Associations of sitting behaviour patterns with cardiometabolic risk in children: The Sit Less for Health Cross-Sectional Study.

Stockwell SL[1,2,3], Smith LR[1], Weaver HM[1], Hankins DJ[1], and Bailey DP[1].

[1] Institute for Sport and Physical Activity Research, School of Sport Science and Physical Activity, University of Bedfordshire, Polhill Avenue, Bedford, MK41 9EA.

[2] The Cambridge Centre for Sport and Exercise Sciences, Anglia Ruskin University, East Road, Cambridge, CB1 1PT.

[3] Faculty of Health, Social Care and Education, Anglia Ruskin University, , East Road, Cambridge, CB1 1PT.

Abstract

Background: The objective of this study was to investigate the associations between sedentary behaviour patterns and cardiometabolic risk in children using a monitor that accurately distinguishes between different postures. **Methods:** In this cross-sectional study, 118 children (67 girls) aged 11-12-years had adiposity, blood pressure, lipids and glucose measured and then wore an activPAL device to record sitting, standing and stepping for seven consecutive days. Data was analysed using multiple linear regression. **Results:** After adjustment for potential confounders and moderate-to-vigorous physical activity, the number of breaks in sitting was significantly negatively associated with adiposity (standardised β≥-0.546; p≤0.001) and significantly positively associated with high-density lipoprotein cholesterol (HDL) (β=0.415; p≤0.01). Time in prolonged sitting bouts was significantly negatively associated with adiposity (β≥-0.577; p≤0.001) and significantly positively associated with HDL (β=0.432; p≤0.05). Standing time was significantly negatively associated with adiposity (β≥-0.270; p≤0.05) and significantly positively associated with HDL (=0.312; p≤0.05). **Conclusions:**

28 This study suggests that increasing the number of breaks in sitting and increasing standing
29 time are beneficially associated with cardiometabolic risk and should be considered in health
30 promotion interventions in children.
31

Background

Cardiometabolic disease is an uncommon occurrence or cause of death in children. However, cardiometabolic risk markers such as obesity, high blood pressure, adverse lipid profile and impaired glucose levels can begin to develop in childhood, increasing the likelihood of cardiometabolic disease in adulthood[1,2]. A clustering of these risk markers in childhood confers significantly greater risk of Type 2 diabetes mellitus and cardiovascular disease in adult years[3] and it is therefore important that appropriate interventions are identified to reduce cardiometabolic risk marker levels in children.

Sedentary behaviour is defined as any waking behaviour characterised by an energy expenditure of ≤ 1.5 Metabolic Equivalents (METs) whilst in a sitting, reclining or lying posture[4]. It has been reported that children aged 10-14 years old engage in approximately 7–8 hours of objectively measured sedentary time each day[5,6] and may spend up to 80% of their waking day being sedentary[7]. However, some previous studies have reported that total sedentary time was not associated with cardiometabolic risk in 6-19-year-old children[8,9]. Conversely, other studies have reported that total sedentary time was significantly negatively correlated with abdominal adiposity in 10-14-year-old children[10] and inversely associated with high-density lipoprotein cholesterol (HDL) in overweight and obese 5-10-year-olds[11]. In 9-10 and 15-16-year-old children, total sedentary time was also adversely associated with blood pressure, fasting glucose, triglycerides, insulin and a clustered cardiometabolic risk score[12]. The associations of total sedentary time with cardiometabolic risk reported in the literature is thus inconclusive.

It has been proposed that the manner in which sedentary time is accumulated may be associated with cardiometabolic risk, independent of total sedentary time[13]. However, there has been only a limited number of studies that have explored associations between sedentary behaviour *patterns* and cardiometabolic risk in children and the findings have provided contradictory results[8-10,14,15]. For instance, in 10-13-year-old children, accumulated time in prolonged sedentary bouts (≥ 30 minutes) was positively associated with body mass index (BMI) and negatively associated with triglycerides[14]. These findings were supported by

a study in 10-14-year-old children which observed that an increased number of prolonged sedentary bouts per day was associated with higher odds of hypertriglyceridemia and increased clustered cardiometabolic risk[10]. There is also evidence that the number of breaks in sedentary time per day was negatively associated with a clustered cardiometabolic risk score and BMI Z-score in 8-11-year-olds[16]. However, other studies have reported that time accumulated in prolonged sedentary bouts was not associated with cardiometabolic risk markers in 6-19-year-old children[8,9]. Furthermore, no association was found between the number of breaks per day and cardiometabolic risk in 10-14-year-old children, although the mean duration of the breaks in sedentary time was associated with lower odds of abdominal obesity and elevated diastolic blood pressure (DBP)[10].[16] The inconclusive findings with respect to the association between sedentary behaviour patterns and cardiometabolic risk in children may be a result of measuring sedentary time using accelerometers that are unable to detect postural allocation. Therefore, standing time could be misclassified as sitting[8,14,15,17,18]. This is problematic as it may lead to overestimations of sedentary time and underestimations of breaks in sedentary time, which may affect the observed associations with health outcomes[19].

To the authors' knowledge, there are currently no studies that have explored the associations between objectively measured sedentary behaviour patterns using inclinometry (that permits detection of postural allocation) and cardiometabolic risk in children. The objective of this study, therefore, was to investigate the associations between sedentary behaviour patterns and cardiometabolic risk in children using the activPAL device that accurately distinguishes between sitting and standing. It was hypothesised that higher total daily sitting time and a lower number of breaks in sitting would be associated with increased cardiometabolic risk marker levels.

Methods

Study design

This was a cross-sectional study design across schools in Bedfordshire, UK. Data collection took place in spring 2017 and the study was approved by the University of Bedfordshire Institute for Sport and Physical Activity Research Ethics Committee (approval number 2017ISPAR001). Other than measurement of sitting, standing and stepping, all other measures took place at the children's schools.

Participants

Participants were 11-12-year-old schoolchildren recruited on a voluntary basis. Volunteers were excluded from the study if they had any known blood borne disease, had clinically diagnosed diabetes, were taking glucose-lowering and/or lipid-lowering medication, smoking, hypertension, major illness/injury, or other health issues that could affect the associations being assessed in the study. Written parental/guardian informed consent was obtained and verbal assent obtained from the participants before any test procedures.

Recruitment

Seventeen middle schools within Bedford Borough and surrounding areas were contacted by telephone and email to discuss their willingness and availability to help facilitate the study. Four state schools with mixed gender students agreed to take part in the study. A presentation during class or assembly time was given by the research team to year groups who were eligible for the study. This provided an opportunity for children and teachers to ask questions and for information sheets, health screening questionnaires and consent forms to be distributed to children to take home to their parents/guardians to be completed. Following this, schools were asked to send reminders via their text message or email system to parents to complete and return the forms. Participants received a £5 shopping gift voucher for returning their activPAL device.

Measurements

Biological maturity and socioeconomic status

115 Biological maturity was self-reported using the Tanner scale[20] and Indices of Multiple
116 Deprivation (IMD) scores were calculated using participants' home postcodes (self-reported
117 by parent/guardian) as a measure of socioeconomic status[21].
118
119 *Anthropometry and body composition*
120 Standing height was measured to the nearest 0.1 cm using a transportable stadiometer (Seca,
121 Hamburg, Germany). Body mass was measured to the nearest 0.1 kg and body fat%
122 estimated by bioelectrical impedance analysis to the nearest 0.1% using the Tanita BC-418
123 MA Segmental Body Composition Analyzer (Tanita Corp., Tokyo, Japan). Body fat% was
124 estimated using manufacturer prediction equations that are based on gender, age, body mass,
125 height and impedance. BMI was calculated as: BMI = body mass (kg) ÷ height (m^2). BMI z-
126 score was calculated using UK reference values[22]. Waist circumference (WC) was measured
127 using an adjustable tape measure (HaB Direct, Southam, UK) to the nearest 0.1 cm at the
128 level of the umbilicus following gentle expiration[10].
129
130 *Blood pressure, lipids and glucose*
131 Following 5 minutes of rest in a seated position, resting blood pressure was measured on the
132 left arm using an Omron M5-I automatic blood pressure monitor (Omron Matsusaka Co Ltd.,
133 Matsusaka, Japan). Two measures were taken with a two-minute rest between each and the
134 average recorded. Fasting whole blood samples were obtained (100 µl) via a finger prick
135 method and analysed using the Cholestech LDX Analyzer (Cholestech Corp., Hayward, CA.)
136 to provide measures of total cholesterol (TC), high-density lipoprotein cholesterol (HDL), low-
137 density lipoprotein cholesterol (LDL), triglycerides, non-HDL, TC:HDL ratio and glucose. This
138 system has been validated in adults[23] and has been used in previous paediatric research[10,24].
139 A continuous clustered cardiometabolic risk score was calculated by summing the z-scores
140 for WC, DBP, TC:HDL ratio, triglycerides and glucose[10]. A non-obesity clustered
141 cardiometabolic risk score was calculated by summing the z-scores for DBP, TC:HDL ratio,
142 triglycerides and glucose[12]. These clustered risk scores were calculated as they provide

143 greater statistical power[25], account for daily variations in individual risk markers and have
144 previously been used in paediatric research[10,12,16] Impaired fasting glucose was defined as ≥
145 5.6 mmol · L^{-1}[26]. Hypercholesterolemia was defined as ≥ 5.17 mmol · L^{-1}[27]. Triglycerides were
146 considered high between 1.02 – 1.46 mmol · L^{-1} and HDL considered low between 0.91 – 1.16
147 mmol · L^{-1}[27]. The present study defined hypertriglyceridemia as ≥ 1.24 mmol · L^{-1} and low HDL
148 as ≤ 1.03 mmol · L^{-1} as this is the mid-point between these ranges[10,28].
149
150 *Sitting, standing and stepping*
151 Participants were asked to wear an activPAL device (PAL technologies, Glasgow, Scotland)
152 continuously for seven consecutive days following the data collection session. Participants
153 completed a diary to record what time they woke up, got out of bed, what time they went to
154 bed, went to sleep and timings of any periods during the day when the monitor was removed.
155 The monitor was wrapped in a nitrile flexible sleeve to protect it from water and fitted to the
156 mid anterior aspect of the right thigh with a hypo-allergenic transparent film roll (Hypafix,
157 BSNmedical, UK). The activPAL measures bodily accelerations and identifies postural
158 changes depending on the inclination of the wearer's thigh[29]. The monitor categorises each
159 15 s epoch as sitting/lying, standing or stepping[30]. The activPAL monitor provides reliable and
160 valid measures of time spent sitting/lying, standing, stepping, sit-to-upright and upright-to-sit
161 transitions in children[31].
162 Periods and patterns of sitting (total sitting time, prolonged sitting bouts and breaks in
163 sitting time), standing, light stepping (i.e. light physical activity) and moderate-to-vigorous
164 stepping (i.e. moderate-to-vigorous physical activity [MVPA]) were determined using an
165 automated algorithm developed for use with Stata (StataCorp LLC, Texas, US)[32]. Inclusion
166 criteria for valid wear time was a minimum of four days including at least one weekend day[29].
167 A valid day was required to have a minimum of 10 hours wear time and >500 steps[29,32]. A
168 prolonged sitting bout was defined as a period ≥30 minutes in a sitting/reclining posture
169 during waking time in line with previous studies[8,14]. A break in sitting was defined as a non-

sitting period in between two sitting bouts[33]. All variables were calculated for each valid day and then averaged across all included valid days for analysis.

Statistical analysis

SPSS v23.0 (SPSS Inc., Armonk, N.Y., USA) was used for all statistical analysis. Skewness and kurtosis in addition to visual inspection of Q-Q plots were used to check normality of the data. Variables that were non-normally distributed were log transformed prior to analysis, which included weight, BMI, WC and TC:HDL ratio. Descriptive data is presented as mean ± SD. Multiple linear regression was used to assess associations between sitting, standing and stepping variables (i.e. total sitting time, number of breaks in sitting per day, total time spent in prolonged sitting bouts, standing time and light physical activity) with cardiometabolic risk marker levels. Sex, IMD scores, biological maturity, school attended, and activPAL wear time were significantly correlated with ≥1 cardiometabolic risk marker and were thus adjusted for in the analysis (model 1). In model 2, these covariates were entered in addition to moderate-MVPA to explore whether MVPA mediates any of the associations between sitting, standing and light physical activity variables and cardiometabolic risk markers. The level of significance was accepted at $p \leq 0.05$.

Results

Of the 610 information sheets distributed across four schools, 148 participants returned consent forms, of which 20 participants withdrew from the study prior to data collection. Ten participants did not provide valid activPAL data (six did not meet wear time criteria, two devices malfunctioned, and two devices were not returned) and thus were excluded from the analysis. A total of 118 participants (67 girls) were included in the present analysis. Three participants (two girls) withdrew from the blood sampling during the measurement morning, thus 115 participants were included for analyses of blood markers.

Anthropometric and cardiometabolic risk marker descriptive characteristics are shown in Table 1. The prevalence of abdominal obesity in the whole sample was 37.3% (n=44),

198 elevated systolic blood pressure (SBP) 2.6% (n=3), and elevated DBP 3.4% (n=4). From the
199 115 participants that provided blood samples, the prevalence of hypercholesterolemia was
200 41.7% (n=48), hypertriglyceridemia 28.7% (n=33), low HDL 4.4% (n=5) and impaired fasting
201 glucose 6.1% (n=7). The proportion of the sample meeting the government recommended 60
202 minutes/day of MVPA [34] was 91.5 ± 0.4%.

203 Sitting, standing and physical activity descriptives are shown in Table 2. Associations
204 within both regression models are shown in Table 4 and Table 5 (the latter additionally
205 adjusting for MVPA). Due to high collinearity with wear time, total sitting time was removed
206 from the analysis in both regression models. In both regression models the number of breaks
207 in sitting per day was significantly negatively associated with weight, BMI, WC and body fat%
208 and significantly positively associated with TC and HDL. Total time spent in prolonged sitting
209 bouts was significantly negatively associated with weight, BMI, WC and body fat% and
210 significantly positively associated with TC and HDL in both regression models. In regression
211 model 1, total time spent in prolonged sitting bouts was significantly positively associated with
212 LDL and non-HDL, however, this was attenuated in regression model 2 and became non-
213 significant.

214 In regression model 1, standing time was significantly negatively associated with
215 weight and body fat% and significantly positively associated with HDL. In regression model 2,
216 standing time remained significantly negatively associated with weight and body fat% and
217 significantly positively associated with HDL. Standing time became significantly negatively
218 associated with WC in model 2. Light physical activity was significantly negatively associated
219 with body fat% in regression model 1, however, this association was weakened when MVPA
220 was additionally adjusted for in regression model 2 and became non-significant.

221

222 **Discussion**

223 The main findings of this study were that the number of breaks in sitting and the time in
224 prolonged sitting bouts are significantly negatively associated with adiposity and significantly
225 positively associated with HDL and TC in 11-12-year-old children. The significant negative

association of time in prolonged sitting with weight, BMI, WC and body fat% in present study was unexpected, as this suggests that children who spend longer periods of time engaging in prolonged sitting had reduced adiposity levels. Conversely, Altenburg *et al.* [14] found that time spent in prolonged sedentary bouts (≥ 30 minutes) was significantly positively associated with BMI, but not WC, in children aged 10-13 years old. Participants in the study by Altenburg *et al.* [14] had a similar mean BMI to the participants in the present study but also had a lower WC, which could explain some of the variation in results. Furthermore, the participants in the current study were highly active and it is thus possible that prolonged sitting is not unfavourably associated with adiposity in highly active children. Time in prolonged sitting bouts was significantly positively associated with HDL in the present study, which was also unexpected. This could have been confounded by dietary intake[35,36], which was not accounted for in the present study whereby those who engaged in more prolonged sitting consumed a diet that encourages higher levels of HDL. Alternatively, prolonged sitting may not be detrimentally associated with HDL, which is supported by previous research[10]. In the present study, time in prolonged sitting bouts was significantly positively associated with TC, which may be due to the higher levels of HDL in participants who engaged in more prolonged sitting time. Altenburg *et al.* [14] found no significant association between time in prolonged sedentary bouts and TC in children aged 10-13 years. This discrepancy could be due to the low volume of uninterrupted prolonged sedentary time accumulated in the study by Altenburg *et al.* [14] (32 minutes/day) compared to the present study (265 minutes/day). The associations between prolonged sitting with adiposity and lipids thus remains unclear and longitudinal studies should be conducted to examine causal relationships and to establish if prolonged sitting should be considered an intervention target for health promotion in children.

In the present study, time spent in prolonged sitting bouts was significantly positively associated with LDL and non-HDL, however, this association was attenuated by MVPA. This suggests that MVPA may protect against high levels of LDL in children who spend more time in prolonged sitting bouts. However, the beneficial association between the number of breaks

253 in sitting and HDL was independent of MVPA and children should thus be encouraged to
254 engage in more breaks regardless of their MVPA levels.

255 The number of breaks in sitting was significantly negatively associated with weight,
256 BMI, WC and body fat%. A longitudinal study in children at age 7, 9, 12 and 15 years old
257 supports these findings in which more breaks in sedentary time between the ages of 9-12
258 years was significantly associated with a decrease in fat mass index and BMI[37]. However, the
259 number of breaks in sitting was significantly positively associated withTC in the present study,
260 which may be because higher levels of HDL were seen with an increased number of breaks
261 without any change in LDL. In children aged 8-11 years old, breaks in sedentary time was
262 significantly associated with reduced clustered cardiometabolic risk score and BMI z-scores[16].
263 This is similar to the present study for BMI but conflicting with regards to no association
264 between breaks and clustered cardiometabolic risk score. This may be because children in
265 the study by Saunders *et al.* [16] had a higher BMI and clustered cardiometabolic risk score,
266 which could strengthen the associations observed due to poorer metabolic health. Based on
267 this evidence, it may be appropriate for interventions to target increases in the number of
268 breaks in sedentary time to reduce cardiometabolic risk in children.

269 The present study is the first, to the authors' knowledge, to evaluate the association of
270 standing time with cardiometabolic risk in children. Standing time was significantly negatively
271 associated with weight and body fat% and positively associated with HDL, independent of
272 MVPA. Increased standing time may elicit a greater daily energy expenditure, thus decreasing
273 excess energy that could be stored as fat. Nonetheless, standing time became significantly
274 negatively associated with WC when adjusting for MVPA, which suggests that the association
275 between standing and WC is mediated by MVPA. The findings suggest that standing may be
276 beneficially associated with adiposity in children and it may thus be appropriate to encourage
277 more opportunities to stand throughout the day, such as in the classroom. However, further
278 research is needed to establish causal effects of increases in standing time on adiposity to
279 inform public health interventions.

In this study, children accumulated 553 minutes (9.2 hours) of sitting per day. Although no previous studies have measured *sitting time* in children, the daily sitting time reported in the present study is higher than the 504 minutes per day of sedentary time reported in a previous UK study[10]. It is also higher than that reported by Colley *et al.* [9] in Canadian children aged 11-14 years old in which boys accumulated 508 minutes and girls 524 minutes per day. However, the higher sitting time in girls (529 min/day vs. 514 min/day in boys) in the present study is consistent with this previous study[9]. Children in Europe aged 10-14 years old engaged in approximately 7-8 hours of objectively measured sedentary time each day[5,6], which is markedly lower than in the present study. This could be due to samples being recruited from different regions or that the use of the activPAL inclinometer may have been more sensitive to detecting sedentary time than previously used accelerometers[31]. Consistent across studies, though, is that children accumulate relatively high amounts of daily sedentary time and public health interventions may be needed to reduce sedentary time in young populations.

The present study found that children aged 11-12 years old spent an average of 265 minutes in prolonged sitting bouts (≥ 30 minutes) per day, which was approximately half of their total sitting time. This is similar to the findings of Bailey *et al.* [10] who reported that children aged 10-14 years old spent 260 minutes in prolonged bouts of ≥ 20 minutes, but higher than that found by Carson and Janssen [8] who reported 204 minutes in prolonged sedentary bouts of ≥ 30 minutes in 6-19 year-olds. It thus appears that the children in the present sample engaged in more prolonged sedentary time than previous studies. However, a potential reason for the discrepancies could be differences in the age of the samples or different devices and thresholds used to define sedentary/sitting time. Future studies should therefore consider developing a universal approach for measurement and classification of sedentary time in children to establish the time they spend in prolonged sitting. Nonetheless, this data suggests that strategies may be needed to reduce prolonged sitting in the paediatric population.

The mean number of breaks in sitting was 81 per day, which is similar to results found in children aged 6-19 years old who engaged in 83 breaks per day[9]. Bailey *et al.* [10] found that children aged 10 -14 years old engaged in 63 breaks per day. A reason for the lower number

of breaks observed previously could be the use of an accelerometer that did not differentiate between postures and may have misclassified standing time as sitting that would have been classified as a break in the current study[38]. In addition, Bailey *et al.* [10] used a 1-min epoch length, which is longer than the 15 s epoch used in the present study but the same as used by Colley *et al.* [9]. Due to children's sporadic and intermittent behaviour[17], the longer epoch may not capture all breaks between shorter periods of sedentary time. Despite children in the present study breaking up their sedentary time 81 times per day, approximately half of their total sitting time was spent in prolonged bouts, meaning that these breaks were not evenly spread throughout the day. Future research should identify segments of the day when children engage in prolonged sitting (e.g. during class time, break time or at home) to inform appropriate interventions.

The main strength of this study was the use of a validated device for measurement of sitting, standing and stepping. In addition, a wide array of cardiometabolic risk markers were measured to provide an in-depth exploration of their association with sitting behaviour patterns. However, the study was a cross-sectional design, which limits conclusions regarding causality and the sample size is small limiting generalisability of the findings. The children in this study were also generally normal weight and highly active. The findings thus cannot be generalised to other population groups. Researchers are thus encouraged to investigate the associations of sitting behaviour patterns with cardiometabolic risk in overweight and obese children as well as children with low activity levels as these populations may have increased cardiometabolic risk that may be more strongly associated with sitting time. The sample was also of a narrow age range and further research should be conducted in other age groups using combined accelerometry and inclinometry methods.

Conclusions

This study provides evidence that an increased number of breaks in sitting and daily standing time are beneficially associated with cardiometabolic risk in 11-12-year-old children, independent of MVPA. However, the association between prolonged sitting and cardiometabolic risk markers was mixed. Although longitudinal and experimental studies are required to determine cause and effect relationships between sitting behaviour patterns and cardiometabolic risk, these findings suggest that increasing breaks from sitting and increasing standing time may be potential intervention strategies to improve cardiometabolic health in children.

Acknowledgements

The authors would like to thank Charlotte A. Stringer and Rachael B. Champion for their help with data collection, Benjamin D. Maylor for his guidance on collecting and processing the activPAL data, and the University of Bedfordshire Sport and Exercise Laboratory technicians Warwick Riley, Roisin McBride and Callum Mould for their assistance with preparation for data collection.

References

1. Kavey R-EW, Daniels SR, Lauer RM, Atkins DL, Hayman LL and Taubert K. American Heart Association Guidelines for Primary Prevention of Atherosclerotic Cardiovascular Disease Beginning in Childhood. *Circulation* 2003;107(11):1562-1566.

2. Morrison JA, Friedman LA and Gray-McGuire C. Metabolic Syndrome in Childhood Predicts Adult Cardiovascular Disease 25 Years Later: The Princeton Lipid Research Clinics Follow-up Study. *Pediatrics* 2007;120(2):340-345.

3. Isomaa B, Almgren P, Tuomi T*, et al.* Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes care* 2001;24(4):683-689.

4. Tremblay MS, Aubert S, Barnes JD*, et al.* Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. *Int J Behav Nutr Phys Act* 2017;14(1):75.

5. Bailey DP, Boddy LM, Savory LA, Denton SJ and Kerr CJ. Associations between cardiorespiratory fitness, physical activity and clustered cardiometabolic risk in children and adolescents: the HAPPY study. *Eur J Pediatr* 2012;171(9):1317-1323.

6. Verloigne M, Van Lippevelde W, Maes L*, et al.* Self-reported TV and computer time do not represent accelerometer-derived total sedentary time in 10 to 12-year-olds. *Eur J Public Health* 2013;23(1):30-32.

7. Basterfield L, Adamson AJ, Frary JK, Parkinson KN, Pearce MS and Reilly JJ. Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics* 2011;127(1):e24-30.

8. Carson V and Janssen I. Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. *BMC Public Health* 2011;11(1):1-10.

371 9. Colley RC, Garriguet D, Janssen I*, et al.* The association between accelerometer-
372 measured patterns of sedentary time and health risk in children and youth: results from the
373 Canadian Health Measures Survey. *BMC Public Health* 2013;13(1):1-9.
374 10. Bailey DP, Charman SJ, Ploetz T, Savory LA and Kerr CJ. Associations between
375 prolonged sedentary time and breaks in sedentary time with cardiometabolic risk in 10–14-
376 year-old children: The HAPPY study. *J Sports Sci* 2017;35(22):2164-2171.
377 11. Cliff DP, Jones RA, Burrows TL, Morgan PJ, Collins CE and Baur LA. Volumes and bouts
378 of sedentary behavior and physical activity: associations with cardiometabolic health in obese
379 children. *Obesity* 2014;22:e112-e118.
380 12. Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB and Brage S.
381 Independent associations of physical activity and cardiorespiratory fitness with metabolic risk
382 factors in children: the European youth heart study. *Diabetologia* 2007;50:1832–1840.
383 13. Healy GN, Matthews CE, Dunstan DW, Winkler EA and Owen N. Sedentary time and
384 cardio-metabolic biomarkers in US adults: NHANES 2003-06. *European heart journal*
385 2011;32(5):590-597.
386 14. Altenburg TM, de Niet M, Verloigne M*, et al.* Occurrence and duration of various
387 operational definitions of sedentary bouts and cross-sectional associations with
388 cardiometabolic health indicators: the ENERGY-project. *Prev med* 2015;71:101-106.
389 15. Saunders TJ, Chaput J-P, Goldfield GS*, et al.* Prolonged sitting and markers of
390 cardiometabolic disease risk in children and youth: A randomized crossover study.
391 *Metabolism* 2013;62(10):1423-1428.
392 16. Saunders TJ, Tremblay MS, Mathieu ME*, et al.* Associations of sedentary behavior,
393 sedentary bouts and breaks in sedentary time with cardiometabolic risk in children with a
394 family history of obesity. *PloS one* 2013;8(11):e79143.

17. Carson V, Stone M and Faulkner G. Patterns of sedentary behavior and weight status among children. *Ped Ex Sci* 2014;26(1):95-102.

18. Cooper AR, Goodman A, Page AS*, et al.* Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). *IJBNPA* 2015;12(1):113.

19. Janssen X, Mann KD, Basterfield L*, et al.* Development of sedentary behavior across childhood and adolescence: longitudinal analysis of the Gateshead Millennium Study. *IJBNPA* 2016;13(1):1-10.

20. Tanner JM. *Growth at adolescence; with a general consideration of the effects of hereditary and environmental factors upon growth and maturation from birth to maturity.* Oxford: Blackwell Scientific Publications; 1962.

21. Department for Communities and Local Government. English indices of deprivation 2015. 2015; www.imd-by-postcode.opendatacommunities.org. Accessed 30 June, 2017.

22. Cole TJ, Freeman JV and Preece MA. Body mass index reference curves for the UK, 1990. *Arch Dis Child* 1995;73(1):25-29.

23. Parikh P, Mochari H and Mosca L. Clinical Utility of a Fingerstick Technology to Identify Individuals with Abnormal Blood Lipids and High-Sensitivity C-Reactive Protein Levels. *Am J Health Promot* 2009;23(4):279-282.

24. Ahrens W, Moreno LA, Marild S*, et al.* Metabolic syndrome in young children: definitions and results of the IDEFICS study. *I J Obesity* 2014;38:S4-14.

25. Ragland DR. Dichotomizing continuous outcome variables: dependence of the magnitude of association and statistical power on the cutpoint. 1992;3(5):434-440.

26. Zimmet P, Alberti KG, Kaufman F*, et al.* The metabolic syndrome in children and adolescents - an IDF consensus report. *Pediatr Diabetes* 2007;8(5):299-306.

27. National Cholesterol Education Program Expert Panel on Blood Cholesterol Levels in Children and Adolescents. National Cholesterol Education Program (NCEP): Highlights of the Report of the Expert Panel on Blood Cholesterol Levels in Children and Adolescents. *Pediatrics* 1992;89(3):495-501.

28. Cook S, Weitzman M, Auinger P, Nguyen M and Dietz WH. Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third National Health and Nutrition Examination Survey, 1988-1994. *Arch Pediatr Adolesc Med* 2003;157(8):821-827.

29. Harrington DM, Dowd KP, Bourke AK and Donnelly AE. Cross-sectional analysis of levels and patterns of objectively measured sedentary time in adolescent females. *IJBNPA* 2011;8(120):1-7.

30. Ryan CG, Grant PM, Tigbe WW and Granat MH. The validity and reliability of a novel activity monitor as a measure of walking. *British journal of sports medicine* 2006;40(9):779-784.

31. Aminian S and Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. *BioMed Cent* 2012;9(119):1-9.

32. Winkler EA, Bodicoat DH, Healy GN*, et al.* Identifying adults' valid waking wear time by automated estimation in activPAL data collected with a 24 h wear protocol. *Physiol Meas* 2016;37(10):1653-1668.

33. Altenburg TM and Chinapaw MJ. Bouts and breaks in children's sedentary time: currently used operational definitions and recommendations for future research. *Prev med* 2015;77:1-3.

34. Department of Health. Start Active, Stay Active: a report on physical activity for health from the four home countries' Chief Medical Officers.

www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_128210.pdf. Accessed 14 July 2011. 2011.

35. Rocha NP, Milagres LC, Longo GZ, Ribeiro AQ and Novaes JF. Association between dietary pattern and cardiometabolic risk in children and adolescents: a systematic review. *Jornal de pediatria* 2017;93(3):214-222.

36. Rauber F, Campagnolo PDB, Hoffman DJ and Vitolo MR. Consumption of ultra-processed food products and its effects on children's lipid profiles: A longitudinal study. *Nutr Metab Cardiovasc Dis* 2015;25(1):116-122.

37. Mann KD, Howe LD, Basterfield L*, et al.* Longitudinal study of the associations between change in sedentary behavior and change in adiposity during childhood and adolescence: Gateshead Millennium study. *I J Obesity* 2017;41(7):1042-1047.

38. Chastin SF and Granat MH. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. *Gait Posture* 2009;31:82-86.

456 **Table 1. Anthropometric and cardiometabolic risk marker descriptives**

	All (n=118)	Boys (n=51)	Girls (n=67)
Height (cm)	154.3 ± 7.2	153.4 ± 6.6	154.9 ± 7.5
Weight (kg)	45.3 ± 11.3	43.7 ± 10.4	46.5 ± 11.9
Body mass index (kg/m^2)	18.9 ± 3.9	18.5 ± 3.5	19.3 ± 4.4
Body mass index z-score	0.01 ± 1.02	-0.12 ± 0.89	0.10 ± 1.10
Body fat%	23.3 ± 7.1	21.3 ± 6.9	24.9 ± 6.9
Waist circumference (cm)	67.3 ± 10.1	67.6 ± 9.0	67.0 ± 10.9
Systolic blood pressure (mmHg)	104 ± 10.93	101 ± 11.17	107 ± 10.18
Diastolic blood pressure (mmHg)	67 ± 7.62	65 ± 7.41	68 ± 7.64
Total cholesterol (mmol · L^{-1})	5.94 ± 2.79	5.76 ± 2.65	6.08 ± 2.90
HDL (mmol · L^{-1})	2.12 ± 1.08	2.18 ± 1.08	2.07 ± 1.08
Triglycerides (mmol · L^{-1})	1.50± 1.53	1.26 ± 1.30	1.68 ± 1.67
LDL (mmol · L^{-1})	3.36 ± 1.76	3.21 ± 1.61	3.47 ± 1.87
Non-HDL (mmol · L^{-1})	3.82 ± 1.93	3.59 ± 1.74	3.99 ± 2.05
TC:HDL ratio	2.93 ± 0.80	2.72 ± 0.46	3.09 ± 0.95
Glucose (mmol · L^{-1})	4.96 ± 0.49	4.93 ± 0.43	4.98 ± 0.53
Clustered risk score	0.01 ± 3.08	-0.54 ± 2.46	0.44 ± 3.44
Non-obesity clustered risk score	0.56 ± 2.58	-0.59 ± 2.03	0.55 ± 2.85

457 Data presented as mean ± SD.

458 HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; TC, total
459 cholesterol.

460 n=115 for blood parameters.

461 **Table 2. Sitting, standing and stepping descriptives**

	All (n=118)	Boys (n = 51)	Girls (n = 67)
activPAL weartime (minutes/day)	849.91 ± 42.6	852.00 ± 42.6	848.40 ± 42.6
Total sitting time (minutes/day)	522.60 ± 67	513.60 ± 1.13	529.20 ± 52.3
Standing time (minutes/day)	177.00 ± 39.6	165.60 ± 45.6	185.40 ± 31.8
Light physical activity (minutes/day)	60.60 ± 15	69.60 ± 13.2	54.00 ± 12.6
MVPA (minutes/day)	90.00 ± 24	103.20 ± 22.2	79.80 ± 19.8
Number of breaks in sitting per day	81.32 ± 11.50	82.71 ± 17.66	80.26 ± 19.17
Number of prolonged sitting bouts	3.7 ± 1.2	3.6 ± 1.4	3.8 ± 1.1
Time spent in prolonged sitting bouts (minutes/day)	265.91 ± 93	262.63 ± 107.4	268.42 ± 81.6

462 Data presented as mean ± SD.

463 MVPA, moderate-to-vigorous physical activity

Table 3. Associations of sitting variables, standing and light physical activity with cardiometabolic risk markers in 11-12-year-old children (Model 1)

	Standing time (minutes/ day)	Light physical activity (minutes/ day)	Number of breaks in sedentary time per day	Total time in prolonged sedentary bouts (minutes/day)
Weight[a] (kg)	-.253 (-.074, -.001)*	-.141 (-.156, .049)	-.591 (-.005, -.002)***	-.590 (-.057, -.016)***
BMI[a] (kg/m^2)	-.150 (-.049, .013)	-.149 (-.133, .041)	-.526 (-.004, -.001)***	-.581 (-.047, -.012)***
WC[a] (cm)	-.252 (-.048, .001)	-.084 (-.089, .050)	-.514 (-.003, -.001)**	-.473 (-.032, -.004)*
Body Fat%	-.274 (-5.615, -.260)*	-.310 (-16.012, -.934)*	-.497 (-.299, -.075)***	-.624 (-4.300, -1.265)***
Systolic Blood Pressure (mmHg)	.097 (-2.742, 6.013)	-.098 (-16.550, 8.100)	-.177 (-.288, .077)	-.151 (-3.534, 1.411)
Diastolic Blood Pressure (mmHg)	-.056 (-2.603, 3.932)	-.021 (-9.839, 8.563)	-.070 (-.165, .108)	.037 (-1.664, 2.027)
TC (mmol · L^{-1})	.241 (-.023, 2.041)	-.051 (-3.538, 2.428)	.343 (.007, .095)*	.421 (.126, 1.348)*
HDL (mmol · L^{-1})	.309 (.115, .898)*	-.152 (-1.786, .479)	.404 (.007, .040)**	.417 (.054, .518)*
Triglycerides (mmol · L^{-1})	.151 (-.290, 1.002)	-.145 (-2.760, .974)	.186 (-.012, .043)	.134 (-.250, .515)
LDL (mmol · L^{-1})	.162 (-.249, 1.103)	.032 (-1.733, 2.175)	.264 (-.004, .054)	.374 (.011, .811)*
Non-HDL (mmol · L^{-1})	.178 (-.235, 1.263)	.005 (-2.128, 2.201)	.272 (-.004, .060)	.376 (.011, .898)*
TC:HDL[a]	-.119 (-.064, .026)	.157 (-.063, .196)	-.145 (-.003, .001)	-.021 (-.028, .025)
Glucose (mmol · L^{-1})	.163 (-.077, .320)	-.228 (-1.022, .126)	.148 (-.005, .012)	.339 (-.012, .223)
Clustered risk score	-.002 (-1.341, 1.321)	-.105 (-5.145, 2.551)	-.130 (-.079, .035)	.003 (-.783, .793)
Non-obesity clustered risk score	.078 (-.801, 1.418)	-.100 (-4.244, 2.170)	.008 (-.046, .049)	.137 (-.430, .883)

Standardised beta values from multiple regression. Data are standardised regression coefficients (95% CI). All outcomes are adjusted for sex, IMD score, school and Tanner stage, total sedentary time and weartime.

[a] log-transformed

*p≤0.05 **p≤0.01 ***p≤0.001

BMI, body mass index; WC, waist circumference; TC, total cholesterol; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; non-HDL, non-high-density lipoprotein cholesterol; TC:HDL, total cholesterol to high-density lipoprotein cholesterol ratio.

Table 4. Associations of sitting variables, standing and light physical activity with cardiometabolic risk markers in 11-12-year-old children additionally adjusting for moderate-to-vigorous physical activity (Model 2)

	Standing time (minutes/ day)	Light physical activity (minutes/ day)	Number of breaks in sedentary time per day	Total time in prolonged sedentary bouts (minutes/ day)
Weight[a] (kg)	-.270 (-.076, -.004)*	-.013 (-.118, .109)	-.661 (-.005, -.002)***	-.678 (-.063, -.021)***
BMI[a] (kg/m^2)	-.168 (-.051, .010)	-.012 (-.100, .093)	-.601 (-.004, -.001)***	-.675 (-.052, -.016)***
WC[a] (cm)	-.272 (-.049, -.001)* [b]	.069 (-.060, .093)	-.597 (-.003, -.001)***	-.577 (-.036, -.008)***
Body Fat%	-.286 (-5.741, -.388)*	-.220 (-14.447, 2.424) [b]	-.546 (-.321, -0.90) ***	-.685 (-4.629, -1.495)***
Systolic Blood Pressure (mmHg)	.090 (-2.882, 5.921)	-.046 (-15.855, 11.887)	-.206 (-.312, .067)	-.186 (-3.889, 1.265)
Diastolic Blood Pressure (mmHg)	.072 (-2.406, 4.104)	-.140 (-14.476, 6.041)	-.005 (-.142, .138)	.118 (-1.325, 2.487)
TC (mmol · L^{-1})	.239 (-.045, 2.041)	-.037 (-3.755, 2.947)	.334 (.003, .096)*	.410 (.070, 1.363)*
HDL (mmol · L^{-1})	.312 (.116, .907)*	-.169 (-2.000, .543)	.415 (.007, .042)**	.432 (.051, .542)*
Triglycerides (mmol · L^{-1})	.137 (-.328, .971)	-.067 (-2.499, 1.673)	.134 (-.018, .040)	.069 (-.335, .470)
LDL (mmol · L^{-1})	.160 (-.261, 1.105)	.043 (-1.899, 2.491)	.257 (-.006, .054)	.365 (-.022, .824) [b]
Non-HDL (mmol · L^{-1})	.172 (-.259, 1.254)	.034 (-2.172, 2.688)	.253 (-.008, .060)	.351 (-.044, .893) [b]
TC:HDL[a]	-.129 (-.066, .024)	.210 (-.056, .234)	-.180 (-.003, .001)	-.066 (-.032, .024)
Glucose (mmol · L^{-1})	.158 (-.082, .319)	-.203 (-1.041, .247)	.131 (-.005, .012)	.317 (-.025, .223)
Clustered risk score	-.014 (-1.407, 1.275)	-.042 (-4.834, 3.783)	-.172 (-.088, .031)	-.050 (-.930, .732)
Non-obesity clustered risk score	.072 (-.835, 1.406)	-.070 (-4.321, 2.879)	-.013 (-.052, .048)	.111 (-.511, .878)

Standardised beta values from multiple regressions. Data are standardised regression coefficients (95% CI). All outcomes are adjusted for sex, IMD score, school and Tanner stage, total sedentary time, weartime and moderate-to-vigorous physical activity.

[a] log-transformed [b] Different from Partially adjusted regression model

*p≤0.05 **p≤0.01 ***p≤0.001

BMI, body mass index; WC, waist circumference; TC, total cholesterol; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; non-HDL, non-high-density lipoprotein cholesterol; TC:HDL, total cholesterol to high-density lipoprotein cholesterol ratio.