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1 **Relationships between outdoor time, physical activity, sedentary time and body mass index**
2 **in children: a 12-country study**

3

4 **Running head:** Outdoor time and children's physical activity

ABSTRACT

5
6 **Purpose:** This study investigated the relationship between outdoor time and physical activity (PA),
7 sedentary time (SED), and BMI Z-scores among children from 12 lower-middle-income, upper-
8 middle-income, and high-income countries.

9 **Methods:** 6,478 children (54.4% girls) aged 9-11 years participated. Outdoor time was self-
10 reported, PA and SED were assessed with ActiGraph GT3X+ accelerometers, and height and
11 weight were measured. Data on parental education, neighbourhood collective efficacy, and
12 accessibility to neighborhood recreation facilities were collected from parent questionnaires.
13 Country latitude and climate statistics were collected through national weather data sources.
14 Gender-stratified multilevel models with parental education, climate, and neighborhood variables
15 as covariates were used to examine the relationship between outdoor time, accelerometry
16 measures, and BMI Z-scores.

17 **Results:** Each additional hour/day spent outdoors was associated with higher moderate- to
18 vigorous-intensity PA (boys: +2.8 min/day; girls: +1.4 min/day), higher light-intensity PA (boys:
19 +2.0 min/day; girls: +2.3 min/day) and lower SED (boys: -6.3 min/day; girls: -5.1 min/day). Effect
20 sizes were generally weaker in lower-middle-income countries. Outdoor time was not associated
21 with BMI Z-scores.

22 **Conclusions:** Outdoor time was associated with higher PA and lower SED independent of climate,
23 parental education and neighborhood variables, but effect sizes were small. However, more
24 research is needed in low- and middle-income countries.

25 Consistent evidence indicates that the vast majority of children and youth worldwide are
26 insufficiently active (18, 39). This situation is concerning because, even in children, insufficient
27 physical activity (PA) is associated with a clustering of cardiovascular disease risk factors (12),
28 higher risk of obesity (22), and poorer mental health outcomes (5). While secular trends in
29 children's PA are difficult to establish because of inconsistent survey methodologies and lack of
30 data on overall PA (13), researchers have suggested that PA within specific domains has decreased
31 over time (3, 11). For example, data from the United States show that while participation in
32 organized sports has increased over time, engagement in active transportation and outdoor play
33 has markedly decreased over the last four decades (3).

34 Mounting evidence suggests that children who spend more time outdoors are more
35 physically active overall (17, 25, 26, 35, 38) and spend less time sedentary (26, 35, 38). Outdoor
36 play is instrumental in developing children's resilience, self-regulation and coping skills (40), and
37 spending more time outdoors is associated with reduced odds of peer relationship problems (26).
38 Furthermore, exposure to natural environments could augment the benefits of PA for mental health
39 (36). However, previous studies examining the relationship between outdoor time and adiposity
40 have obtained conflicting findings (1, 9, 26, 35, 38). To our knowledge, all previous studies
41 investigating the relationship between outdoor time and PA were conducted in high-income
42 countries; thus, it is unclear if similar relationships exist in low- and middle-income countries.

43 In addition to outdoor time, previous research suggests that children's PA is associated
44 with variables such as gender (18, 37), parental education (37), access to PA facilities in the
45 neighborhood (32), weather and season (28, 41), and daylight hours (16). Furthermore, a recent
46 study reported that children spent more time outdoors if their mother had a positive perception of
47 her neighborhood's collective efficacy (24), which refers to "*social cohesion among neighbors*

48 *combined with their willingness to intervene on behalf of the common good*” (34). It is unclear if
49 previously reported associations between outdoor time and PA are independent of such variables
50 and if they vary by gender. Moreover, previous studies conducted in a single country or region
51 may provide less variability in environmental conditions.

52 Therefore, this study aimed to investigate whether outdoor time is associated with PA
53 levels, sedentary time (SED), and BMI Z-scores in a large sample of 9- to 11-year-old children
54 from 12 countries located in all inhabited continents. We hypothesized that, in both boys and girls,
55 outdoor time would be positively associated with PA, and negatively associated with SED and
56 BMI z-scores across lower-middle-income, upper-middle-income, and high-income countries.

57

58 **Methods**

59 The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE)
60 was designed to investigate the influence of behavioural settings and the physical, social, and
61 policy environments on the observed relationship between lifestyle and weight status among
62 school-aged children from study sites located in 12 countries (21). ISCOLE countries represent
63 five major geographic regions including Africa (Kenya, South Africa), the Americas (Brazil,
64 Colombia, Canada, United States), Europe (Finland, Portugal, United Kingdom), South Asia
65 (India), and the Western Pacific (China, Australia). These include lower-middle-income (Kenya
66 and India), upper-middle-income (Brazil, China, Columbia and South Africa), and high-income
67 countries (Australia, Canada, Finland, Portugal, United Kingdom and United States) based on the
68 World Bank classification ([https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-
69 world-bank-country-and-lending-groups](https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups)). The study design also incorporated comprehensive and
70 robust indicators of lifestyle behaviours (e.g. PA, food consumption, SED, and sleep) and

71 anthropometry. A detailed account of the ISCOLE study protocol has been published elsewhere
72 (21). Data collection was conducted in accordance with the Declaration of Helsinki, following
73 ethical approval from relevant research ethics boards in each country and after obtaining parental
74 consent and child assent.

75 **ISCOLE study design.** Recruitment in each country targeted a gender-balanced sample of at
76 least 500 children 9–11 years of age. The primary sampling frame in all sites was schools in urban
77 and suburban areas, stratified by indicators of socio-economic status to maximize variability within
78 sites. Classrooms were then selected to include children with minimum variability around age 10
79 years. Data collection was conducted during a full school year, which varied across countries. In
80 all sites, data were collected between September 2011 and December 2013. Any variations in
81 recruitment strategies employed in the different countries are reported elsewhere (21). Overall,
82 739 schools were approached and 256 registered in ISCOLE (34.6% participation rate), as
83 described by Katzmarzyk et al. (23). Of the 13,015 students invited to participate, 7,372 did so
84 (56.6% participation rate). The analytical sample for this study comprised 6,478 children (54.4%
85 girls) with measured BMI, valid accelerometry data and child questionnaire data for outdoor time
86 and gender.

87 **Questionnaires.** Children completed a Diet and Lifestyle Questionnaire (21) adapted from the
88 United States Youth Risk Behavior Surveillance System
89 (<http://www.cdc.gov/HealthyYouth/yrbs/index.htm>) and the Health Behaviour in School-aged
90 Children Survey (<http://www.hbsc.org/>). Outdoor time was assessed via the three following items
91 developed specifically for this study: “On a school day how much time did you spend outside
92 before school?”; “On a school day how much time did you spend outside after school before
93 bedtime?”; “On a weekend day, how much time did you spend outside?”. For all items, response

94 options were: 1) < 1 hour; 2) 1 hour; 3) 2 hours; 4) 3 hours; 5) 4 hours; and 6) 5 or more hours.
95 Together, the three outdoor time items had good internal consistency (Cronbach $\alpha = 0.83$).

96 Parents completed a Demographic and Family History Questionnaire to provide
97 information on demographics, family health, and socioeconomic factors (21). A collective efficacy
98 index was computed as the sum of two 5-item subscales. Specifically, social cohesion and informal
99 social control items were collected pertaining to the participants' neighbors and/or neighborhoods
100 (34), with higher scores indicating greater perceived collective efficacy. In the ISCOLE sample,
101 both subscales had a Cronbach α value of 0.75 (27). We also calculated an index of accessibility
102 to neighborhood recreation facilities (e.g., parks, trails, beaches and indoor recreation facilities)
103 based on 9 items adapted from the Neighborhood Environment Walkability Scale for Youth (32).
104 Parents reported how long it would take them to walk to each destination. Response options were:
105 1) 1-5 min; 2) 6-10 min; 3) 11-20 min; 4) 21-30 min; 5) ≥ 31 min; and 6) don't know. "Don't
106 know" responses were recoded as ≥ 31 min because if respondents do not know whether the facility
107 is within walking distance, it is likely more than a 30 minute walk away (James F. Sallis, personal
108 communication). Smaller scores on this index indicate shorter travel time to destinations. This
109 index had good internal consistency ($\alpha = 0.85$) in the ISCOLE sample (27). Mothers' and fathers'
110 education was assessed on a 6-point scale ranging from less than high school to
111 professional/graduate degree. Then, the highest level of either parents' education was used as a
112 measure of socioeconomic status.

113 **Anthropometry.** Participants' standing height was measured by trained research staff
114 using a Seca 213 portable stadiometer (Hamburg, Germany), with the participants standing as erect
115 as possible and head positioned in the Frankfort horizontal plane. Participants' weight was
116 measured using a portable Tanita Body Composition Analyser (Arlington Heights, Illinois, United

117 States), after all outer clothing, heavy pocket items, shoes, and socks were removed. Body mass
118 index (BMI) was derived from weight and height (kg/m^2), and BMI z-scores calculated based on
119 growth reference algorithms developed by the World Health Organization (10).

120 **Accelerometry.** PA and SED were objectively measured with ActiGraph GT3X+
121 accelerometers (Pensacola, Florida, United States). Accelerometers were attached firmly to belts,
122 and worn on the right side of the waist. Children were instructed to wear the devices 24 h/day for
123 7 consecutive days (at all times except when bathing or swimming), in addition to an initial
124 familiarization day (42). This protocol maximized the number of children providing ≥ 4 days
125 (including one weekend day) with ≥ 10 waking hours per day of monitored wear time. Non-wear
126 time within a day was classified as 20 or more consecutive minutes of '0' counts after extracting
127 sleep time (2, 21). Sleep time was defined as the time between sleep onset and the end of sleep,
128 including all sleep epochs and wakefulness after onset (42), using an algorithm developed
129 specifically for a 24 h/day waist-worn accelerometry protocol (2). Moderate- to vigorous-intensity
130 physical activity (MVPA) was defined as all activity ≥ 574 counts per 15 s, light-intensity physical
131 activity (LPA) was defined as all activity between 26 and 573 counts per 15 s, and SED was
132 defined as all movement 25 or less counts per 15 s (14).

133 **Weather.** Geographical and climate data for each city were extracted from the respective
134 country's national geographical or climate organization's website for the month of data collection.
135 For instances where the geographical or climate data were not available from the city's national
136 online resources, global geographical and climate web resources (i.e., [http://www.weather-and-](http://www.weather-and-climate.com)
137 [climate.com](http://www.weather-and-climate.com)) were used to access the information. Historical mean monthly temperature and mean
138 monthly precipitation for each city were obtained from the National Oceanic and Atmospheric
139 Administration – National Climatic Data Center; the weather station closest to each city was

140 utilized as the data source. For mean monthly daylight hours, each city's data were obtained from
141 an independent climate website (available at <http://www.climatemps.com/>).

142 **Data treatment.** The following steps were used to compute an outdoor time index in
143 hours/day. First, the response options "< 1 hour" and "5 hours or more" were converted to 0.5
144 hours and 5 hours respectively. Second, outdoor time before and after school were summed to
145 obtain the time spent outdoors on weekdays. Third, outdoor time in hours per day was calculated
146 as: $(5 * \text{outdoor time on weekdays}) + (2 * \text{outdoor time on weekend days}) / 7$. The highest level of
147 parental education was collapsed into a 3-level variable and dummy-coded for analyses: 1) Did
148 not complete high school; 2) Completed high school/some college; and 3) Bachelor's degree or
149 postgraduate degree. Scores for the indices of collective efficacy and accessibility to neighborhood
150 recreation facilities were calculated as the mean of the relevant items.

151 **Statistical analysis.** First, chi-squared and t-tests were used to examine differences between
152 participants included in the analytical sample and those excluded. To examine variation in outdoor
153 time by country-site, gender-stratified generalized linear mixed models including school as a
154 random effect were used. Then, to assess differences between genders in outdoor time, MVPA,
155 LPA, SED, and the likelihood of achieving an average of at least 60 minutes of MVPA per day,
156 generalized linear mixed models including school and country-sites as random effects were used.

157 To test our main hypothesis that greater time spent outdoors is associated with higher MVPA
158 and LPA and lower SED and BMI Z-scores, we performed a series of generalized linear mixed
159 models. For each outcome, we built three gender-stratified models in a hierarchical fashion: 1)
160 without covariates; 2) with climate variables and parent education; 3) with climate, parental
161 education, and neighborhood variables. School and country-site were treated as random effects
162 and their corresponding intra-class correlation coefficients were calculated. The Satterthwaite

163 method was used to calculate degrees of freedom. Given the inclusion of 4 outcome variables, a
164 p -value of <0.0125 was used for statistical significance based on Bonferroni adjustment. All
165 predictors were grand-mean centered prior to analyses. Model fit was assessed using the deviance
166 statistic which is expected to decline significantly if a model fits the data better than the previous
167 one. When models are nested, differences in deviances follow a chi-square distribution whose
168 degrees of freedom correspond to the number of predictors added to each model (31).

169 We conducted sensitivity analyses to examine our main hypothesis while stratifying by country
170 income status. We also conducted additional analyses examining the relationship between outdoor
171 time in different time periods (i.e., before school, after school, and on weekend days) and our
172 outcome measures. All analyses were computed with IBM SPSS version 21 (IBM Corporation,
173 Armonk, NY), except the analysis of differences between included and excluded participants
174 which was performed with SAS version 9.3 (SAS Institute, Cary, North Carolina, USA).

175

176 **Results**

177 Descriptive characteristics of the sample are shown in Table 1. ISCOLE sites provided
178 wide variability in terms of latitude, temperature, precipitation, and parental education. On
179 average, children reported spending 2.5 ± 1.5 h/day outdoors with substantial variation between
180 country-sites ($F = 23.25$; $p < 0.01$), from 1.8 h/day in Portugal to 3.7 in South Africa. Participants
181 with missing data on parental education, collective efficacy and accessibility to neighborhood
182 recreation facilities scores reported spending more time outdoors and accumulated more minutes
183 of MVPA ($p < 0.05$), though differences were generally small (data not shown).

184 Using the United States as the reference group, boys and girls in Canada, China,
185 Colombia, and Portugal had significantly lower outdoor time scores (all $p \leq 0.01$; data not shown).

186 Conversely, boys and girls in Brazil and South Africa had significantly higher scores (all
187 $p \leq 0.01$). Compared to boys, girls spent 16.5 fewer minutes/day outdoors (95% CI = 12.6; 20.3;
188 $p < 0.01$), accumulated 17.3 less minutes of MVPA/day (95% CI = -18.3; -16.3; $p < 0.01$), 7.8
189 fewer minutes of LPA/day (95% CI = -10.2; -5.3; $p < 0.01$), and 16.3 more minutes of SED (95%
190 CI = 13.2; 19.4; $p < 0.01$). Girls were over four times less likely to accumulate at least 60 minutes
191 of MVPA/day than boys (OR = 0.23; 95% CI = 0.20; 0.25; $p < 0.01$).

192 Relationships between the outdoor time score and accelerometry measures are presented
193 in Tables 2 to 4. After adjusting for covariates, each additional hour/day spent outdoors was
194 consistently associated with higher MVPA (boys: +2.8 min/day; girls: +1.4 min/day), higher
195 LPA (boys: +2.0 min/day; girls: +2.3 min/day) and lower SED (boys: -6.3 min/day; girls: -5.1
196 min/day). Inclusion of parental education, climate and neighborhood variables generally had
197 minimal effects on these associations. Similar relationships were observed for outdoor time
198 before school, after school, and on weekend days (Appendix 1). When stratifying by country
199 income status, the effect sizes were generally weaker in lower-income countries (Appendix 2).

200 Lower parental education was consistently associated with more time spent in MVPA and
201 LPA, and less SED in a graded manner (Tables 2 to 4). Each additional minute of daylight was
202 associated with 0.02 minutes of additional MVPA (representing a 1.2 min/day increase for each
203 hour of daylight), but this difference was only significant for girls. Similarly, each unit increase
204 in collective efficacy scores was associated with 1.1 more minutes of MVPA/day in girls only.
205 Each degree increase in mean daily temperature was associated with more LPA in boys (+0.9
206 min/day) and girls (+1.2 min/day) and with less SED in girls (-1.3 min/day). Finally, each unit
207 increase in the index of accessibility to neighborhood recreation facilities (reflecting that
208 facilities are further away) was associated with 3.5 less min/day of SED in girls only. In the

209 models stratified by country income status, the climate, parental education, and neighborhood
210 variables that were significantly associated with our outcomes of interest varied across country
211 income groups and gender.

212 As shown in Table 5, neither the outdoor time score nor any of the included covariates
213 were associated with BMI z-scores. In lower-middle-income countries, higher parental education
214 was associated with higher BMI z-scores. The opposite was observed in high-income countries
215 and parental education was not associated with BMI Z-scores in upper-middle-income countries.

216

217 **Discussion**

218 We examined the relationship between outdoor time and objective measures of PA, SED,
219 and BMI in a large sample of children from study sites within 12 different countries representing
220 all inhabited continents and providing wide variability in environmental conditions. In support of
221 our hypotheses, greater time spent outdoors was associated with significantly higher MVPA,
222 LPA, and lower SED, although the effect sizes were small. Our results were similar in boys and
223 girls and observed differences persisted after adjusting for socioeconomic status, neighborhood
224 environment and climate variables. However, effect sizes were weaker in lower-middle-income
225 countries compared to high- and upper-middle-income countries. We found no relationship
226 between outdoor time and BMI z-scores.

227 In line with previous research, we observed that children who spend more time outdoors
228 were more active overall (9, 17, 25, 26, 35, 38) and accumulated less SED (26, 35, 38). The
229 magnitude of the observed associations (about 2 additional min/day of MVPA and LPA, and 6
230 fewer min/day of SED for each additional hour spent outdoors) was smaller than in most
231 previous studies conducted in high-income countries. Except for one study using global

232 positioning systems (25), all previous studies discussed above have used self- or proxy-reports of
233 outdoor time. However, it is worth noting that the differences that we observed were similar for
234 boys and girls and remained virtually unchanged when controlling for parental education,
235 climate and neighborhood variables. Our models examining outdoor time before school, after
236 school, and on weekends also suggest that relationships between outdoor time, PA, and SED are
237 similar regardless of when outdoor time occurs.

238 Increasing opportunities for children to spend more time outdoors is likely to be a
239 scalable public health intervention that could simultaneously increase PA and reduce SED,
240 among other positive outcomes (40). For instance, a recent study suggests that pediatrician
241 prescriptions to spend time outdoors may be feasible, well-accepted by parents, and show some
242 promise in increasing PA (44). In a brief 4-week program wherein parents merely received
243 suggestions to increase family outdoor time and information about suitable locations to be active,
244 family outdoor time increased by 100-135 minutes per week (15). Moreover, spending less time
245 indoors may have additional benefits that were not examined in the present analyses (e.g., better
246 mental health and air quality and lower exposure to unhealthy snacks and cyber-predators) (40).

247 Our study extends previous research by including countries at different stages of
248 development. We observed that associations between outdoor time and indicators of MVPA,
249 LPA and SED were weaker in lower-middle-income countries than in richer countries.
250 Conceptually, the relationship between outdoor time and accelerometry measures depends on
251 what children are actually doing while outdoors and this may vary between countries due to
252 factors such as culture, social norms and the broader PA transition. Interestingly, the two lower-
253 middle-income countries included, Kenya and India, are experiencing a rapid PA transition
254 wherein physically demanding occupations and active transportation are replaced by sedentary

255 occupations and motorized transportation (7, 29, 30). There may be limited opportunities for
256 outdoor PA in the cities of Bangalore and Nairobi where data collection occurred. For instance,
257 of all the ISCOLE sites, Bangalore had the lowest prevalence of active transportation (27).

258 Greater parental education was associated with lower BMI Z-scores in high-income
259 countries, but higher BMI Z-scores in lower-middle-income countries. Broyles and colleagues
260 previously reported a similar association between household income and anthropometric
261 indicators (7). These findings are consistent with the epidemiological transition model, which
262 suggests that lifestyle changes associated with economic growth and urbanization in developing
263 countries initially affect families who are relatively well-off (29).

264 Despite the significant relationships with more PA and less SED, outdoor time was not
265 associated with BMI z-scores. Other cross-sectional analyses have shown inconsistent
266 relationships between outdoor time and body composition indicators with some showing no
267 associations (9, 26, 35) and some showing beneficial effect of outdoor time (24, 38). In contrast,
268 results from a longitudinal study indicated that Australian 10- to 12-year-olds who spent more
269 time outdoors were less likely to be overweight after three years of follow-up (9). Similarly, a
270 study of preschoolers in the United States found that, over one year, outdoor play was associated
271 with more favourable changes in BMI and a reduced risk of obesity (1). While the effect of
272 spending more time outdoors on energy expenditure may be small, it could add up over time in
273 the absence of compensatory changes in PA or diet. In ISCOLE, diet was measured with a food
274 frequency questionnaire which does not allow us to quantify energy intake precisely.
275 Nevertheless, Chaput and colleagues (8) reported that children who spend more time outdoors
276 had higher scores for the consumption of “healthy foods” (e.g., vegetables, fruit, whole grains,
277 low-fat milk, etc.), but consumption of “unhealthy foods” (fast food, hamburgers, soft drinks,

278 sweets, fried food, etc.) did not vary according to outdoor time. In a sensitivity analysis, we
279 included these two diet scores in the models examining the effect of outdoor time on BMI, but
280 our results were unchanged (data not shown). Given the inconclusive evidence, future studies
281 should clarify the relationship between outdoor time and weight status.

282 We observed that girls spent significantly less time outdoors and were less active and
283 more sedentary than boys. These findings are consistent with previous studies of outdoor time (9,
284 25) and with population-based studies of PA and SED (18). Gender studies suggest that parents
285 may perceive girls to be more vulnerable than boys (19, 43), and as a result, they may impose
286 more restrictions on girls' independent mobility which may partly explain why girls spend less
287 time outdoors. Yet, previous research suggests that girls can achieve similar levels of
288 independence as boys by traveling outdoors in groups (6). A neighborhood's collective efficacy
289 and additional daylight could be other enablers of girls' PA as suggested by our observation that
290 these variables were positively associated with MVPA in girls, but not in boys. Kimbro and
291 colleagues (24) also observed that collective efficacy was associated with more outdoor time and
292 less TV time among children in the United States. Neighborhoods with greater collective
293 efficacy could help alleviate parental safety concerns, potentially encouraging more outdoor time
294 and PA. When stratifying by country income status, we found that collective efficacy was
295 associated with higher MVPA only in high-income countries. Previous research in developing
296 countries suggest that individuals may be active in unfavorable environments by necessity rather
297 than by choice, and our findings may reflect that (33).

298 We observed that, independent of temperature, additional daylight was associated with
299 higher MVPA in girls. This association was only significant in high-income countries, which
300 generally experience greater seasonal variations in daylight. While the amount of daylight is not

301 modifiable, previous research suggests that daylight saving time is associated with increased PA,
302 particularly in the late afternoon and evening (16). Interestingly, mean daily temperature was not
303 associated with MVPA. The relationship between temperature and MVPA may be curvilinear
304 (i.e., in the form of an inverted U), as suggested in a previous analysis of Australian and
305 Canadian data (28). Nevertheless, we did find that higher temperature was associated with
306 slightly more LPA in both genders and with less SED in girls. When stratifying by country
307 income, different climate variables were associated with LPA and SED. However, given the
308 limited variability in climate variables when stratified by country income status, these findings
309 should be interpreted cautiously.

310 **Limitations and strengths.** The main study limitation is the cross-sectional design which
311 precludes causal inference. In addition, reports of outdoor time may be subject to social
312 desirability and recall biases, and the test-retest reliability and validity of the questions used to
313 assess outdoor time is unknown. Yet, inaccuracies in reports of outdoor time (i.e., random error)
314 could attenuate the effect sizes for the relationship between outdoor time and accelerometry
315 measures. Limited data pertaining to the psychometric properties of methods to assess outdoor
316 time are available in the extant literature (4), underscoring a clear need for future research. In the
317 ISCOLE Diet and Lifestyle Questionnaire (21), participants were asked to report their activities
318 in the “last week”, so they may have reported their outdoor time in the week before they wore
319 the accelerometer, which would likely bias our results towards the null hypothesis. Our measure
320 of outdoor time does not provide contextual information about the activities that children did
321 while outdoors, which may include play, sport, transportation, and sedentary activities. Finally,
322 as in previous studies examining the relationship between outdoor time and anthropometric
323 variables (1, 9, 26, 35, 38), we did not have a measure of total energy intake.

324 In contrast, the large sample size and the objective measures of PA, SED and BMI Z-
325 scores are major study strengths. Unlike previous multi-country studies on childhood obesity and
326 PA, which focused on high-income countries, ISCOLE included 12 countries at different stages
327 of development representing all geographical regions of the world (21). Furthermore, our
328 analyses included many potential covariates that have seldom been considered in previous
329 studies on this topic.

330

331 **Conclusion**

332 Our study extends previous research by showing consistent positive associations between
333 outdoor time and objective measures of MVPA, LPA and negative associations with SED in a
334 large sample of boys and girls. Furthermore, although effect sizes were small, these relationships
335 were independent of parental education, climate and neighborhood variables. However, we noted
336 that the effect sizes were weaker in lower-middle-income countries, suggesting that the
337 relationship between outdoor time and accelerometry measures might be context-dependent. This
338 underscores a need for future studies examining the relationship between outdoor time and
339 measures of PA and SED in developing countries where less evidence is currently available.

340 Given the consistency of the epidemiological evidence that more time spent outdoors is
341 associated with higher PA in high-income countries (9, 17, 25, 26, 35, 38), researchers,
342 practitioners, and other stakeholders should promote increased opportunities for children to
343 spend time outdoors, and examine whether this leads to an increase in PA. Future research
344 should also investigate the correlates of outdoor time to inform interventions, especially in low-
345 and middle-income countries where such research is lacking. Finally, there remains a need for
346 validating existing measures of outdoor time (4).

347

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Table 1: Descriptive statistics for child, household, neighborhood and country characteristics from the 12-country International Study of Childhood Obesity, Lifestyle and the Environment, 2011-2013.

Geographic Region	Africa		Americas				Europe			South East Asia	Western Pacific	
Country (site)	Kenya (Nairobi)	South Africa (Cape Town)	Brazil (Sao Paulo)	Colombia (Bogota)	Canada (Ottawa)	US (Baton Rouge)	Finland (Helsinki)	Portugal (Porto)	UK (Bath)	India (Bangalore)	China (Tianjin)	Australia (Adelaide)
World Bank Ranking (income)	Lower-middle	Upper-Middle	Upper-Middle	Upper-Middle	High	High	High	High	High	Lower-Middle	Upper-Middle	High
Child Level Characteristics	501	460	467	857	523	466	504	679	478	553	500	490
Age (years)	10.2	10.2	10.5	10.5	10.5	9.9	10.5	10.4	10.9	10.4	9.9	10.7
Sex - <i>n</i> (%)												
Boys	233 (47)	181 (39)	225(48)	422 (49)	217 (41)	191(41)	235 (47)	302 (44)	211 (44)	254 (46)	260 (52)	225 (46)
Girls	268 (53)	279 (61)	242 (52)	435 (51)	306 (59)	275(59)	269 (53)	377 (56)	267 (56)	299 (54)	240 (48)	265 (54)
BMI Categories - <i>n</i> (%)												
Underweight	19 (4)	11 (2)	10 (2)	13 (2)	2 (0)	2 (0)	8 (2)	2 (0)	4 (1)	26 (5)	13 (3)	4 (1)
Normal weight	383 (76)	323 (70)	249 (53)	646 (75)	360 (69)	284(61)	376 (75)	360 (53)	331 (69)	346 (63)	279 (56)	303 (62)
Overweight	66 (13)	74 (16)	107 (23)	149 (17)	98 (19)	98(21)	93 (18)	200 (29)	99 (21)	121 (22)	85 (17)	133 (27)
Obese	33 (7)	52 (11)	101 (22)	49 (6)	63 (12)	82(18)	27 (5)	117 (17)	44 (9)	60 (11)	123 (25)	50 (10)
Daily Minutes of - mean (SD)												
Sedentary time	495 (66)	487 (65)	500 (69)	500 (67)	511 (63)	520 (62)	530 (68)	552 (62)	497 (60)	516 (67)	565 (68)	477 (6)
LPA	330 (52)	325 (53)	337 (53)	333 (49)	305 (45)	314 (51)	293 (44)	302 (50)	285 (46)	340 (50)	293 (54)	311 (48)
MVPA	72 (31)	65 (25)	59 (26)	68 (25)	59 (19)	50 (19)	71 (26)	56(22)	63 (22)	49 (21)	45 (16)	65 (23)
Total reported outdoor time score	3.0 (1.6)	3.7(1.9)	3.4 (1.9)	2.2 (0.9)	2.0 (1.3)	2.7(1.5)	2.9 (1.5)	1.8 (0.9)	2.6 (1.2)	2.3 (1.1)	1.9 (1.1)	2.6 (1.3)
Screen time score	2.4 (1.7)	3.1 (2.1)	3.7 (2.3)	2.9 (1.5)	2.5 (1.9)	3.2 (2.3)	2.8 (1.7)	2.3 (1.5)	2.9 (1.7)	1.8 (1.3)	1.9 (1.7)	2.8 (1.8)
Accumulate ≥ 60 min/day of MVPA - <i>n</i> (%)	287 (57.3)	238 (51.7)	204 (43.7)	509 (59.4)	226 (43.2)	122 (26.2)	316 (62.7)	249 (36.7)	243 (50.8)	140 (25.3)	79 (15.8)	268 (54.7)
Household Characteristics												
Highest Parental Education – <i>n</i> (%)	500	396	433	856	517	459	470	615	430	546	497	478
Did not complete high school	72 (14)	187 (47)	103 (24)	263 (31)	10 (2)	25 (5)	13 (3)	280 (46)	13 (3)	28 (5)	166 (33)	54 (11)
Completed high school / Some college	229 (46)	154 (39)	233 (54)	439 (51)	136 (26)	188 (41)	259 (55)	208 (34)	217 (50)	119 (22)	223 (45)	224 (47)
Bachelor's degree or Post-graduate degree	199 (40)	55 (14)	97 (22)	154 (18)	371 (72)	246 (54)	198 (42)	127 (21)	200 (47)	399 (73)	108 (22)	200 (42)
Neighborhood Characteristics - <i>n</i>	496	396	429	857	517	452	466	614	430	545	500	479
Collective efficacy score	3.4 (0.8)	3.4 (0.8)	3.2 (0.6)	3.4 (0.8)	3.8 (0.7)	3.7 (0.8)	3.7 (0.7)	3.5 (0.7)	3.7 (0.7)	3.5 (0.7)	3.8 (0.6)	3.5 (0.7)
Accessibility to neighborhood recreation facilities score	4.2 (0.7)	4.0 (0.9)	3.7 (0.8)	3.3 (0.6)	2.5 (0.8)	3.8 (0.9)	2.5 (0.8)	3.9 (0.8)	3.1 (0.7)	3.8 (0.8)	3.6 (0.8)	3.1 (0.9)
Country Site Characteristics												
Latitude (degrees)	1° 25'S	33° 55'S	23° 31'S	4° 32'N	45° 24'N	30° 27'N	57° 9'N	41° 9'N	51° 26'N	12° 59'N	39° 8'N	34° 55'S
Mean daylight hours	12:06	12:08	12:07	12:06	12:10	12:07	12:21	12:09	12:13	12:06	12:08	12:08
Mean daily temperature	17.7°C	16.6°C	19.3°C	13.3°C	6.0°C	19.8°C	4.8°C	14.5°C	10°C	24.1°C	12°C	16.4°C
Yearly temperature variation	9°C - 30°C	4°C - 31°C	8°C - 32°C	2°C - 22°C	-24 - 31°C	-2°C - 35°C	-20°C - 27°C	2°C - 30°C	3°C - 20°C	16°C - 34°C	-4°C - 27°C	7°C - 29°C
Annual precipitation (mm)	925.0	475.0	1454.8	824.0	869.5	1546.7	688.0	1267.0	1128.0	905.0	600.0	447.5

Note: World Bank Ranking reflect the situation of each country at the time of data collection. BMI = Body Mass Index; LPA = Light-intensity physical activity; MVPA = Moderate-to-Vigorous Physical Activity; US = United States; UK = United Kingdom.

Table 2. Relationship between outdoor time and minutes of daily moderate to vigorous physical activity among participants in the 12-country International Study of Childhood Obesity, Lifestyle and the Environment, 2011-2013.

Variable	Model 1			Model 2			Model 3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Boys									
Intercept	69.68	2.43	<0.01	67.35	2.63	<0.01	67.09	2.61	<0.01
Outdoor time (hours/day)	2.87	0.32	<0.01	2.73	0.33	<0.01	2.76	0.33	<0.01
Daylight (min/day)	-	-	-	0.02	0.01	0.03	0.02	0.01	0.03
Mean daily temperature (degrees)	-	-	-	-0.08	0.20	0.69	-0.08	0.20	0.70
Annual minimum temperature (degrees)	-	-	-	-0.18	0.31	0.58	-0.13	0.31	0.68
Annual maximum temperature (degrees)	-	-	-	-0.84	0.62	0.22	-0.80	0.62	0.24
Monthly precipitation (mm)	-	-	-	-0.01	0.01	0.46	-0.01	0.01	0.52
Latitude (degrees)	-	-	-	-0.08	0.11	0.46	-0.08	0.11	0.49
Parental education (< high school)	-	-	-	8.03	1.48	<0.01	8.30	1.50	<0.01
Parental education (high school/some college)	-	-	-	2.33	1.08	0.03	2.57	1.09	0.02
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	-1.18	0.56	0.04
Collective efficacy score	-	-	-	-	-	-	0.40	0.63	0.52
<i>Deviance statistic (model fit)*</i>	26992.57	-	<0.01	25705.64	-	<0.01	25372.67	-	<0.01
Girls									
Intercept	53.01	2.19	<0.01	51.24	2.07	<0.01	51.02	2.06	<0.01
Outdoor time (hours/day)	1.33	0.24	<0.01	1.35	0.24	<0.01	1.39	0.24	<0.01
Daylight (min/day)	-	-	-	0.02	0.01	<0.01	0.02	0.01	<0.01
Mean daily temperature (degrees)	-	-	-	0.08	0.17	0.62	0.08	0.17	0.63
Annual minimum temperature (degrees)	-	-	-	-0.37	0.25	0.17	-0.37	0.25	0.17
Annual maximum temperature (degrees)	-	-	-	-0.99	0.50	0.08	-0.98	0.49	0.08
Monthly precipitation (mm)	-	-	-	0.00	0.01	0.83	0.00	0.01	0.78
Latitude (degrees)	-	-	-	-0.10	0.08	0.26	-0.11	0.08	0.25
Parental education (< high school)	-	-	-	5.81	1.04	<0.01	6.43	1.05	<0.01
Parental education (high school/some college)	-	-	-	1.17	0.75	0.12	1.46	0.76	0.05
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	-0.09	0.39	0.82
Collective efficacy score	-	-	-	-	-	-	1.12	0.44	0.01
<i>Deviance statistic (model fit)*</i>	30270.50	-	<0.01	28976.04	-	<0.01	28445.59	-	<0.01

Note: regression coefficients represent the effect of each additional hour of outdoor time per day. Bold text indicates statistical significance. Model 1 is unadjusted. Model 2 is adjusted for climate variables and parental education. Model 3 is adjusted for climate variables, parental education, and the accessibility to neighborhood recreation facilities and collective efficacy scales. School-level intra-class correlation coefficient (ICC): boys = 0.123; girls = 0.161. Site-level ICC: boys = 0.185; girls = 0.291. *Improvement in fit for Model 1 was assessed by comparing its deviance to that of an “empty model” without fixed effects.

Table 3. Relationship between outdoor time and minutes of daily light physical activity among participants in the 12-country International Study of Childhood Obesity, Lifestyle and the Environment, 2011-2013.

Variable	Model 1			Model 2			Model 3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Boys									
Intercept	318.02	5.28	<0.01	313.86	4.41	<0.01	313.64	4.47	<0.01
Outdoor time (hours/day)	2.42	0.66	<0.01	1.96	0.68	<0.01	1.95	0.69	<0.01
Daylight (min/day)	-	-	-	0.01	0.01	0.49	0.01	0.01	0.39
Mean daily temperature (degrees)	-	-	-	0.91	0.33	<0.01	0.86	0.33	<0.01
Annual minimum temperature (degrees)	-	-	-	-0.04	0.52	0.94	0.00	0.52	0.99
Annual maximum temperature (degrees)	-	-	-	1.29	1.03	0.25	1.30	1.04	0.25
Monthly precipitation (mm)	-	-	-	-0.02	0.02	0.38	-0.02	0.02	0.45
Latitude (degrees)	-	-	-	-0.13	0.18	0.47	-0.13	0.18	0.48
Parental education (< high school)	-	-	-	7.13	3.02	0.02	7.88	3.08	0.01
Parental education (high school/some college)	-	-	-	5.09	2.22	0.02	5.35	2.26	0.02
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	0.11	1.17	0.92
Collective efficacy score	-	-	-	-	-	-	1.32	1.33	0.32
<i>Deviance statistic (model fit)*</i>	31278.20	-	<0.01	29836.87	-	<0.001	29458.08	-	<0.01
Girls									
Intercept	311.21	5.82	<0.01	305.91	4.70	<0.01			<0.01
Outdoor time (hours/day)	2.45	0.66	<0.01	2.32	0.67	<0.01	2.29	0.68	<0.01
Daylight (min/day)	-	-	-	0.01	0.01	0.26	0.01	0.01	0.24
Mean daily temperature (degrees)	-	-	-	1.20	0.33	<0.01	1.21	0.33	<0.01
Annual minimum temperature (degrees)	-	-	-	-0.15	0.55	0.80	-0.25	0.55	0.67
Annual maximum temperature (degrees)	-	-	-	1.08	1.11	0.36	0.94	1.12	0.43
Monthly precipitation (mm)	-	-	-	-0.04	0.02	0.07	-0.04	0.02	0.08
Latitude (degrees)	-	-	-	-0.18	0.19	0.37	-0.19	0.19	0.35
Parental education (< high school)	-	-	-	8.06	2.86	<0.01	8.12	2.91	<0.01
Parental education (high school/some college)	-	-	-	6.30	2.10	<0.01	6.37	2.12	<0.01
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	2.21	1.11	0.05
Collective efficacy score	-	-	-	-	-	-	0.58	1.25	0.64
<i>Deviance statistic (model fit)*</i>	37489.01	-	<0.01	35919.48	-	<0.01	35297.31	-	<0.01

Note: regression coefficients represent the effect of each additional hour of outdoor time per day. Bold text indicates statistical significance. Model 1 is unadjusted. Model 2 is adjusted for climate variables and parental education. Model 3 is adjusted for climate variables, parental education, and the accessibility to neighborhood recreation facilities and collective efficacy scales. School-level intra-class correlation coefficient (ICC): boys = 0.130; girls = 0.151. Site-level ICC: boys = 0.083; girls = 0.104. *Improvement in fit for Model 1 was assessed by comparing its deviance to that of an “empty model” without fixed effects.

Table 4. Relationship between outdoor time and minutes of daily sedentary time among participants in the 12-country International Study of Childhood Obesity, Lifestyle and the Environment, 2011-2013.

Variable	Model 1			Model 3			Model 4		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Boys									
Intercept	503.57	6.39	<0.01	508.62	6.29	<0.01	509.29	6.18	<0.01
Outdoor time (hours/day)	-6.40	0.90	<0.01	-6.27	0.92	<0.01	-6.26	0.93	<0.01
Daylight (min/day)	-	-	-	0.00	0.02	0.88	0.00	0.02	0.82
Mean daily temperature (degrees)	-	-	-	-0.12	0.45	0.79	-0.09	0.45	0.84
Annual minimum temperature (degrees)	-	-	-	-0.08	0.73	0.92	-0.20	0.72	0.79
Annual maximum temperature (degrees)	-	-	-	0.89	1.47	0.56	0.76	1.44	0.61
Monthly precipitation (mm)	-	-	-	0.02	0.03	0.63	0.01	0.03	0.74
Latitude (degrees)	-	-	-	0.42	0.25	0.14	0.41	0.25	0.14
Parental education (< high school)	-	-	-	-13.57	4.11	<0.01	-14.70	4.19	<0.01
Parental education (high school/some college)	-	-	-	-5.50	3.03	0.07	-5.89	3.07	0.06
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	2.88	1.60	0.07
Collective efficacy score	-	-	-	-	-	-	-0.63	1.81	0.73
<i>Deviance statistic (model fit)*</i>	33111.20	-	<0.01	31571.99	-	<0.01	31164.93	-	<0.01
Girls									
Intercept	518.20	7.80	<0.01	522.13	8.00	<0.01	522.45	8.14	<0.01
Outdoor time (hours/day)	-4.99	0.81	<0.01	-4.85	0.83	<0.01	-5.10	0.84	<0.01
Daylight (min/day)	-	-	-	-0.01	0.01	0.60	0.00	0.01	0.61
Mean daily temperature (degrees)	-	-	-	-1.25	0.42	<0.01	-1.26	0.42	<0.01
Annual minimum temperature (degrees)	-	-	-	1.07	0.93	0.28	1.23	0.94	0.23
Annual maximum temperature (degrees)	-	-	-	1.95	1.92	0.34	2.17	1.95	0.30
Monthly precipitation (mm)	-	-	-	0.04	0.03	0.16	0.04	0.03	0.16
Latitude (degrees)	-	-	-	0.56	0.33	0.13	0.58	0.33	0.12
Parental education (< high school)	-	-	-	-10.17	3.53	<0.01	-10.39	3.58	<0.01
Parental education (high school/some college)	-	-	-	-2.76	2.58	0.28	-3.15	2.60	0.23
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	-3.54	1.36	<0.01
Collective efficacy score	-	-	-	-	-	-	-2.01	1.53	0.19
<i>Deviance statistic (model fit)*</i>	38917.98	-	<0.01	37289.58	-	<0.01	36630.93	-	<0.01

Note: regression coefficients represent the effect of each additional hour of outdoor time per day. Bold text indicates statistical significance. Model 1 is unadjusted. Model 2 is adjusted for climate variables and parental education. Model 3 is adjusted for climate variables, parental education, and the accessibility to neighborhood recreation facilities and collective efficacy scales. School-level intra-class correlation coefficient (ICC): boys = 0.115; girls = 0.188. Site-level ICC: boys = 0.077; girls = 0.120. *Improvement in fit for Model 1 was assessed by comparing its deviance to that of an “empty model” without fixed effects.

Table 5. Relationship between outdoor time and BMI Z-scores among participants in the 12-country International Study of Childhood Obesity, Lifestyle and the Environment, 2011-2013.

Variable	Model 1			Model 3			Model 4		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Boys									
Intercept	0.55	0.10	<0.01	0.51	0.12	<0.01	0.51	0.12	<0.01
Outdoor time (hours/day)	0.02	0.02	0.31	0.02	0.02	0.32	0.01	0.02	0.50
Daylight (min/day)	-	-	-	0.00	0.00	0.62	0.00	0.00	0.58
Mean daily temperature (degrees)	-	-	-	0.00	0.01	0.58	0.00	0.01	0.57
Annual minimum temperature (degrees)	-	-	-	0.00	0.01	0.78	-0.01	0.01	0.70
Annual maximum temperature (degrees)	-	-	-	0.01	0.03	0.64	0.01	0.03	0.69
Monthly precipitation (mm)	-	-	-	0.00	0.00	0.11	0.00	0.00	0.13
Latitude (degrees)	-	-	-	0.00	0.01	0.74	0.00	0.01	0.80
Parental education (< high school)	-	-	-	0.02	0.08	0.83	0.03	0.08	0.72
Parental education (high school/some college)	-	-	-	0.06	0.06	0.32	0.06	0.06	0.34
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	0.04	0.03	0.23
Collective efficacy score	-	-	-	-	-	-	0.02	0.04	0.66
<i>Deviance statistic (model fit)*</i>	9824.29	-	1.00	9423.06	-	<0.01	9316.15	-	<0.01
Girls									
Intercept	0.39	0.08	<0.01	0.35	0.09	<0.01	0.35	0.09	<0.01
Outdoor time (hours/day)	0.01	0.02	0.42	0.01	0.02	0.48	0.01	0.02	0.56
Daylight (min/day)	-	-	-	0.00	0.00	0.24	0.00	0.00	0.21
Mean daily temperature (degrees)	-	-	-	0.00	0.01	0.79	0.00	0.01	0.72
Annual minimum temperature (degrees)	-	-	-	0.00	0.01	0.69	0.00	0.01	0.72
Annual maximum temperature (degrees)	-	-	-	0.03	0.02	0.20	0.03	0.02	0.22
Monthly precipitation (mm)	-	-	-	0.00	0.00	0.34	0.00	0.00	0.39
Latitude (degrees)	-	-	-	0.00	0.00	0.58	0.00	0.00	0.54
Parental education (< high school)	-	-	-	0.04	0.07	0.59	0.01	0.07	0.88
Parental education (high school/some college)	-	-	-	0.08	0.05	0.10	0.07	0.05	0.17
Parental education (≥ undergraduate degree)	-	-	-	Ref	-	-	Ref	-	-
Accessibility to neighborhood recreation facilities score	-	-	-	-	-	-	0.03	0.03	0.29
Collective efficacy score	-	-	-	-	-	-	-0.05	0.03	0.07
<i>Deviance statistic (model fit)*</i>	11200.64	-	1.00	10816.14	-	<0.01	10603.97	-	<0.01

Note: BMI Z-scores are based on the World Health Organization growth references (de Onis et al., 2007). Note: regression coefficients represent the effect of each additional hour of outdoor time per day. Bold text indicates statistical significance. Model 1 is unadjusted. Model 2 is adjusted for climate variables and parental education. Model 3 is adjusted for climate variables, parental education, and the accessibility to neighborhood recreation facilities and collective efficacy scales. School-level intra-class correlation coefficient (ICC): boys = 0.067; girls = 0.044. Site-level ICC: boys = 0.019; girls = 0.034. *Improvement in fit for Model 1 was assessed by comparing its deviance to that of an “empty model” without fixed effects.