

## Sitting behaviour and cardiometabolic risk

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

3

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13

14 **Abstract**

15 **Background:** The objective of this study was to investigate the associations between  
16 sedentary behaviour patterns and cardiometabolic risk in children using a monitor that  
17 accurately distinguishes between different postures. **Methods:** In this cross-sectional study,  
18 118 children (67 girls) aged 11-12-years had adiposity, blood pressure, lipids and glucose  
19 measured and then wore an activPAL device to record sitting, standing and stepping for seven  
20 consecutive days. Data was analysed using multiple linear regression. **Results:** After  
21 adjustment for potential confounders and moderate-to-vigorous physical activity, the number  
22 of breaks in sitting was significantly negatively associated with adiposity (standardised  $\beta$ ≥-  
23 0.546;  $p$ ≤0.001) and significantly positively associated with high-density lipoprotein cholesterol  
24 (HDL) ( $\beta$ =0.415;  $p$ ≤0.01). Time in prolonged sitting bouts was significantly negatively  
25 associated with adiposity ( $\beta$ ≥-0.577;  $p$ ≤0.001) and significantly positively associated with HDL  
26 ( $\beta$ =0.432;  $p$ ≤0.05). Standing time was significantly negatively associated with adiposity ( $\beta$ ≥-  
27 0.270;  $p$ ≤0.05) and significantly positively associated with HDL ( $\beta$ =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

## 32 **Background**

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

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

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

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

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

84

## 85 **Methods**

### 86 Study design

87 This was a cross-sectional study design across schools in Bedfordshire, UK. Data collection  
88 took place in spring 2017 and the study was approved by the University of Bedfordshire  
89 Institute for Sport and Physical Activity Research Ethics Committee (approval number  
90 2017ISPAR001). Other than measurement of sitting, standing and stepping, all other  
91 measures took place at the children's schools.

92

### 93 Participants

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

100

### 101 Recruitment

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

112

### 113 Measurements

114 *Biological maturity and socioeconomic status*

115 Biological maturity was self-reported using the Tanner scale<sup>20</sup> 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<sup>21</sup>.

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:  $BMI = \text{body mass (kg)} \div \text{height (m}^2\text{)}$ . BMI z-  
126 score was calculated using UK reference values<sup>22</sup>. 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<sup>10</sup>.

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  $\mu$ l) 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<sup>23</sup> and has been used in previous paediatric research<sup>10,24</sup>.  
139 A continuous clustered cardiometabolic risk score was calculated by summing the z-scores  
140 for WC, DBP, TC:HDL ratio, triglycerides and glucose<sup>10</sup>. A non-obesity clustered  
141 cardiometabolic risk score was calculated by summing the z-scores for DBP, TC:HDL ratio,  
142 triglycerides and glucose<sup>12</sup>. These clustered risk scores were calculated as they provide

143 greater statistical power<sup>25</sup>, account for daily variations in individual risk markers and have  
144 previously been used in paediatric research<sup>10,12,16</sup> Impaired fasting glucose was defined as  $\geq$   
145  $5.6 \text{ mmol} \cdot \text{L}^{-126}$ . Hypercholesterolemia was defined as  $\geq 5.17 \text{ mmol} \cdot \text{L}^{-127}$ . Triglycerides were  
146 considered high between  $1.02 - 1.46 \text{ mmol} \cdot \text{L}^{-1}$  and HDL considered low between  $0.91 - 1.16$   
147  $\text{mmol} \cdot \text{L}^{-127}$ . The present study defined hypertriglyceridemia as  $\geq 1.24 \text{ mmol} \cdot \text{L}^{-1}$  and low HDL  
148 as  $\leq 1.03 \text{ mmol} \cdot \text{L}^{-1}$  as this is the mid-point between these ranges<sup>10,28</sup>.

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<sup>29</sup>. The monitor categorises each  
159 15 s epoch as sitting/lying, standing or stepping<sup>30</sup>. 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<sup>31</sup>.

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)<sup>32</sup>. Inclusion  
166 criteria for valid wear time was a minimum of four days including at least one weekend day<sup>29</sup>.  
167 A valid day was required to have a minimum of 10 hours wear time and  $>500$  steps<sup>29,32</sup>. A  
168 prolonged sitting bout was defined as a period  $\geq 30$  minutes in a sitting/reclining posture  
169 during waking time in line with previous studies<sup>8,14</sup>. A break in sitting was defined as a non-

170 sitting period in between two sitting bouts<sup>33</sup>. All variables were calculated for each valid day  
171 and then averaged across all included valid days for analysis.

172

### 173 Statistical analysis

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

187

### 188 **Results**

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

196 Anthropometric and cardiometabolic risk marker descriptive characteristics are shown  
197 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<sup>34</sup> was  $91.5 \pm 0.4\%$ .

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

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

249 In the present study, time spent in prolonged sitting bouts was significantly positively  
250 associated with LDL and non-HDL, however, this association was attenuated by MVPA. This  
251 suggests that MVPA may protect against high levels of LDL in children who spend more time  
252 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<sup>37</sup>. However, the  
259 number of breaks in sitting was significantly positively associated with TC 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<sup>16</sup>.  
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.*<sup>16</sup> 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.

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

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

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

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

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

331 **Conclusions**

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

340

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454 analysis of sedentary behaviour and inactivity. *Gait Posture* 2009;31:82-86.

455

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 <sup>2</sup> )	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 <sup>-1</sup> )	5.94 ± 2.79	5.76 ± 2.65	6.08 ± 2.90
HDL (mmol · L <sup>-1</sup> )	2.12 ± 1.08	2.18 ± 1.08	2.07 ± 1.08
Triglycerides (mmol · L <sup>-1</sup> )	1.50 ± 1.53	1.26 ± 1.30	1.68 ± 1.67
LDL (mmol · L <sup>-1</sup> )	3.36 ± 1.76	3.21 ± 1.61	3.47 ± 1.87
Non-HDL (mmol · L <sup>-1</sup> )	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 <sup>-1</sup> )	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 wear time (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

464 **Table 3. Associations of sitting variables, standing and light physical activity with cardiometabolic risk markers in 11-12-year-old**  
 465 **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 <sup>a</sup> (kg)	-.253 (-.074, -.001)*	-.141 (-.156, .049)	-.591 (-.005, -.002)***	-.590 (-.057, -.016)***
BMI <sup>a</sup> (kg/m <sup>2</sup> )	-.150 (-.049, .013)	-.149 (-.133, .041)	-.526 (-.004, -.001)***	-.581 (-.047, -.012)***
WC <sup>a</sup> (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 <sup>-1</sup> )	.241 (-.023, 2.041)	-.051 (-3.538, 2.428)	.343 (.007, .095)*	.421 (.126, 1.348)*
HDL (mmol · L <sup>-1</sup> )	.309 (.115, .898)*	-.152 (-1.786, .479)	.404 (.007, .040)**	.417 (.054, .518)*
Triglycerides (mmol · L <sup>-1</sup> )	.151 (-.290, 1.002)	-.145 (-2.760, .974)	.186 (-.012, .043)	.134 (-.250, .515)
LDL (mmol · L <sup>-1</sup> )	.162 (-.249, 1.103)	.032 (-1.733, 2.175)	.264 (-.004, .054)	.374 (.011, .811)*
Non-HDL (mmol · L <sup>-1</sup> )	.178 (-.235, 1.263)	.005 (-2.128, 2.201)	.272 (-.004, .060)	.376 (.011, .898)*
TC:HDL <sup>a</sup>	-.119 (-.064, .026)	.157 (-.063, .196)	-.145 (-.003, .001)	-.021 (-.028, .025)
Glucose (mmol · L <sup>-1</sup> )	.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)

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

468 <sup>a</sup> log-transformed

469 \*p≤0.05      \*\*p≤0.01      \*\*\*p≤0.001

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

472 **Table 4. Associations of sitting variables, standing and light physical activity with cardiometabolic risk markers in 11-12-year-old**  
 473 **children additionally adjusting for moderate-to-vigorous physical activity (Model 2)**  
 474

	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 <sup>a</sup> (kg)	-.270 (-.076, -.004)*	-.013 (-.118, .109)	-.661 (-.005, -.002)***	-.678 (-.063, -.021)***
BMI <sup>a</sup> (kg/m <sup>2</sup> )	-.168 (-.051, .010)	-.012 (-.100, .093)	-.601 (-.004, -.001)***	-.675 (-.052, -.016)***
WC <sup>a</sup> (cm)	-.272 (-.049, -.001)* <sup>b</sup>	.069 (-.060, .093)	-.597 (-.003, -.001)***	-.577 (-.036, -.008)***
Body Fat%	-.286 (-5.741, -.388)*	-.220 (-14.447, 2.424) <sup>b</sup>	-.546 (-.321, -.090)***	-.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 <sup>-1</sup> )	.239 (-.045, 2.041)	-.037 (-3.755, 2.947)	.334 (.003, .096)*	.410 (.070, 1.363)*
HDL (mmol · L <sup>-1</sup> )	.312 (.116, .907)*	-.169 (-2.000, .543)	.415 (.007, .042)**	.432 (.051, .542)*
Triglycerides (mmol · L <sup>-1</sup> )	.137 (-.328, .971)	-.067 (-2.499, 1.673)	.134 (-.018, .040)	.069 (-.335, .470)
LDL (mmol · L <sup>-1</sup> )	.160 (-.261, 1.105)	.043 (-1.899, 2.491)	.257 (-.006, .054)	.365 (-.022, .824) <sup>b</sup>
Non-HDL (mmol · L <sup>-1</sup> )	.172 (-.259, 1.254)	.034 (-2.172, 2.688)	.253 (-.008, .060)	.351 (-.044, .893) <sup>b</sup>
TC:HDL <sup>a</sup>	-.129 (-.066, .024)	.210 (-.056, .234)	-.180 (-.003, .001)	-.066 (-.032, .024)
Glucose (mmol · L <sup>-1</sup> )	.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)

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

477 <sup>a</sup> log-transformed <sup>b</sup> Different from Partially adjusted regression model

478 \*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001

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