego, CA). Participant data were included in analyses if accelerometers were worn for ≥600 min.d⁻¹ on ≥3 days (73% and 95% had ≥7 and ≥5 days of valid data, respectively), after exclusion of non-wearing time (≥20min of consecutive zero counts). The mean (SD) number of valid days and minutes monitored were 7.0 (±1.3) days and 756 (±48) min.d⁻¹. Data were categorized into minutes of sedentary behavior or MVPA using child-specific cut-points that have been shown to be the most accurate in this age group (26). Cut-points were as follows - sedentary behavior: ≤100 counts per minute (cpm) and MVPA: ≥2296 cpm (26). Outcomes were expressed as a percentage of total monitored time to adjust for differences in valid wear time.

For each valid day of monitoring, the number of sustained periods or bouts of sedentary behavior and physical activity were derived and divided by the number of valid monitoring days to calculate average bouts.d⁻¹. Sedentary behavior bouts of 10min, 20min, and 30min were calculated, excluding non-wear time. A bout of sedentary behavior ended when the accelerometer counts broke the sedentary threshold. This range in sedentary
behavior bout durations was selected because: i) breaks in sedentary behavior at 20min (12) and 30min (13) intervals have been shown to improve postprandial glucose and insulin levels among adults, ii) children’s television programs are commonly 30min in duration, and ii) 20min and 30min bouts have been examined in previous research among children (11, 15).

MVPA bouts of 5min, 10min, and 15min were also calculated. For MVPA bouts of 10min and 15min, interruption periods of 1min and 2min, respectively, were permitted. That is, during a 10min bout, counts were permitted to drop below the MVPA threshold for up to 1min. This approach takes into account children’s intermittent physical activity patterns (16, 27). The MVPA bout durations were selected because: i) MVPA bouts ≥10min have been shown to confer benefits on weight status in children, independent of total MVPA (16), ii) and similar durations have been examined in previous research (16, 27).

**Individual cardio-metabolic risk factors and clustered cardio-metabolic risk**

Resting systolic and diastolic blood pressure were measured by use of an automated blood pressure monitor (Critikon, Tampa, Florida) following standardized procedures (21-23), and mean arterial pressure (MAP) was calculated ([systolic pressure-diastolic pressure]/3 + diastolic blood pressure). Fasting blood was analyzed for triglycerides, high-density lipoprotein (HDL) cholesterol, insulin, and glucose at a single accredited pathology service (National Association of Testing Authorities, Australia, accredited) (21-23), and the homeostasis model assessment of insulin resistance (HOMA-IR) was derived (insulin [mU/ml] * glucose [mmol/l] /22.5).

A continuous clustered cardio-metabolic risk (cMet) score that has demonstrated adequate construct validity was calculated by regressing the individual components (triglycerides, HDL cholesterol, MAP, and HOMA-IR) onto age and sex, and summing the standardized residuals (HDL cholesterol * -1) (28). To examine if associations between sedentary behavior or physical activity and cMet were independent of adiposity, waist
circumference was included in models as a covariate rather than as a risk factor in the cMet score (2). For descriptive purposes, the proportion of the sample exhibiting abnormal cardiometabolic risk factor levels was calculated. Triglycerides, HDL cholesterol and glucose were first converted to the appropriate units (mg/dL). Elevated waist circumference and triglycerides, and low HDL cholesterol were defined using recently proposed age- and sex-specific cut-points that have been linked to adult definitions using NHANES growth curve data (29). Elevated blood pressure was defined as systolic or diastolic blood pressure ≥90th percentile for age, sex, and height (30). Impaired fasting glucose was defined as ≥100 mg/dL (31).

**Assessment of covariates**

Waist circumference, height, and weight were assessed, and z-scores for waist circumference and BMI were calculated using standardized procedures as previously reported (21-23). Total energy intake (kJ.kg⁻¹), percent energy contribution from saturated fat, and fiber intake were assessed using the Australian Child and Adolescent Eating Survey which was completed by parents (32). Parents also reported their child’s time spent watching TV or DVDs, playing electronic games, and using the computer or the Internet for fun during a typical week (Monday to Friday) and weekend (Saturday and Sunday), as reported elsewhere (25). Weekday and weekend times for each type of screen behavior were summed to calculate weekly electronic screen time.

**Statistical analyses**

Analyses were conducted using Stata v.12 (Stata Corporation, College Station, TX). Normality of outcomes was assessed prior to analysis, and triglycerides, HDL cholesterol, and insulin were log transformed due to skewed distributions. Means and standard deviations were calculated for normally distributed variables, and medians and interquartile ranges were
reported for those that were not normally distributed. Descriptive characteristics were compared between girls and boys using chi-square tests, t-tests, or Mann-Whitney U-tests. Chi-square tests were used to compare differences in the proportion of boys and girls exhibiting elevated cardio-metabolic risk factor levels.

As linear associations with cardio-metabolic outcomes have been found for volumes and patterns of sedentary behavior among adults (14, 33) and for physical activity among youth (2, 3, 11, 16), linear regression analyses were used to examine associations for total volumes and bouts. For total volumes, Model 1 was adjusted for age, sex, waist circumference z-score, energy intake, percent energy contribution from saturated fat, fiber intake and weekly electronic screen time. Model 2 was adjusted for total MVPA or sedentary behavior where associations for sedentary behavior or MVPA were tested, respectively. Cohen’s $f^2$ was used to estimate effect sizes and values of 0.02, 0.15, and 0.35 are generally considered small, medium and large effects, respectively (34). With a sample size of 120 participants and nine predictors in Model 2, there was 80% power to detect an $f^2$ of 0.14 at $p <0.05$.

Linear regression analyses were also used to examine associations for bouts. An a priori decision was made to examine associations for bouts only with cardio-metabolic outcomes exhibiting significant associations with total volumes of sedentary behavior or MVPA. This decision was based on previous research indicating that patterns of sedentary behavior and MVPA such as breaks or bouts were unlikely to be associated with cardio-metabolic outcomes where the total volume exhibited non-significant associations (14, 16). Participants were grouped into quartiles to examine associations. In some cases quartiles had uneven participant numbers to avoid placing children with the same mean bouts.d$^{-1}$ in different groups. For 30min sedentary behavior bouts and 10min and 15min MVPA bouts, participants who recorded no bouts formed a group. Models were adjusted for all covariates
included in Model 1, as well as total volumes of sedentary behavior and MVPA (min), and valid accelerometer wear time. For ease of interpretation, results for bouts are reported as marginal means for each quartile, back-transformed from the log scale for non-normal outcomes. For a sample of \( \approx 30 \) children in each group there was \( \approx 90\% \) and 30\% power to detect large and medium standardized effect sizes (Cohen’s \( d \)) of \( \geq 1.0 \) and \( \geq 0.5 \) (34), respectively, at \( p < 0.05 \). For all models, interactions between age or sex and sedentary behavior or physical activity variables were examined but were not significant (\( p > 0.1 \)). Statistical significance was set at \( p < 0.05 \).

**Results**

Descriptive characteristics for the total sample and for boys and girls are reported in Table 1. Sixty three percent of participants were girls and 74\% were classified as obese. Of the mean 755 min.d\(^{-1}\) monitored by accelerometry, participants on average spent 287 min.d\(^{-1}\) sedentary, 415 min.d\(^{-1}\) in light physical activity, and 53 min.d\(^{-1}\) in MVPA. Forty-four participants (36.7\%) averaged more than the recommended 60 min.d\(^{-1}\) of MVPA. Boys had larger waist circumference \( z \)-scores and spent a greater percentage of time in MVPA than girls; no other sex differences were statistically significant. The prevalence of abnormal levels of individual cardio-metabolic risk factors was highest for waist circumference (78\%), low HDL cholesterol (53\%), and triglycerides (21\%), while very few participants exhibited elevated blood pressure (1\%) or glucose (1\%) (Figure 1). A greater proportion of girls than boys had a high waist circumference (87\% vs. 63\%, \( p = 0.003 \)); other differences were not significant.

< insert Table 1 and Figure 1 about here >
Results of the linear regression models examining the associations of objectively measured sedentary behavior and physical activity with individual cardio-metabolic health outcomes and cMet are reported in Table 2. In Model 1, sedentary behavior was inversely associated with HDL cholesterol ($p < 0.01, f^2 = 0.08$) and MVPA was inversely associated with diastolic blood pressure ($p = 0.046, f^2 = 0.03$) and cMet ($p = 0.03, f^2 = 0.04$). In Model 2, the association between sedentary behavior and HDL cholesterol remained after adjusting for MVPA ($p = 0.02, f^2 = 0.05$), as did the association between MVPA and diastolic blood pressure after adjusting for sedentary behavior ($p = 0.049, f^2 = 0.04$). Although log-transformed HDL cholesterol was used for analyses, the same models were run using non-transformed data for the purpose of interpretation: a one standard deviation decrease in sedentary behavior (58.1 min.d$^{-1}$) was associated with an average increase in HDL cholesterol of 5.4% (0.07 mmol/L). Likewise, a one standard deviation increase in MVPA (20.4 min.d$^{-1}$) was associated with an average decrease in diastolic blood pressure of 2.2% (1.23 mmHg). The association between MVPA and cMet was no longer significant after adjusting for sedentary behavior in Model 2 ($p = 0.17, f^2 = 0.02$).

< insert Table 2 about here >

Descriptive characteristics for sedentary behavior bouts and estimated marginal means for HDL cholesterol by sedentary behavior bout category are reported in Table 3. Associations between 10min and 20min sedentary behavior bouts and HDL cholesterol were not significant (all $p > 0.05$). The estimated marginal mean for HDL cholesterol was on average 12% (0.15 mmol/L) lower in those in the highest quartile of 30min sedentary behavior bouts, who recorded approximately two 30min sedentary behavior bouts every three days compared to those in the lowest quartile, who recorded no 30min bouts ($p = 0.046, d = 0.53$). However,
this was not a consistent linear association ($p_{trend} = 0.11$).

< insert Table 3 about here >

Descriptive characteristics for MVPA bouts and estimated marginal means for diastolic blood pressure by MVPA bout category are reported in Table 4. Associations between MVPA bouts and diastolic blood pressure were not statistically significant (all $p > 0.05$).

< insert Table 4 about here >

**Discussion**

Among overweight/obese children, the overall volume of objectively measured sedentary behavior was inversely associated with HDL cholesterol, independent of waist circumference and other potential confounders, including MVPA. Likewise, the overall volume of MVPA was inversely associated with diastolic blood pressure, independent of sedentary behavior and other covariates. MVPA was more strongly associated with cMet than sedentary behavior, although the association was no longer significant after adjusting for total sedentary time. However, effect sizes for the associations were small. Bouts of MVPA were not associated with diastolic blood pressure. In contrast, overweight/obese children in the highest quartile of 30min sedentary behavior bouts had lower HDL cholesterol than children who recorded no 30min bouts, independent of total MVPA and sedentary time, waist circumference and other confounders. The difference was equivalent to a medium effect.

The findings that MVPA was associated with diastolic blood pressure and more strongly associated with cMet than sedentary behavior is consistent with the substantial body of evidence indicating that MVPA has beneficial effects on cardio-metabolic health in youth (3, 4, 11, 17). Likewise, the finding that objectively measured total sedentary behavior was
associated with HDL cholesterol is consistent with cross-sectional evidence among adults (14) and longitudinal (33, 35) and experimental studies (12, 13), indicating that total or prolonged sedentary behavior in adulthood is a predictor of cardio-metabolic morbidity and all-cause mortality, independent of MVPA. However, most of the available cross-sectional evidence suggests that objectively measured total sedentary time is not associated with metabolic biomarkers in young people after adjusting for MVPA (3, 4, 11).

Our sample only included overweight/obese children and although most cardio-metabolic outcomes were not elevated, ≥50% had low HDL cholesterol, which may have contributed to our contrasting findings. Methodological differences, such as the classification of non-wear time and the subsequent impact on sedentary time estimates, may have contributed to this. In previous research non-wear has been defined as 60min of consecutive zeros, allowing for 2min of non-zero interruptions (3, 4, 11). However, we used a more conservative definition of 20min of consecutive zeros. Our findings suggest that children’s bouts of sedentary behavior are rarely more than 20-30min, and so the use of less stringent criteria increases the risk of mis-classifying non-wear-time as sedentary time, and subsequently confounding potential associations. Other factors, such as differing definitions of MVPA, and differing patterns of sedentary behavior in overweight/obese children (15) may have also contributed to this finding.

Overweight/obese children in the highest quartile of 30min bouts of sedentary behavior had lower HDL cholesterol than those in the lowest quartile. This finding is consistent with adult studies which indicate that limiting bouts of sedentary behavior to <20min (12) or <30min (13), or having more breaks in sedentary behavior (14), have beneficial effects on cardio-metabolic outcomes. In contrast, two cross-sectional studies have reported that bouts of sedentary behavior were not independently associated with cardio-metabolic outcomes such as non-HDL cholesterol in US (11) and Canadian (15) 6-19 year-
olds. Variations in the definition of a sedentary bout may have contributed to this difference. In these studies, up to 20% of a bout was permitted to be above the sedentary threshold. In the current study bout interruptions were not permitted because the aforementioned studies among adults indicate that the adverse effects on cardio-metabolic processes might be ameliorated once a bout of sedentary behavior was interrupted with a break. Observational studies comparing alternative sedentary bout definitions may be needed to understand if associations with health outcomes differ by definition. Consistent with previous cross-sectional studies in children, an experimental study by Saunders and colleagues (36) reported that limiting bouts of sedentary behavior to 20min did not have an acute effect on levels of HDL cholesterol or other cardio-metabolic risk factors in 10-14 year-olds, relative to 8h of uninterrupted sitting. Saunders et al. (36) noted that their sample included active, non-sedentary, and metabolically healthy children, which may partly explain the differing results compared to our overweight/obese sample.

The novel finding that the total volume and 30min bouts of sedentary behavior were moderately and adversely associated with HDL cholesterol in overweight/obese children are supported by mechanistic studies, which indicate that excessive sedentariness or “sitting” has distinct physiological effects to that of insufficient MVPA (37, 38). Sedentary behaviors are characterized by sustained deactivation of the large muscle groups in the legs, back and trunk which appears to suppress lipoprotein lipase activity (37, 38), an enzyme that contributes to HDL cholesterol production.

This study extends previous findings in adults to younger overweight/obese children, and addresses limitations of past investigations by adjusting for additional confounders such as dietary outcomes and electronic screen time. However, there may be additional unmeasured confounders, such as genetic factors which also influence metabolic health. A strength of the study is the objective measurement of volumes and bouts of sedentary
behavior and MVPA using accelerometry. Although the threshold definition of sedentary behavior used has been shown to be most accurate in children (26), there is potential for standing activities involving low movement to be classified as sedentary behavior. Likewise, accelerometer assessments of child sedentary behavior and MVPA have high within-individual variability (intraclass correlation coefficient [ICC] \( \approx 0.6 \) and 0.5, respectively) (39). Both of these factors may have resulted in true associations being underestimated, and contributed to the small-to-medium effects observed, which may be considered by some as not clinically meaningful. However, Ekelund et al. (3) noted that if all measurement error is assumed to be derived from within-individual variability, regression coefficients can be corrected by dividing by the ICC (40). As such, the magnitude of associations could be more than twice as strong as observed. The bouts analyses were underpowered and so larger studies are needed to confirm these findings. Finally, the associations are cross-sectional; prospective and experimental studies are required to establish causality.

**Conclusion**

In addition to increasing MVPA, targeting reductions in sedentary behavior may also contribute to improved cardio-metabolic health in overweight/obese children. Although further examination is needed, these exploratory findings suggest that limiting bouts of sedentary behavior to \(<30\text{min}\) might be an important public health message for supporting cardio-metabolic health among overweight/obese children, particularly in relation to HDL cholesterol levels.

**Acknowledgements**

Data collection was funded by a NHMRC of Australia (NHMRC) project grant (ID 354101). DPC is funded by a National Heart Foundation of Australia Postdoctoral Research Fellowship
ADO is funded by a National Heart Foundation of Australia Career Development Award. CEC is funded by an NHMRC Career Development Award. We thank the participating children, parents, and research assistants involved. DC conceived the study and analyzed data. All authors contributed to designing the data collection procedures and wrote the paper.

Conflict of Interest Statement

The authors have no competing interests.

References


Figure Caption

**Figure 1:** Prevalence of abnormal levels of cardio-metabolic risk factors in the total sample of overweight and obese children (n=120) and for boys (n=46) and girls (n=74). Waist, waist circumference; HDL, HDL cholesterol. **p = 0.003** for boys vs. girls.
Table 1
Descriptive characteristics of participating overweight and obese children.

<table>
<thead>
<tr>
<th></th>
<th>Total (N = 120)</th>
<th>Boys (N = 46)</th>
<th>Girls (N = 74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>8.3 ± 1.1</td>
<td>8.4 ± 1.1</td>
<td>8.2 ± 1.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>46.4 ± 11.0</td>
<td>47.0 ± 10.2</td>
<td>46.1 ± 11.4</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>24.7 ± 3.7</td>
<td>24.5 ± 3.4</td>
<td>24.7 ± 3.9</td>
</tr>
<tr>
<td>BMI z-score (SD units)</td>
<td>2.8 ± 0.7</td>
<td>2.9 ± 0.6</td>
<td>2.7 ± 0.7</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>75.9 ± 9.3</td>
<td>77.3 ± 8.9</td>
<td>75.0 ± 9.4</td>
</tr>
<tr>
<td>Waist circumference z-score (SD units)</td>
<td>3.0 ± 0.8</td>
<td>3.3 ± 1.0</td>
<td>2.8 ± 0.7**</td>
</tr>
<tr>
<td>Obese (N, %)</td>
<td>89 (74%)</td>
<td>36 (78%)</td>
<td>53 (72%)</td>
</tr>
<tr>
<td>Sedentary behavior (% of time)</td>
<td>38.2 ± 7.7</td>
<td>38.3 ± 8.3</td>
<td>38.2 ± 7.3</td>
</tr>
<tr>
<td>Light physical activity (% of time)</td>
<td>54.5 ± 6.6</td>
<td>53.7 ± 7.0</td>
<td>54.9 ± 6.3</td>
</tr>
<tr>
<td>MVPA (% of time)</td>
<td>7.3 ± 2.7</td>
<td>8.0 ± 3.1</td>
<td>6.9 ± 2.3*</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>0.9 (0.6-1.2)</td>
<td>0.9 (0.7-1.3)</td>
<td>0.9 (0.6-1.2)</td>
</tr>
<tr>
<td>HDL cholesterol (mmol/L)</td>
<td>1.3 (1.1-1.4)</td>
<td>1.3 (1.1-1.4)</td>
<td>1.2 (1.1-1.4)</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>98.3 ± 9.0</td>
<td>99.3 ± 9.1</td>
<td>97.6 ± 9.0</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>55.9 ± 5.6</td>
<td>56.8 ± 5.0</td>
<td>55.3 ± 5.9</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>4.2 ± 0.5</td>
<td>4.2 ± 0.4</td>
<td>4.1 ± 0.5</td>
</tr>
<tr>
<td>Insulin (mU/ml)</td>
<td>8.4 (5.7-13.3)</td>
<td>8.1 (4.8-14.0)</td>
<td>8.5 (6.0-13.2)</td>
</tr>
</tbody>
</table>

Data are means ± SD or median (interquartile range).

Abbreviations: BMI, body mass index; MVPA, moderate-to-vigorous physical activity; LDL, low-density lipoprotein cholesterol; HDL, high-density lipoprotein cholesterol. *p = 0.037 and **p = 0.002 for boys vs. girls.
### Table 2

Standardized regression coefficients for the associations of objectively measured sedentary behavior and MVPA with individual cardio-metabolic risk factors and clustered cardio-metabolic risk in overweight and obese children (N = 120).

<table>
<thead>
<tr>
<th>Cardio-metabolic risk factor</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sedentary behavior</td>
<td>MVPA</td>
<td>Sedentary behavior</td>
<td>MVPA</td>
</tr>
<tr>
<td>Triglycerides&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.08 (-0.13, 0.29)</td>
<td>0.001 (-0.19, 0.19)</td>
<td>0.11 (-0.14, 0.35)</td>
<td>0.05 (-0.17, 0.27)</td>
</tr>
<tr>
<td>HDL cholesterol&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.30 (-0.50, -0.10)**</td>
<td>0.16 (-0.04, 0.35)</td>
<td>-0.29 (-0.52, -0.05)*</td>
<td>0.03 (-0.19, 0.24)</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>0.02 (-0.19, 0.21)</td>
<td>-0.07 (-0.25, 0.11)</td>
<td>-0.04 (-0.26, 0.19)</td>
<td>-0.09 (-0.29, 0.12)</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>0.06 (-0.15, 0.27)</td>
<td>-0.19 (-0.38, -0.004)*</td>
<td>-0.06 (-0.30, 0.18)</td>
<td>-0.22 (-0.44, -0.001)*</td>
</tr>
<tr>
<td>Glucose</td>
<td>-0.08 (-0.29, 0.14)</td>
<td>-0.03 (-0.23, 0.17)</td>
<td>-0.12 (-0.37, 0.13)</td>
<td>-0.09 (-0.31, 0.14)</td>
</tr>
<tr>
<td>Insulin&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.02 (-0.16, 0.21)</td>
<td>-0.07 (-0.24, 0.10)</td>
<td>-0.02 (-0.16, 0.21)</td>
<td>-0.07 (-0.27, 0.12)</td>
</tr>
<tr>
<td>cMet</td>
<td>0.17 (-0.006, 0.34)</td>
<td>-0.19 (-0.36, -0.01)*</td>
<td>0.10 (-0.10, 0.30)</td>
<td>-0.14 (-0.33, 0.06)</td>
</tr>
</tbody>
</table>

Model 1: adjusted for age, sex, waist circumference z-score, daily saturated fat intake, daily fiber intake, daily energy intake, weekly electronic screen time. Models for cMet are adjusted for waist circumference z-score, daily saturated fat intake, daily fiber intake, daily energy intake, weekly electronic screen time.

Model 2: adjusted for the same covariates as Model 1. Models testing sedentary behavior are additionally adjusted for MVPA. Models testing MVPA are additionally adjusted for sedentary behavior.

<sup>a</sup> Models for triglycerides, HDL cholesterol and insulin were completed using log-transformed data. *p < 0.05, ** p < 0.01
Table 3
Descriptive characteristics for sedentary behavior bouts and estimated marginal means for HDL cholesterol by sedentary behavior bout category.

<table>
<thead>
<tr>
<th>Sedentary bout length</th>
<th>Sedentary bout category</th>
<th>Median (IQ range) bouts.day(^{-1})</th>
<th>Range bouts.day(^{-1})</th>
<th>HDL cholesterol (estimated marginal mean, 95% CI)(^{a})</th>
</tr>
</thead>
<tbody>
<tr>
<td>10min</td>
<td>Low (n=31)</td>
<td>3.13 (2.50-3.71)</td>
<td>1.60-3.83</td>
<td>1.30 (1.20-1.41)</td>
</tr>
<tr>
<td></td>
<td>Low-Moderate (n=29)</td>
<td>4.57 (4.00-5.00)</td>
<td>3.88-5.63</td>
<td>1.17 (1.08-1.26)</td>
</tr>
<tr>
<td></td>
<td>Moderate-High (n=30)</td>
<td>6.78 (6.00-7.19)</td>
<td>5.75-7.50</td>
<td>1.29 (1.20-1.39)</td>
</tr>
<tr>
<td></td>
<td>High (n=30)</td>
<td>9.63 (8.59-10.6)</td>
<td>7.60-15.88</td>
<td>1.31 (1.20-1.43)</td>
</tr>
<tr>
<td></td>
<td>Total Sample (n=120)</td>
<td>5.69 (3.83-7.58)</td>
<td>1.60-15.88</td>
<td>P(_{trend}) = 0.74</td>
</tr>
<tr>
<td>20min</td>
<td>Low (n=31)</td>
<td>0.29 (0.20-0.40)</td>
<td>0.13-0.43</td>
<td>1.26 (1.16-1.36)</td>
</tr>
<tr>
<td></td>
<td>Low-Moderate (n=29)</td>
<td>0.57 (0.50-0.65)</td>
<td>0.50-0.80</td>
<td>1.26 (1.17-1.36)</td>
</tr>
<tr>
<td></td>
<td>Moderate-High (n=30)</td>
<td>1.25 (1.00-1.50)</td>
<td>0.86-1.63</td>
<td>1.26 (1.17-1.36)</td>
</tr>
<tr>
<td></td>
<td>High (n=30)</td>
<td>2.00 (1.83-2.66)</td>
<td>1.71-6.13</td>
<td>1.28 (1.18-1.40)</td>
</tr>
<tr>
<td></td>
<td>Total Sample (n=120)</td>
<td>0.83 (0.43-1.69)</td>
<td>0.13-6.13</td>
<td>P(_{trend}) = 0.75</td>
</tr>
<tr>
<td>30min</td>
<td>None (n=32)</td>
<td>-</td>
<td>-</td>
<td>1.35 (1.25-1.45)</td>
</tr>
<tr>
<td></td>
<td>Low-Moderate (n=28)</td>
<td>0.13 (0.13-0.14)</td>
<td>0.13-0.14</td>
<td>1.24 (1.14-1.34)</td>
</tr>
<tr>
<td></td>
<td>Moderate-High (n=26)</td>
<td>0.25 (0.20-0.29)</td>
<td>0.17-0.33</td>
<td>1.30 (1.20-1.41)</td>
</tr>
<tr>
<td></td>
<td>High (n=34)</td>
<td>0.63 (0.50-0.88)</td>
<td>0.38-3.13</td>
<td>1.20 (1.11-1.29)*</td>
</tr>
<tr>
<td></td>
<td>Total Sample (n=120)</td>
<td>0.20 (0.0-0.38)</td>
<td>0.0-3.13</td>
<td>P(_{trend}) = 0.11</td>
</tr>
</tbody>
</table>

All models were adjusted for age, sex, waist circumference z-score, daily saturated fat intake, daily fiber intake, daily energy intake, weekly electronic screen time, accelerometer wear time, and total volumes of MVPA and sedentary behavior (mean min.d\(^{-1}\)).

\(^{a}\) Estimated marginal means are back-transformed from the log scale. * p=0.046 for difference between “None” category (reference).
Table 4
Descriptive characteristics for MVPA bouts and estimated marginal means for diastolic blood pressure by MVPA bout category.

<table>
<thead>
<tr>
<th>MVPA bout length</th>
<th>MVPA bout Category</th>
<th>Median (IQ range)</th>
<th>Range bouts.day⁻¹</th>
<th>Diastolic blood pressure (estimated marginal means, 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5min</td>
<td>Low (n=28)</td>
<td>0.35 (0.20-0.55)</td>
<td>0.0-0.63</td>
<td>54.9 (52.1-57.6)</td>
</tr>
<tr>
<td></td>
<td>Low-Moderate (n=31)</td>
<td>1.00 (0.83-1.13)</td>
<td>0.75-1.38</td>
<td>55.3 (53.0-57.5)</td>
</tr>
<tr>
<td></td>
<td>Moderate-High (n=33)</td>
<td>1.75 (1.54-1.94)</td>
<td>1.40-2.14</td>
<td>56.2 (54.2-58.2)</td>
</tr>
<tr>
<td></td>
<td>High (n=28)</td>
<td>3.23 (2.52-3.77)</td>
<td>2.17-5.00</td>
<td>57.1 (54.0-60.2)</td>
</tr>
<tr>
<td></td>
<td>Total Sample (n=120)</td>
<td>1.41 (0.75-2.14)</td>
<td>0.0-5.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$P_{\text{trend}} = 0.37$</td>
</tr>
<tr>
<td>10min</td>
<td>None (n=32)</td>
<td>-</td>
<td>-</td>
<td>55.7 (53.4-58.1)</td>
</tr>
<tr>
<td></td>
<td>Low-Moderate (n=26)</td>
<td>0.14 (0.13-0.17)</td>
<td>0.13-0.25</td>
<td>54.8 (52.6-57.1)</td>
</tr>
<tr>
<td></td>
<td>Moderate-High (n=32)</td>
<td>0.43 (0.34-0.50)</td>
<td>0.29-0.57</td>
<td>56.9 (54.9-58.9)</td>
</tr>
<tr>
<td></td>
<td>High (n=30)</td>
<td>0.85 (0.63-1.13)</td>
<td>0.60-1.63</td>
<td>55.8 (53.2-58.3)</td>
</tr>
<tr>
<td></td>
<td>Total Sample</td>
<td>0.29 (0.0-0.59)</td>
<td>0.0-1.63</td>
<td>$P_{\text{trend}} = 0.70$</td>
</tr>
<tr>
<td>15min</td>
<td>None (n=59)</td>
<td>-</td>
<td>-</td>
<td>55.5 (53.9-57.2)</td>
</tr>
<tr>
<td></td>
<td>Moderate (n=28)</td>
<td>0.14 (0.13-0.25)</td>
<td>0.13-0.25</td>
<td>55.9 (53.8-58.0)</td>
</tr>
<tr>
<td></td>
<td>High (n=33)</td>
<td>0.38 (0.29-0.50)</td>
<td>0.29-1.13</td>
<td>56.4 (54.1-58.7)</td>
</tr>
<tr>
<td></td>
<td>Total Sample</td>
<td>0.13 (0.0-0.29)</td>
<td>0.0-1.13</td>
<td>$P_{\text{trend}} = 0.58$</td>
</tr>
</tbody>
</table>

All models were adjusted for age, sex, waist circumference z-score, daily saturated fat intake, daily fiber intake, daily energy intake, weekly electronic screen time, accelerometer wear time, and total volumes of MVPA and sedentary behavior (mean min.d⁻¹).
Abbreviations: MVPA, moderate-to-vigorous physical activity.