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8 **Longitudinal and cross-sectional associations of adherence to 24-hour movement guidelines**  
9 **with cardiometabolic risk**

10

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28 **ABSTRACT**

29

30 This study aimed to examine 1) adherence to 24-hour movement guidelines over a 2-year follow-  
31 up in children aged 6-8 years and 2) association of this adherence with cardiometabolic risk  
32 factors. Physical activity and sleep were assessed by a monitor combining heart rate and  
33 accelerometry measurements. Screen time was reported by the parents. Body fat percentage, waist  
34 circumference, blood glucose, serum insulin, plasma lipids and blood pressure were assessed, and  
35 a cardiometabolic risk score was calculated using z-scores. Children were classified as meeting the  
36 guidelines if they had on average  $\geq 60$ min/day of moderate-to-vigorous physical activity during the  
37 valid days;  $\leq 120$ min/day of screen time; and 9–11h/day of sleep. In total, 485 children had valid  
38 data at baseline or at 2-year follow-up. Analyses were conducted using adjusted logistic and linear  
39 regression models. Most children adhered to the 24-hour movement guidelines at baseline, but the  
40 adherence decreased over the 2-year follow-up. Meeting physical activity guidelines individually,  
41 or in combination with screen time and/or sleep, was longitudinally associated with a lower  
42 cardiometabolic risk score, insulin and waist circumference, and cross-sectionally additionally  
43 with lower diastolic blood pressure and higher high-density lipoprotein cholesterol. However,  
44 these associations became statistically non-significant after adjustment for body fat. In conclusion,  
45 meeting 24-hour movement guidelines at baseline increases the odds of meeting them at 2-year  
46 follow-up in school-aged children. Furthermore, meeting 24-hour movement guidelines is  
47 associated with lower levels of cardiometabolic risk factors, but these associations are partly  
48 explained by lower body fat. Thus, promoting movement behaviors, especially physical activity,  
49 and healthy weight in early childhood is important in supporting cardiometabolic health in  
50 children.

51

52 **Clinical Trial Registration:** [clinicaltrials.gov](https://clinicaltrials.gov) NCT01803776

53 **Keywords:** body fat, metabolic profile, movement guidelines, paediatrics, prospective

## 54 INTRODUCTION

55

56 Engaging in sufficient levels of physical activity (PA), limiting screen time (ST), and having a  
57 sufficient amount of sleep have been associated with numerous health benefits in children.<sup>1-3</sup>  
58 Current 24-hour movement guidelines recommend that a healthy 24-hour day in school-aged  
59 children should include 1) at least 60 minutes of moderate-to-vigorous PA (MVPA), 2) no more  
60 than two hours of ST, and 3) 9–11 hours of sleep.<sup>4,5</sup> However, only 2.0 to 14.9% of children aged  
61 9-11 years from 12 countries participating in the large International Study of Childhood Obesity,  
62 Lifestyle and the Environment (ISCOLE) met all these recommendations for MVPA, ST, and  
63 sleep.<sup>6</sup> Adherence to the 24-hour movement guidelines may track over time in preschool-aged  
64 children,<sup>7</sup> but not among students,<sup>8</sup> while such knowledge in school-aged children remains scarce.

65 Pathophysiological processes for cardiovascular diseases, the main cause of  
66 premature mortality worldwide,<sup>9</sup> start already in childhood.<sup>10</sup> Metabolic syndrome, referring to a  
67 cluster of cardiometabolic risk factors, including central obesity, insulin resistance,  
68 hyperglycemia, hypertriglyceridemia, low plasma high-density lipoprotein (HDL) cholesterol and  
69 hypertension, has been found to increase the risk of subclinical and clinical cardiovascular  
70 diseases in adults.<sup>11</sup> A large systematic review<sup>12</sup> estimated that the prevalence of childhood  
71 metabolic syndrome varies between 0 and 29% in different study populations, highlighting a need  
72 to clarify lifestyle-related factors that contribute to this variability.

73 There are few earlier studies on the combined association of movement behaviors,  
74 including PA, ST, and sleep, with cardiometabolic risk factors,<sup>13,14</sup> and most of them have been  
75 cross-sectional.<sup>13,14</sup> Studies in Canada<sup>13</sup> and the United States<sup>14</sup> have reported that children and  
76 youth who met a larger number of 24-hour movement guidelines had lower serum triglycerides  
77 (TG) and insulin,<sup>13,14</sup> higher serum HDL cholesterol,<sup>13</sup> and lower systolic blood pressure (SBP)  
78 than those meeting a smaller number of these guidelines.<sup>13</sup> In a longitudinal study among children  
79 in Denmark,<sup>15</sup> a combination of decreased MVPA and sleep duration and increased ST was  
80 associated with a 3.3 unit increase in the metabolic syndrome score over a 200-day follow-up  
81 compared with increased MVPA and sleep duration and decreased ST. Meeting the 24-hour  
82 movement guidelines has also been associated with a lower z-score for body mass index (BMI),<sup>6</sup>  
83 higher aerobic fitness,<sup>13</sup> and better health-related quality of life.<sup>16</sup> Thus, it is important to increase  
84 knowledge on the role of combined movement behaviors in supporting health in children and how  
85 fat mass may be related to it.



86 The longitudinal associations of adherence to the current 24-hour movement  
87 guidelines with cardiometabolic risk factors are unknown. We therefore examined individual and  
88 combined adherence to these guidelines at baseline, tracking of the adherence over a 2-year  
89 follow-up, and how the adherence is related to cardiometabolic risk factors cross-sectionally and  
90 longitudinally. In addition, we investigated whether differences in body fat may explain the  
91 associations of adherence to these guidelines with cardiometabolic risk factors.

92

## 93 **MATERIALS AND METHODS**

94

### 95 **Participants and Study Design**

96 The present study is a secondary analysis utilizing baseline and 2-year follow-up data from the  
97 Physical Activity and Nutrition in Children (PANIC) study (ClinicalTrials.gov NCT01803776)  
98 that is an 8-year PA and dietary intervention study in a population sample of children from the city  
99 of Kuopio, Finland.<sup>17</sup> The Research Ethics Committee of the Hospital District of Northern Savo  
100 approved the study protocol in 2006 (Statement 69/2006). The parents or caregivers of the  
101 children gave their written informed consent, and the children provided their assent to  
102 participation. We invited 736 children 6-8 years of age who started the first grade in 16 primary  
103 schools of the city of Kuopio in 2007-2009. Of those children, 512 (69.6%) had data on PA, ST, or  
104 sleep. The current study population consists of 249 boys (51.3%) and 236 girls (48.7%) with  
105 complete data on PA, ST, and sleep duration at baseline or at 2-year follow-up. The included  
106 children did not differ in terms of cardiometabolic risk factors from the children who were  
107 excluded.

108

### 109 **Assessment of movement behaviors**

110 PA was assessed using a combined heart rate and body movement sensor Actiheart® (CamNtech  
111 Ltd., Papworth, UK) for a minimum of four consecutive days and analyzed in 60 second epochs.<sup>18</sup>  
112 The combined heart rate and movement sensor were attached to the child's chest with two  
113 standard electrocardiographic electrodes (Bio Protech Inc., Wonju, South Korea). The children  
114 were asked to wear the monitor continuously, including sleep and water-based activities. Heart  
115 rate data were cleaned<sup>19</sup> and individually calibrated using parameters obtained from the maximal  
116 cycle exercise test,<sup>20</sup> and were combined with movement sensor data to derive PA energy  
117 expenditure. Instantaneous PA energy expenditure was estimated using branched equation

118 modelling<sup>21</sup> and expressed as time spent at intensity levels of standard metabolic equivalents  
119 (METs), one MET corresponding to 71.2 J/min/kg, in minutes per day. In the current analyses,  
120 MVPA was defined as PAs at  $\geq 4$  METs. PA data were accepted as a valid day if there was a  
121 minimum of 48 h of activity recording in weekday and weekend day hours that included at least  
122 12 h from morning (3–9 am), noon (9 am–3 pm), afternoon (3–9 pm), and night (9 pm–3 am) to  
123 avoid potential bias from over-representing specific times and activities of the days. The children  
124 were defined reaching the PA guidelines if they had at least 60 minutes of MVPA per day as an  
125 average of the valid registered days.<sup>4,5</sup>

126 ST separately over weekdays and weekend days was assessed by the PANIC  
127 Physical Activity Questionnaire that was filled out by the parents together with their child.<sup>22</sup> The  
128 types of ST in our analyses included watching television and videos, using computer and playing  
129 video and console games, and using mobile phone and playing mobile games. Time spent in ST  
130 was calculated by summing up times spent in each type of activity and expressed in hours per  
131 week weighted by the number of weekdays and weekend days. The children were defined  
132 reaching the ST guidelines if they had no more than two hours of ST per day.<sup>4,5</sup>

133 Sleep duration was inferred from the combined heart rate and movement data by a  
134 trained exercise specialist and was confirmed by a physician, was subtracted from sedentary time  
135 to obtain the final sleep duration for the analyses.<sup>23</sup> The time of falling asleep was defined as  
136 accelerometer counts decreasing to zero and heart rate to a plateau level. The time of waking up  
137 was defined as accelerometer counts increasing and remaining above zero and heart rate  
138 increasing and remaining above the plateau level. The children were defined reaching the sleep  
139 guidelines if they had 9–11 hours of sleep per night.<sup>4,5</sup>

140

#### 141 **Assessment of cardiometabolic risk factors**

142 A research nurse took blood samples in the morning after a 12-hour overnight fast. Plasma glucose  
143 was measured by a hexokinase method, serum insulin by an electrochemiluminescence  
144 immunoassay, plasma TG by a colorimetric enzymatic assay, and plasma HDL cholesterol by a  
145 homogeneous colorimetric enzymatic assay.<sup>24</sup> SBP and diastolic blood pressure (DBP) were  
146 measured from the right arm using the Heine Gamma G7<sup>®</sup> aneroid sphygmomanometer (Heine  
147 Optotechnik, Herrsching, Germany) to the accuracy of 2 mm Hg. The measurement protocol  
148 included a 5-minute seated resting period followed by three measurements with 2-minute intervals  
149 in between. The average of all three values was used for both SBP and DBP.

150 Body weight was measured using a calibrated InBody 720<sup>®</sup> bioelectrical impedance  
151 device (Biospace, Seoul, South Korea). Height was measured using a wall-mounted stadiometer  
152 without shoes. BMI was calculated by dividing body weight (kg) by height (m) squared, and BMI-  
153 SDS was obtained using Finnish reference values.<sup>25</sup> The prevalence of normal weight, overweight,  
154 and obesity were defined using the cut-off values provided by Cole and Lobstein.<sup>26</sup> Waist  
155 circumference (WC) was measured at mid-distance between the bottom of the rib cage and the top  
156 of the iliac crest, and the mean of the closest two values was used in the analyses. Body fat  
157 percentage (BF%) was measured using the Lunar<sup>®</sup> dual-energy X-ray absorptiometry device (GE  
158 Medical Systems, Madison, Wisconsin, USA).<sup>27</sup>

159 A continuous cardiometabolic risk score (CRS) was calculated as the sum of  
160 population-specific z-scores of WC, insulin, glucose, TG, HDL cholesterol, and the mean of SBP  
161 and DBP.<sup>24</sup> The z-score of HDL cholesterol was multiplied by -1 due to its inverse association  
162 with cardiometabolic risk. A higher CRS indicates a less favourable cardiometabolic risk profile.

163

#### 164 **Assessment of covariates**

165 The education of the more educated parent was used as parental education (categorized as low  
166 [vocational school or less], middle [polytechnic], or high [university degree]). The children were  
167 allocated to the intervention group (N=293, 60.4%) and the control group (N=192, 39.6%) after  
168 the baseline measurements.<sup>28</sup> The combined PA and dietary intervention consisted of six  
169 intervention visits during the 2-year follow-up. The children and their parents received  
170 individualized advice regarding PA and diet from a specialist in exercise medicine and a clinical  
171 nutritionist. The intervention and control groups were merged in the present analyses. Food  
172 consumption as well as energy and nutrient intake were assessed by food records administered by  
173 the parents on four predefined consecutive days, including two weekdays and two weekend days  
174 (99%) or three weekdays and one weekend day (1%). The Finnish Children Healthy Eating Index  
175 was used as an indicator of diet quality. The index was calculated by summing the reported  
176 consumption of the following foods based on their quantiles in the present study population:  
177 vegetables, fruit and berries (scored 1–10); high-fat ( $\geq 60\%$ ) vegetable oil-based spreads and  
178 vegetable oils (0–10); low-fat ( $< 1\%$ ) milk (0–9); fish (0–6); and foods with high sugar content  
179 (10–1). The index ranged between 2 and 45, a higher score indicating higher diet quality.<sup>29</sup>

180

#### 181 **Statistical Analysis**

182 The characteristics of the children are provided as arithmetic means (standard deviations, SDs) or  
183 frequencies (percentages, %). The children were categorized as meeting or not meeting 1)  
184 individual movement guidelines, 2) combinations of any two movement guidelines, or 3) all three  
185 movement guidelines at baseline. Logistic regression analyses were used to assess whether  
186 adherence to guidelines at baseline tracked over the 2-year follow-up. All models were adjusted  
187 for age, sex, parental education, and study group at baseline. Furthermore, linear regression  
188 analyses were used to examine the associations of CRS and each cardiometabolic risk factor with  
189 1) individual movement guidelines, 2) combinations of any two movement guidelines, 3) all three  
190 movement guidelines, and 4) the number of movement guidelines met. The models were  
191 conducted both cross-sectionally at baseline and prospectively over the 2-year follow up (i.e.,  
192 association of adherence to movement guidelines with CRS at baseline and with individual  
193 cardiometabolic risk factors at 2-year follow-up). The Model 1 was unadjusted, and in Model 2,  
194 the data were adjusted for sex, age, parental education, and study group at baseline. In additional  
195 analyses, the Model 2 was adjusted for BF%. In the sensitivity analyses, we included also energy  
196 intake and the Finnish Children Healthy Eating Index in the model as possible confounding  
197 factors. However, further adjustment for these dietary factors had no influence on the associations  
198 studied (Data not shown), and thus, we decided not to include them in the final models. All  
199 statistical analyses were performed using the SPSS Statistics software, Version 25 (IBM, Armonk,  
200 NY, USA). Associations with 2-sided p-values of <0.05 were considered statistically significant.

201

## 202 **RESULTS**

203

204 The characteristics of the children at baseline and at 2-year follow-up are described in Table 1.  
205 Out of 448 children with complete data on PA, ST, and sleep duration at baseline, 235 (52.5%)  
206 complied with all three 24-hour movement guidelines (Figure 1), 173 (38.6%) two guidelines, 37  
207 (8.3%) one guideline, and 3 (0.7%) none of the guidelines. Out of 365 children with complete data  
208 on PA, ST, and sleep duration at 2-year follow-up, 91 (24.9%) complied with all three guidelines  
209 (Figure 2), 167 (45.8%) two guidelines, 91 (24.9%) one guideline, and 16 (4.4%) none of the  
210 guidelines.

211

### 212 **Adherence to the 24-hour movement guidelines**

213 Children who met all three 24-hour movement guidelines at baseline had 3.4 (95% confidence  
214 interval [CI] 1.97 to 6.02) times higher odds of meeting the guidelines also at 2-year follow-up  
215 compared with children who did not meet the guidelines at baseline after adjustments ( $P<0.001$ ).  
216 Similarly, children who met the PA guidelines at baseline had 2.5 (95% CI 1.41 to 4.56) times  
217 higher odds of meeting the PA guidelines also at 2-year follow-up compared with children who  
218 did not meet the PA guidelines at baseline ( $P=0.002$ ). Children who met the ST guidelines at  
219 baseline had 5.0 (95% CI 2.88 to 8.74) times higher odds of meeting the ST guidelines at 2-year  
220 follow-up compared with children who did not meet the ST guidelines at baseline ( $P<0.001$ ).  
221 Meeting the sleep guidelines at baseline was significantly not associated with odds of meeting the  
222 sleep guidelines at 2-year follow-up (OR 1.9, 95% CI 0.87 to 4.32,  $P=0.11$ ).

223

#### 224 **Cross-sectional associations between adherence to the 24-hour movement guidelines and** 225 **cardiometabolic risk factors at baseline**

226 Meeting all three guidelines, the guidelines for PA and ST, the guidelines for PA and sleep, or the  
227 guidelines for PA alone were inversely associated with CRS, WC, and insulin after adjustments  
228 for sex, age, parental education, and study group (Table 2). Similarly, meeting all three guidelines  
229 or the guidelines for PA alone were inversely associated with DBP and directly with HDL  
230 cholesterol. After further adjustment for BF%, the associations were no longer significant  
231 ( $P>0.05$ ). Meeting the guidelines for ST and sleep or for ST alone were inversely associated with  
232 insulin after adjustment for sex, age, parental education, and study group. After further adjustment  
233 for BF%, the associations remained significant (ST+sleep: B -0.54, 95% CI -0.98 to -0.09; ST: B -  
234 0.51, 95% CI -0.99 to -0.03), respectively. Meeting three guidelines compared to two, one or zero  
235 guidelines was inversely associated with CRS, WC, and insulin after adjustment for sex, age,  
236 parental education, and study group (Table 3).

237

#### 238 **Longitudinal associations between adherence to the 24-hour movement guidelines and** 239 **cardiometabolic risk factors**

240 Meeting all three guidelines, the guidelines for PA and ST, or the guidelines for PA alone at  
241 baseline was inversely associated with CRS, WC, and insulin at 2-year follow-up after adjusting  
242 for sex and age, parental education, and study group (Table 4). After further adjustment for BF%,  
243 the associations were no longer significant ( $P>0.05$ ). Meeting three guidelines compared to two,  
244 one, or zero at baseline was inversely associated with CRS and WC at 2-year follow-up after

245 adjusting for sex and age, parental education, and study group (Table 3). In addition, meeting three  
246 guidelines compared to one or zero at baseline was inversely associated with insulin. All  
247 associations became non-significant after further adjustment for BF%.

248

## 249 **DISCUSSION**

250

251 Our study shows that over half of the school-aged children who participated in the PANIC study  
252 met all three 24-hour movement guidelines at baseline, while the proportion was one-fourth two  
253 years later. Meeting the guidelines, for all except sleep, at baseline increased the odds of meeting  
254 the guidelines at 2-year follow-up compared to not meeting the guidelines at baseline.  
255 Furthermore, meeting the guidelines, except for sleep, was cross-sectionally and longitudinally  
256 associated with reduced cardiometabolic risk. However, the associations with cardiometabolic risk  
257 were largely explained by differences in BF%.

258 The proportion of children meeting all three guidelines was higher than the  
259 proportions reported in other studies.<sup>6,13,14,30</sup> The majority of children met the guidelines for sleep,  
260 while the rates were lowest for ST, being still above the rates reported in other studies.<sup>6,13,30</sup> The  
261 decrease in the adherence over the 2-year follow-up was highest regarding sleep, whereas  
262 adherence to ST was moderate and PA did not change remarkably. Varying proportions of  
263 children adhering to the guidelines between the studies may be due to differences in the age of the  
264 participating children, cultural-related practices regarding movement behaviors as well as different  
265 methodologies in assessing movement behaviors. Having a sufficient amount of sleep has been  
266 associated with numerous health benefits in children,<sup>3</sup> and therefore, our finding highlight the  
267 need to promote healthy sleep habits in early childhood. Moreover, the time period from 8 to 10  
268 years may be critical in terms of increasing ST due to entertaining and/or educational reasons.  
269 Since we also found that adherence to guidelines tracked over the 2-year follow-up, the findings  
270 highlight the need to establish good practices already at an early age. Tracking of adherence to 24-  
271 hour movement guidelines has previously been reported in preschool-aged children,<sup>7</sup> but not  
272 among students.<sup>8</sup> Our study shows that the tracking is apparent also in school-aged children,  
273 except what comes to sleep. Therefore, achieving the guidelines already in early childhood may  
274 help to adhere to the guidelines and maintain cardiometabolic health when children get older.

275 To the best of our knowledge, this is the first study investigating longitudinal  
276 associations of adherence to 24-hour movement guidelines with cardiometabolic risk factors.

277 Meeting all the guidelines in which PA was included at baseline were associated with reduced  
278 overall cardiometabolic risk (i.e., CRS) and several individual risk factors (i.e., mainly insulin and  
279 WC) at 2-year follow-up. The findings indicate that PA may be the driver in supporting  
280 cardiometabolic health in midchildhood above and beyond ST and sleep. Using different levels of  
281 each movement behaviors, Hjorth et al.<sup>15</sup> found that lower levels of MVPA and shorter sleep were  
282 associated with an increased cardiometabolic risk profile over 200-day follow-up. Yet, our  
283 findings provide more knowledge on the associations over a longer follow-up period, and indicate  
284 that paying attention to more than one movement behaviour at the same time may optimize the  
285 health benefits in the long-term. However, due to the different methodologies applied between  
286 studies, including differences in follow-up periods, and in the assessment of movement behaviors  
287 and cardiometabolic risk factors, the findings should be confirmed in future studies. Furthermore,  
288 our results showed that body fat influences the associations, which has been found also in Danish  
289 children.<sup>15</sup> In future studies it is also important to investigate more deeply the interactive  
290 associations of body fat and movement behaviors with cardiometabolic risk factors, and to clarify  
291 whether body fat is a mediator or primary cause (i.e., children with overweight have less PA and  
292 sleep as well as more ST leading to increased cardiometabolic risk). Yet, it is evident that  
293 interventions promoting healthy body composition in childhood are warranted in order to support  
294 cardiovascular health in later life. Although we have earlier found that most children participating  
295 in the PANIC study did not meet the dietary recommendations,<sup>31</sup> dietary factors did not explain  
296 the observed associations of meeting the PA guidelines with cardiometabolic risk factors.  
297 However, there may still be some residual confounding by dietary factors in the associations  
298 found, so diet needs to be taken into account in future studies dealing with the associations of  
299 movement behaviors with cardiometabolic risk factors.

300           Contrary to the longitudinal findings, we observed cross-sectionally that meeting all  
301 the guidelines in which PA was included was associated with lower overall cardiometabolic risk  
302 (i.e., CRS) and more favourable levels of individual risk factors (i.e., lower insulin, DBP, and WC,  
303 and higher HDL cholesterol). Our findings are in line with previous reports<sup>13,14</sup> suggesting that  
304 meeting multiple guidelines may have a positive effect in reducing cardiometabolic risk. However,  
305 we also showed that the observed associations were explained by differences in body fat.  
306 Therefore, body fat should be taken into account when investigating associations of adherence to  
307 movement behaviors with cardiometabolic risk factors in future studies.

308 We found that meeting the guidelines for ST and sleep or the guidelines for ST alone  
309 were inversely associated with insulin at baseline, and these associations remained significant also  
310 after adjustment for body fat. Carson and colleagues<sup>13</sup> have previously reported that meeting the  
311 guidelines for ST and sleep was associated with a lower WC. It is notable that the somewhat  
312 different methodologies in assessing ST and sleep may partly explain the differences in the results.  
313 Assessing ST using self-report can be problematic due to the multitude of platforms and the  
314 sporadic and multi-tasking nature of ST in children. Thus, there is a need to clarify associations of  
315 different types of ST (e.g., passive or active use, use for entertaining or educational purposes) with  
316 cardiometabolic risk factors. The results of a previous review<sup>32</sup> suggested that adequate sleep  
317 duration in children and adolescents is associated with lower cardiometabolic risk.<sup>32</sup> Possible  
318 reasons for these findings include alterations in the regulation of appetite and glucose as well as  
319 sympathovagal balance, but these mechanisms are largely based on observations from studies  
320 among adults.<sup>32</sup> One of the reasons for a weak association between sleep and cardiometabolic risk  
321 factors in our study may be that the children were from a general population, and thus most of  
322 them had no diseases and had a relatively healthy lifestyle in terms of PA and sleep. Therefore,  
323 more research are warranted in populations with lower physical activity levels and higher levels of  
324 sedentary time.

325 The strengths of the present study include the valid assessment of free-living PA and  
326 sleep by individually calibrated combined movement and heart rate sensing, comprehensive  
327 measurement of cardiometabolic risk factors and use of a continuous CRS instead of arbitrary cut-  
328 offs for single risk factors, and the assessment of body composition using whole-body dual-energy  
329 X-ray absorptiometry. In addition, the ST included all types of ST (i.e., watching television and  
330 videos, using computer and playing video and console games, and using mobile phone and playing  
331 mobile games) instead of restricting ST only to TV viewing. Finally, body size and composition in  
332 the study sample were similar than in children of the large national reference population<sup>25</sup>  
333 increasing generalization of the results to other children of the same age in Finland.

334 A weakness of our study is that 60% of the children were included in the  
335 intervention group and participated in six family-based intervention visits during the 2-year  
336 follow-up. However, there were no statistically significant differences in movement behaviors or  
337 cardiometabolic risk factors between children in the intervention and those in the control group.  
338 Moreover, the result did not differ essentially when the data were adjusted for the study group.  
339 This limits the conclusion about causality between the observed associations. We also assessed ST



340 using a questionnaire filled out by the parents that has not been validated in Finnish children. It is  
341 possible that the questionnaire may have led to misreporting times spent in different types of  
342 activities, and further, total minutes spent in ST and the proportion of children meeting the ST  
343 guidelines.

344 In conclusion, over half of the children met all three 24-hour movement guidelines at  
345 baseline, while the proportion decreased to one-fourth at 2-year follow-up. Meeting the guidelines  
346 at baseline increased the odds of meeting the guidelines over 2-year follow-up compared to not  
347 meeting the guidelines, except sleep, at baseline. Furthermore, meeting most of the guidelines was  
348 cross-sectionally and longitudinally associated with overall cardiometabolic risk and several  
349 individual risk factors. However, the associations were in part explained by differences in BF%.

350

351

## 352 **PERSPECTIVES**

353

354 Our study shows that meeting the 24-hour movement behavior guidelines, all except sleep, at  
355 baseline increased the odds of meeting the guidelines at 2-year follow-up. Furthermore, the  
356 findings of our cross-sectional and longitudinal analyses emphasize the need to promote  
357 movement behaviors, especially physical activity, in order to support cardiovascular health of the  
358 young children. Yet, there is a need to longer follow-up studies examining the factors related to  
359 higher adherence to the guidelines in long term. Such knowledge would be highly valuable, not  
360 only for researchers, but also for clinicians in promoting health of young children and their  
361 families.

362

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365 data, and we thank Kate Westgate and Stef Hollidge for the processing of the Actiheart data. We  
366 are also indebted to all children and their parents participating in the PANIC Study.

367

## 368 **Conflict of interest**

369

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375 Sydäntutkimussäätiö; the city of Kuopio; Yrjö Jahnssonin Säätiö. None of the authors had a  
376 conflict of interest. The data are not publicly available due to research ethical reasons and because  
377 the owner of the data is the University of Eastern Finland and not the research group. However,  
378 the corresponding author can provide further information on the PANIC study and the PANIC data  
379 on a reasonable request.

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473 **Figure legends**

474 **Figure 1.** Proportion of children adhering to the 24-hour movement guidelines at baseline

475 **Figure 2.** Proportion of children adhering to the 24-hour movement guidelines at 2-year follow-up

**Table 1. Characteristics of children (N=485)**

	At baseline			At 2-year follow-up		
	N	%	Mean (SD)	N	%	Mean (SD)
Sex (% boys)	485	51.3		485	51.3	
Age (years)	485		7.6 (0.4)	426		9.8 (0.4)
Height (cm)	485		129 (5.7)	426		141 (6.3)
Weight (kg)	484		26.9 (5.0)	426		34.4 (7.3)
BMI-SDS <sup>†</sup> (kg/m <sup>2</sup> )	484		-0.2 (1.1)	426		-0.1 (1.1)
Overweight or obese <sup>‡</sup>	63	13.0		73	17.1	
Body fat (%)	476		19.9 (8.2)	406		23.4 (9.2)
Parental education level <sup>§</sup>						
Low	94	19.4		62	14.8	
Medium	217	44.8		196	46.7	
High	173	35.7		162	38.6	
Study group (intervention)	192	39.6		192	39.6	
Actiheart wearing time in days	475		4.6 (1.5)	390		3.9 (1.1)
24-hour movement behaviors						
Moderate-to-vigorous physical activity (min/day)	450		115 (64.3)	373		100 (56.2)
Screen time (min/day)	484		101 (52.1)	419		122 (57.3)
Sleep duration (h/night)	470		9.7 (0.5)	380		9.2 (0.6)
Cardiometabolic risk factors						
CRS	463		0.06 (3.6)	406		0.04 (3.5)

Waist circumference (cm)	485	56.8 (5.9)	426	61.3 (7.3)
Insulin (mU/l)	464	4.5 (2.4)	407	6.1 (3.5)
Glucose (mmol/l)	474	4.8 (0.4)	413	5.0 (0.4)
TG (mmol/l)	474	0.6 (0.2)	413	0.6 (0.3)
HDL cholesterol (mmol/l)	474	1.6 (0.3)	413	1.6 (0.3)
SBP (mmHg)	484	100 (7.3)	426	101 (7.6)
DBP (mmHg)	484	61.5 (7.1)	426	61.4 (7.8)

Abbreviations: BMI-SDS, body mass index SD score; CRS, cardiometabolic risk score; TG, triglycerides; HDL, high-density lipoprotein; SBP, systolic blood pressure; DBP, diastolic blood pressure; SD, standard deviation.

† According to Saari et al. (2011) ‡ According to Cole et al. (2012) § Low indicates  $\leq$  vocational school, medium indicates polytechnic, and high indicates university degree.

**Table 2. Cross-sectional associations between meeting the 24-hour movement guidelines and cardiometabolic risk factors at baseline.**

Cardiometabolic risk factors		Meeting guidelines						
		All guidelines	PA and ST	PA and sleep	ST and sleep	PA	ST	Sleep
		B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
CRS	Model 1	-1.49 (-2.15, -0.83)***	-1.34 (-2.01, -0.67)***	-1.45 (-2.19, -0.72)***	-1.01 (-1.71, -0.31)**	-1.66 (-2.48, -0.84)***	-0.82 (-1.57, -0.07)*	-0.68 (-1.81, 0.46)
	Model 2	-1.33 (-1.98, -0.68)***	-1.16 (-1.83, -0.50)***	-1.44 (-2.17, -0.71)***	-0.89 (-1.59, -0.19)*	-1.66 (-2.49, -0.84)***	-0.66 (-1.42, 0.10)	-0.73 (-1.85, 0.39)
WC	Model 1	-3.19 (-4.25, -2.14)***	-3.17 (-4.24, -2.10)***	-3.59 (-4.76, -2.42)***	-1.36 (-2.51, -0.21)*	-4.36 (-5.64, -3.07)***	-1.19 (-2.42, 0.04)	-1.27 (-3.13, 0.58)
	Model 2	-2.87 (-3.92, -1.82)***	-2.87 (-3.95, -1.81)***	-3.74 (-4.89, -2.59)***	-0.96 (-2.11, 0.19)	-4.71 (-5.98, -3.43)***	-0.70 (-1.94, 0.53)	-1.19 (-3.02, 0.64)
Insulin	Model 1	-0.90 (-1.35, -0.45)***	-0.84 (-1.30, -0.38)***	-0.91 (-1.41, -0.40)***	-0.66 (-1.14, -0.19)**	-1.08 (-1.64, -0.52)***	-0.58 (-1.10, -0.07)*	-0.43 (-1.21, 0.35)
	Model 2	-0.83 (-1.28, -0.38)***	-0.75 (-1.20, -0.29)**	-0.80 (-1.31, -0.30)**	-0.71 (-1.19, -0.23)**	-0.95 (-1.52, -0.38)**	-0.60 (-1.12, -0.09)*	-0.48 (-1.25, 0.29)
Glucose	Model 1	-0.02 (-0.09, 0.05)	0.00 (-0.07, 0.07)	-0.02 (-0.10, 0.06)	-0.06 (-0.13, 0.01)	0.00 (-0.08, 0.09)	-0.04 (-0.12, 0.04)	-0.06 (-0.18, 0.06)
	Model 2	-0.01 (-0.08, 0.06)	0.01 (-0.06, 0.08)	-0.04 (-0.12, 0.04)	-0.03 (-0.10, 0.05)	-0.03 (-0.12, 0.06)	-0.01 (-0.08, 0.08)	-0.05 (-0.17, 0.07)
TG	Model 1	-0.04 (-0.09, 0.01)	-0.04 (-0.09, 0.00)	-0.04 (-0.09, 0.01)	-0.04 (-0.09, 0.01)	-0.06 (-0.12, 0.00)*	-0.05 (-0.10, 0.01)	-0.01 (-0.09, 0.07)
	Model 2	-0.04 (-0.08, 0.01)	-0.04 (-0.09, 0.01)	-0.03 (-0.08, 0.02)	-0.04 (-0.09, 0.01)	-0.04 (-0.10, 0.01)	-0.05 (-0.10, 0.01)	-0.01 (-0.09, 0.07)
HDLc	Model 1	0.07 (0.01, 0.13)*	0.07 (0.02, 0.13)*	0.07 (0.01, 0.14)*	0.03 (-0.03, 0.09)	0.12 (0.05, 0.19)**	0.03 (-0.03, 0.10)	-0.03 (-0.13, 0.07)
	Model 2	0.07 (0.01, 0.13)*	0.08 (0.02, 0.14)*	0.06 (-0.00, 0.13)	0.04 (-0.03, 0.10)	0.11 (0.04, 0.18)**	0.04 (-0.02, 0.11)	-0.03 (-0.13, 0.07)
SBP	Model 1	-1.23 (-2.58, 0.12)	-0.83 (-2.20, 0.55)	-0.85 (-2.35, 0.65)	-1.49, -2.92, -0.06)*	-0.45 (-2.12, 1.22)	-1.27 (-2.80, 0.27)	-1.19 (-3.48, 1.11)
	Model 2	-1.01 (-2.37, 0.36)	-0.53 (-1.92, 0.86)	-0.78 (-2.30, 0.74)	-1.40 (-2.86, 0.05)	-0.33 (-2.03, 1.38)	-1.05 (-2.61, 0.52)	-1.28 (-3.59, 1.03)
DBP	Model 1	-1.65 (-2.97, -0.32)*	-1.47 (-2.82, -0.12)*	-1.68 (-3.15, -0.21)*	-0.56 (-1.97, 0.85)	-1.81 (-3.45, -0.18)*	-0.42 (-1.93, 1.09)	-0.43 (-2.69, 1.84)
	Model 2	-1.40 (-2.74, -0.06)*	-1.22 (-2.59, 0.14)	-1.79 (-3.28, -0.30)*	-0.23 (-1.67, 1.21)	-1.97 (-3.64, -0.30)*	-0.02 (-1.56, 1.53)	-0.50 (-2.77, 1.78)

Abbreviations: CRS, cardiometabolic risk score; WC, waist circumference; DBP, diastolic blood pressure; HDL, high-density lipoprotein; SBP, systolic blood pressure; TG, triglyceride; PA, physical activity, ST, screen time. CRS was calculated as the sum of z-scores of WC + insulin + glucose + TG - HDL cholesterol + mean of SBP and DBP.



Values are unstandardized regression coefficients (B) with their 95% confidence intervals (95% CI) from linear regression analyses providing estimates of meeting the guidelines (not meeting as a reference group) associated with change in the cardiometabolic risk factors (CRS, WC [cm], insulin [mU/l], glucose [mmol/l], TG [mmol/l], HDL [mmol/l], SBP [mmHg], DBP [mmHg]). The Model 1 was unadjusted and Model 2 was adjusted for age, sex, parental education, and research group. \* p-value < 0.05; \*\* p-value < 0.01; \*\*\* p-value < 0.001. In Model 1 N for CRS was 428, for WC 448, for insulin 429, for glucose, TG, and HDL cholesterol 439, and for SBP and DBP 447. In Model 2, N for CRS was 427, for WC 447, for insulin 428, for glucose, TG, and HDL cholesterol 438, and for SBP and DBP 446.

**Table 3. Associations between the number of guidelines met and cardiometabolic risk factors.**

Cardiometabolic risk factors at baseline	Number of guidelines met at baseline		
	2 vs 0 or 1	3 vs 0 or 1	3 vs 2
	B (95% CI)	B (95% CI)	B (95% CI)
CRS	-0.54 (-1.76, 0.69)	-1.76 (-2.95, -0.57)**	-1.23 (-1.92, -0.53)**
WC	-1.24 (-3.19, 0.70)	-3.87 (-5.76, -1.99)***	-2.63 (-3.74, -1.52)***
Insulin	-0.60 (-1.44, 0.24)	-1.32 (-2.13, -0.50)**	-0.72 (-1.19, -0.24)**
Glucose	-0.10 (-0.23, 0.02)	-0.09 (-0.22, 0.03)	0.01 (-0.06, 0.09)
TG	-0.06 (-0.15, 0.03)	-0.08 (-0.17, -0.00)*	-0.03 (-0.07, 0.03)
HDL cholesterol	0.02 (-0.09, 0.13)	0.09 (-0.02, 0.19)	0.07 (0.00, 0.13)*
SBP	-0.56 (-3.09, 1.96)	-1.46 (-3.91, 0.99)	-0.90 (-2.35, 0.55)
DBP	0.83 (-1.66, 3.31)	-0.74 (-3.14, 1.67)	-1.56 (-2.99, -0.14)*

Cardiometabolic risk factors at 2-year follow-up	Number of guidelines met at baseline		
	2 vs 0 or 1	3 vs 0 or 1	3 vs 2
	B (95% CI)	B (95% CI)	B (95% CI)
CRS	-0.82 (-2.12, 0.49)	-1.72 (-2.99, -0.46)**	-0.91 (-1.67, -0.15)*
WC	-1.91 (-4.45, 0.64)	-4.36 (-6.83, -1.89)**	-2.45 (-3.94, -0.97)**
Insulin	-0.90 (-2.18, 0.38)	-1.54 (-2.78, -0.30)*	-0.64 (-1.38, 0.10)
Glucose	0.01 (-0.13, 0.14)	-0.04 (-0.18, 0.09)	-0.05 (-0.13, 0.03)
TG	-0.08 (-0.19, 0.02)	-0.08 (-0.18, 0.02)	0.00 (-0.06, 0.06)
HDL cholesterol	-0.00 (-0.12, 0.12)	0.04 (-0.08, 0.15)	0.04 (-0.04, 0.11)
SBP	1.01 (-1.78, 3.80)	0.77 (-1.95, 3.48)	-0.25 (-1.87, 1.38)
DBP	1.32 (-1.59, 4.24)	0.08 (-2.75, 2.92)	-1.24 (-2.94, 0.46)

Abbreviations: CRS, cardiometabolic risk score; DBP, diastolic blood pressure; HDL, high-density lipoprotein; SBP, systolic blood pressure; TG, triglyceride; WC, waist circumference. CRS was calculated as the sum of z-scores of WC + insulin + glucose + TG - HDL cholesterol + mean of SBP and DBP.

Values are unstandardized regression coefficients (B) with their 95% confidence intervals (95% CI) from linear regression analyses providing estimates of the number of meeting the guidelines (lower number as a reference group) associated with change in the cardiometabolic risk factors (CRS, WC [cm], insulin [mU/l], glucose [mmol/l], TG

[mmol/l], HDL [mmol/l], SBP [mmHg], DBP [mmHg]). All models were adjusted for age, sex, parental education, and study group at baseline. \* p-value < 0.05; \*\* p-value < 0.01; \*\*\* p-value < 0.001.

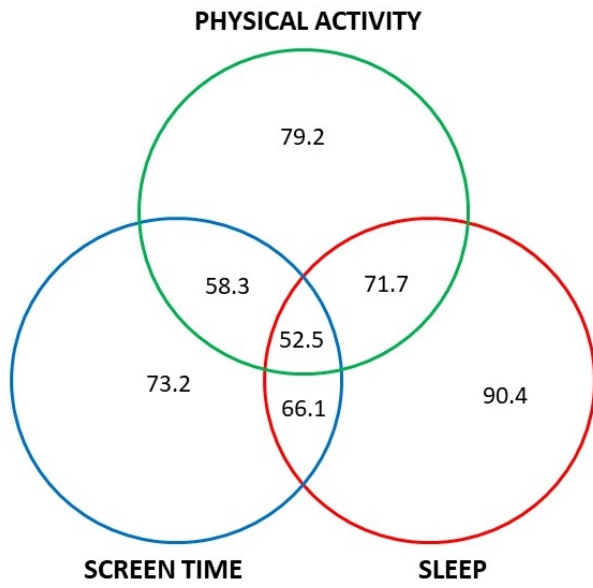
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**Table 4. Prospective associations between meeting guidelines at baseline and cardiometabolic risk factors at 2-year follow-up.**

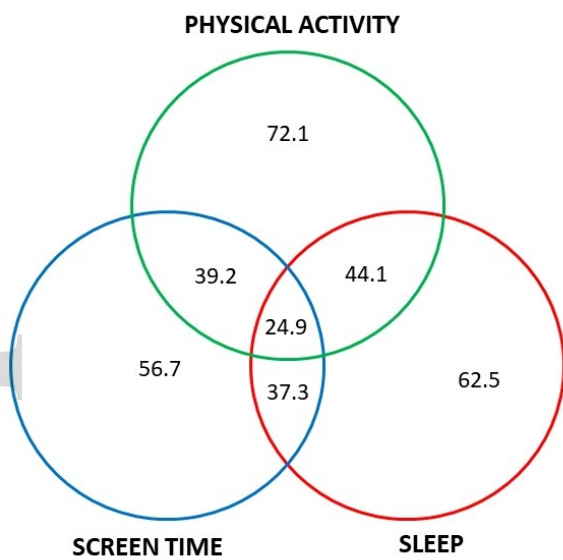
Cardiometabolic risk factors		Meeting guidelines						
		All guidelines	PA and ST	PA and sleep	ST and sleep	PA	ST	Sleep
		B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
<b>CRS</b>	<b>Model 1</b>	-1.19 (-1.90, -0.48)**	-1.29 (-2.01, -0.57)***	-1.33 (-2.12, -0.54)**	-0.58 (-1.34, 0.17)	-1.63 (-2.51, -0.75)***	-0.53 (-1.34, 0.28)	-0.57 (-1.77, 0.63)
	<b>Model 2</b>	-1.07 (-1.78, -0.36)**	-1.14 (-1.86, -0.41)**	-1.29 (-2.08, -0.50)**	-0.53 (-1.29, 0.24)	-1.59 (-2.48, -0.70)**	-0.39 (-1.21, 0.43)	-0.62 (-1.82, 0.58)
<b>WC</b>	<b>Model 1</b>	-3.36 (-4.79, -1.93)***	-3.46 (-4.91, -2.02)***	-3.36 (-4.95, -1.77)***	-1.83 (-3.36, -0.30)**	-4.27 (-6.03, -2.52)***	-1.64 (-3.29, 0.01)	-1.16 (-3.63, 1.30)
	<b>Model 2</b>	-2.83 (-4.23, -1.43)***	-2.99 (-4.41, -1.57)***	-3.65 (-5.18, -2.11)***	-1.04 (-2.55, 0.47)	-4.86 (-6.57, -3.16)***	-0.68 (-2.31, 0.95)	-1.13 (-3.52, 1.26)
<b>Insulin</b>	<b>Model 1</b>	-0.89 (-1.60, -0.17)*	-1.20 (-1.92, -0.49)**	-1.02 (-1.82, -0.23)*	-0.35 (-1.10, 0.41)	-1.59 (-2.47, -0.71)***	-0.53 (-1.34, 0.27)	0.06 (-1.14, 1.26)
	<b>Model 2</b>	-0.82 (-1.52, -0.12)*	-1.07 (-1.77, -0.36)**	-0.72 (-1.50, 0.06)	-0.51 (-1.26, 0.23)	-1.19 (-2.07, -0.31)**	-0.65 (-1.45, 0.14)	0.05 (-1.13, 1.22)
<b>Glucose</b>	<b>Model 1</b>	-0.05 (-0.12, 0.03)	-0.04 (-0.11, 0.04)	-0.04 (-0.12, 0.05)	-0.04 (-0.12, 0.04)	-0.01 (-0.10, 0.08)	-0.02 (-0.11, 0.06)	-0.05 (-0.18, 0.07)
	<b>Model 2</b>	-0.05 (-0.12, 0.03)	-0.04 (-0.11, 0.04)	-0.05 (-0.13, 0.04)	-0.03 (-0.11, 0.05)	-0.03 (-0.13, 0.06)	-0.01 (-0.09, 0.08)	-0.04 (-0.17, 0.09)
<b>TG</b>	<b>Model 1</b>	-0.02 (-0.08, 0.04)	-0.02 (-0.08, 0.03)	-0.05 (-0.11, 0.01)	-0.00 (-0.06, 0.06)	-0.05 (-0.13, 0.02)	0.01 (-0.06, 0.07)	-0.04 (-0.13, 0.06)
	<b>Model 2</b>	-0.01 (-0.07, 0.04)	-0.02 (-0.08, 0.04)	-0.05 (-0.11, 0.02)	-0.00 (-0.06, 0.06)	-0.05 (-0.12, 0.03)	0.01 (-0.06, 0.07)	-0.05 (-0.14, 0.05)
<b>HDLc</b>	<b>Model 1</b>	0.04 (-0.03, 0.10)	0.05 (-0.02, 0.12)	0.03 (-0.05, 0.10)	0.02 (-0.05, 0.08)	0.07 (-0.02, 0.15)	0.02 (-0.05, 0.10)	-0.04 (-0.15, 0.07)
	<b>Model 2</b>	0.04 (-0.03, 0.10)	0.05 (-0.02, 0.12)	0.01 (-0.06, 0.09)	0.02 (-0.05, 0.09)	0.05 (-0.04, 0.13)	0.03 (-0.05, 0.11)	-0.04 (-0.15, 0.07)
<b>SBP</b>	<b>Model 1</b>	-0.34 (-1.86, 1.19)	-0.21 (-1.75, 1.33)	-0.07 (-1.76, 1.61)	-0.29 (-1.89, 1.32)	0.46 (-1.42, 2.33)	-0.26 (-1.98, 1.46)	-1.00 (-3.57, 1.56)
	<b>Model 2</b>	-0.05 (-1.58, 1.48)	0.25 (-1.30, 1.81)	0.11 (-1.58, 1.80)	-0.15 (-1.78, 1.47)	0.91 (-0.99, 2.82)	0.10 (-1.64, 1.85)	-1.42 (-3.98, 1.15)
<b>DBP</b>	<b>Model 1</b>	-0.98 (-2.55, 0.59)	-0.97 (-2.56, 0.62)	-1.48 (-3.21, 0.26)	0.48 (-1.18, 2.13)	-1.74 (-3.67, 0.18)	0.56 (-1.21, 2.34)	-0.77 (-3.41, 1.87)
	<b>Model 2</b>	-0.98 (-2.58, 0.62)	-1.01 (-2.63, 0.62)	-1.58 (-3.34, 0.19)	0.58 (-1.12, 2.28)	-1.97 (-3.95, 0.02)	0.66 (-1.17, 2.48)	-0.71 (-3.40, 1.98)

Abbreviations: CRS, cardiometabolic risk score; WC, waist circumference; DBP, diastolic blood pressure; HDL, high-density lipoprotein; SBP, systolic blood pressure; TG, triglyceride; PA, physical activity, ST, screen time. CRS was calculated as the sum of z-scores of WC + insulin + glucose + TG - HDL cholesterol + mean of SBP and DBP.

Values are unstandardized regression coefficients (B) with their 95% confidence intervals (95% CI) from linear regression analyses providing estimates of meeting the guidelines (not meeting as a reference group) associated with change in the cardiometabolic risk factors (CRS, WC [cm], insulin [mU/l], glucose [mmol/l], TG [mmol/l], HDL [mmol/l], SBP [mmHg], DBP [mmHg]). The Model 1 was unadjusted and Model 2 was adjusted for age, sex, parental education, and research group. \* p-value < 0.05; \*\* p-value < 0.01; \*\*\* p-value < 0.001. In Model 1 N for CRS was 369, for WC 389, for insulin 370, for glucose, TG, and HDL cholesterol 376, and for SBP and DBP 389. In Model 2, N for CRS was 368, for WC 388, for insulin 369, for glucose, TG, and HDL cholesterol 375, and for SBP and DBP 388.



**Figure 1.** Proportion of children adhering to the 24-h movement guidelines at baseline (N=448)



**Figure 2.** Proportion of children adhering to the 24-h movement guidelines at 2-year follow-up (N=365)