

## Isotemporal substitution analysis for sedentary behavior and body mass index

HUANG, Wendy Y J; Wong, Stephen Heung Sang; He, Gang; Salmon, Jo

*Published in:*  
Medicine and Science in Sports and Exercise

*DOI:*  
[10.1249/MSS.0000000000001002](https://doi.org/10.1249/MSS.0000000000001002)

Published: 01/11/2016

*Document Version:*  
Peer reviewed version

[Link to publication](#)

*Citation for published version (APA):*  
HUANG, W. Y. J., Wong, S. H. S., He, G., & Salmon, J. (2016). Isotemporal substitution analysis for sedentary behavior and body mass index. *Medicine and Science in Sports and Exercise*, 48(11), 2135-2141.  
<https://doi.org/10.1249/MSS.0000000000001002>

### General rights

Copyright and intellectual property rights for the publications made accessible in HKBU Scholars are retained by the authors and/or other copyright owners. In addition to the restrictions prescribed by the Copyright Ordinance of Hong Kong, all users and readers must also observe the following terms of use:

- Users may download and print one copy of any publication from HKBU Scholars for the purpose of private study or research
- Users cannot further distribute the material or use it for any profit-making activity or commercial gain
- To share publications in HKBU Scholars with others, users are welcome to freely distribute the permanent publication URLs

## **Isotemporal substitution analysis for sedentary behavior and body mass index**

Wendy Yajun Huang<sup>1</sup>, Stephen Heung Sang Wong<sup>2\*</sup>, Gang He<sup>2,4</sup>, Jo Salmon<sup>3</sup>

<sup>1</sup>Department of Physical Education, Hong Kong Baptist University, Hong Kong, China

<sup>2</sup>Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Hong Kong, China

<sup>3</sup>Centre for Centre for Physical Activity & Nutrition Research (C-PAN), School of Exercise and Nutrition Sciences, Deakin University, Burwood, Victoria, Australia

<sup>4</sup>School of Kinesiology and Health, Capital University of Physical Education and Sports

## 1 **Abstract**

2 **Purposes:** This study examined the prospective associations of reallocating time spent in  
3 different types of sedentary behavior, physical activity and sleep with body mass index  
4 (BMI) in children using isotemporal substitution analysis.

5 **Methods:** Chinese children in grades 1-3 were recruited into a cohort study in 2009 and  
6 were followed up over a two-year period. Reports were gathered from the parents on  
7 children's sedentary behavior, sleep duration, and socio-demographic variables. The  
8 reported sedentary behavior types were then grouped into three categories: screen time (e.g.  
9 watching TV), academic-related activities (e.g. doing homework) and other sedentary  
10 behavior (e.g. sitting and talking). Moderate-to-vigorous physical activity (MVPA) and  
11 light-intensity physical activity (LPA) was assessed by ActiGraph accelerometry.  
12 Isotemporal substitution models were performed to examine the effects of time allocation  
13 on BMI.

14 **Results:** A total of 672 children (359 boys, mean age at recruitment = 7.6 yr) who had  
15 provided valid accelerometer data for at least one assessment time point were included in  
16 the analysis. Controlling for covariates and total behavior time, isotemporal substitution  
17 models indicated that the displacement of 30 min/day of other sedentary behavior with  
18 equal amounts of screen time ( $B = 0.12$ , 95% confidence interval: 0.04, 0.20) or  
19 academic-related activities ( $B = 0.13$ , 95% confidence interval: 0.04, 0.21) was associated

20 with higher BMI. Reallocating 30 min/day of MVPA with each of the sedentary behavior  
21 variables resulted in increased BMI.

22 **Conclusions:** The substituting of screen time or academic-related activities with other  
23 sedentary behavior or MVPA was associated with lower BMI in Chinese children.

24

25 **Key words:** screen time, physical activity, accelerometry, obesity, children

## 26 INTRODUCTION

27 Compelling evidence has shown an inverse relationship between moderate-to-vigorous  
28 physical activity (MVPA) and adiposity markers in youth (12, 19). It is recommended that  
29 children and adolescents engage in at least 60 minutes of MVPA daily to achieve substantial  
30 health benefits, including maintaining a healthy body weight (31, 34). However, MVPA  
31 typically accounts for less than 5% of a 24-hour day. Over 95% of the 24-hour day is made  
32 up of other components on the movement continuum (sedentary behavior, sleep and  
33 light-intensity physical activity [LPA]), which also have important impacts on health from a  
34 young age. In a 24-hour day, a decrease in a specific activity means there is an equal time  
35 substitution of another activity. Therefore, the influences that specific activity intensities  
36 have on health may also depend on the type of activity that it displaces (24).

37

38 Isotemporal substitution analysis can model the effects of displacing one specific type of  
39 activity with another in an equal amount of time (15). In adults, this statistical technique has  
40 been applied to investigate substitution effects of physical activity, sedentary behavior, and  
41 sleep on cardiometabolic risk. For children and adolescents, only two studies have applied  
42 isotemporal substitution analysis to examine the effects of time reallocation on a selected  
43 outcome of interest. It has been shown that substituting 1 hr/day of sedentary time with  
44 physical activity was favorably associated with percentage body fat (1, 20).

45

46 Despite recent applications of isothermal substitution analysis in physical activity research,  
47 current understanding of time allocation is limited to the effects of reallocating sedentary  
48 time (either objectively assessed or self-reported TV time) with MVPA and/or LPA.

49 Furthermore, no studies conducted in youth have considered sleep. Other than screen time,  
50 specific sedentary behaviors have seldom been investigated in relation to obesity. A study

51 conducted with Chinese children found that both studying time and screen time were  
52 positively associated with BMI among boys (37); however, the mechanism for this

53 relationship remains unclear. Some studies have suggested that dietary intake is responsible  
54 for the observed association between screen time and adiposity (8, 13); others have

55 indicated it is partly mediated by the displacement of MVPA (4). Whether sedentary  
56 behavior, other than screen time, yields different effects on obesity risk is little known. Such

57 issues may be particularly important with respect to Chinese children because doing  
58 academic-related activities occupy large amounts of their discretionary time (16). Therefore,

59 the purpose of this study was to examine the prospective associations of substituting  
60 different types of sedentary behavior, LPA, MVPA and sleep with BMI by using isothermal

61 substitution analysis. It was hypothesized that statistically displacing screen time with an  
62 equal amount of physical activity or other types of sedentary behaviors would lead to a

63 reduced obesity risk.

64

## 65 **METHODS**

### 66 **Study design and participants**

67 The participants were recruited from the Understanding Children's Activity and Nutrition  
68 (UCAN) cohort study in school children in Hong Kong. Recruitment was conducted during  
69 June to August 2009 from primary schools located in different districts with varying  
70 socioeconomic status (SES). Details of recruitment procedure have been reported elsewhere  
71 (36). Briefly, after approval was sought from school principals, written consent forms were  
72 sent to the parents of children from two randomly selected classes across grades 1–3 from  
73 each school. A total of 1,666 children from 24 schools consented to participate in the  
74 baseline assessment, while 1,492 (90%) and 1,265 (76%) were retained for 1-yr and 2-yr  
75 follow-ups, respectively. Only a subsample of the parents agreed to their child wearing an  
76 ActiGraph (details shown in 'Physical activity assessment').

77

78 The data collection occurred across the two school semesters (September to November and  
79 January to April). At each time point, measurements were taken at a similar time of year to  
80 minimize seasonal variations. The children's anthropometric data were collected during  
81 school visits by trained staff. The initialized ActiGraph accelerometers and questionnaires  
82 for the parents were distributed to the children during school visits. The parents were

83 instructed to complete the questionnaire at home and to return them to the contact teacher  
84 within one to two weeks. Ethical approval was obtained from the Survey and Behavioral  
85 Research Ethics Committee of the Chinese University of Hong Kong. Written informed  
86 consent was sought from the parents.

87

### 88 **Anthropometric measurements**

89 Body weight, in the minimum clothing possible, and standing height without shoes were  
90 measured by trained assessors. BMI was calculated by dividing weight (kg) by height squared  
91 ( $m^2$ ).

92

### 93 **Sedentary behavior and sleep**

94 The parents completed a validated questionnaire to assess their child's engagement in 13  
95 types of sedentary behavior and sleep during a typical week (17). The questionnaire was  
96 originally developed for children aged 10 years or older to self-report their engagement in  
97 physical activity and sedentary behavior. As the participating children in the current study  
98 may be too young to self-report, their behavior was reported by their parents. Parents were  
99 asked to report the duration (in minutes or hours) of each of the sedentary behaviors on  
100 weekdays and weekends, respectively. Duration estimates exceeding 10hr/day for any given  
101 sedentary behavior were considered reporting errors and were excluded from the analyses



102 (16). The minutes spent in different types of sedentary behavior per day were then grouped  
103 into 3 categories: leisure-time screen time (watching TV, playing electronic games and using  
104 the Internet for leisure purpose), academic-related activities (e.g. doing homework, attending  
105 tutorial class, and using the Internet for academic-related purposes), and other types of  
106 sedentary behavior (e.g. reading excluding those for academic-related purposes, sitting and  
107 talking, and listening to music). Sleep duration was assessed by a single question: “How  
108 much sleep does your child usually get at night?” The parents were asked to report the sleep  
109 duration in hours on weekdays (school days) and weekends (non-school days), respectively.

110

### 111 **Physical activity assessment**

112 Approval for wearing the accelerometer was sought from a subsample of children (n =  
113 1,020) at baseline. At each follow-up, consent forms were re-sent to the parents and  
114 approval was obtained from 874 children at a 1-yr follow-up and 706 children at a 2-yr  
115 follow-up. Due to the limited ActiGraph accelerometers available at the beginning of the  
116 study, the accelerometer data were only collected at baseline for 448 children (44% of those  
117 whose parents had agreed). At the 1-yr and 2-yr follow-ups, the accelerometer data were  
118 collected for all the children whose parents had agreed to wear the device. The children who  
119 wore the accelerometers were older and had lower parental education levels than those who  
120 did not. No differences were found across the other demographic and anthropometric

121 variables.

122

123 The accelerometer (ActiGraph, Pensacola, Florida, USA) was attached to an elasticized belt  
124 which was worn by children at hip level for 8 consecutive days. The accelerometer was  
125 removed during sleeping and water-based activities. The data were recorded in 1-minute  
126 epochs. Non-wear time was defined as at least 60 consecutive minutes of zero recording  
127 (32). At each assessment wave, 3 days of accelerometer data (may or may not including a  
128 weekend day) with a minimum of 10 hours recording per day were considered to be valid  
129 (5). The accelerometer data were downloaded using ActiLife 6 and analyzed using  
130 MeterPlus software (Santech Inc., V.4.3, <http://www.meterplussoftware.com>). MVPA was  
131 defined as  $\geq 4$  METs (3) based on age-specific cut-off counts (33). LPA was classified as  
132  $>100$  cpm and below the age-specific cut-off points. Average minutes in daily MVPA and  
133 LPA were derived for the whole week.

134

### 135 **Other covariates**

136 The parents reported their demographic information, including parents' age, sex, educational  
137 attainment, marital status, body weight and height, and the children's date of birth and sex. To  
138 assess the children's snacking habit, parents were asked, "How often your child has a habit of  
139 snacking while doing the sedentary activity?" Response categories were never, seldom,

140 sometimes, and often. The parents' educational attainment was classified based on the  
141 categories in Hong Kong and details have been reported elsewhere (16).

142

### 143 **Statistical analysis**

144 The data analyses were restricted to children who provided valid accelerometer data for at  
145 least one assessment wave and whose parent returned a questionnaire. Three-level linear  
146 mixed models were performed to examine associations between MVPA, LPA, different  
147 types of sedentary behavior, sleep and BMI. This method is appropriate for estimating  
148 effects over time and it has been applied in investigating longitudinal changes in MVPA and  
149 sedentary time in youth (3, 11). Three levels were the three assessment time points (level 1),  
150 children (level 2), and school (level 3). Time engaging in each behavior was scaled to 30  
151 min/day (divided by 30) to improve the interpretability of the results. Previous studies  
152 among children have used behavior of 60 min/day in regression models to interpret the  
153 associations between the replacing of 1 hour with different activity intensities and health  
154 outcomes (1, 20); however, in adults, a range between 10 min/day and 60 min/day have  
155 been used depending on the outcomes of interest (6, 15, 23). Given that children may have  
156 already engaged in certain amounts of physical activity in a day, reallocating 30 min/day of  
157 one activity type to another may be more practical for informing intervention strategies.

158

159 Three types of regression models were performed: single behavior models, partition models  
160 and isotemporal substitution models. All the models were adjusted for the child's age, sex  
161 and snacking habit, and parent's age, BMI, educational attainment and marital status. Single  
162 models examined the association of each individual behavior with BMI, without the  
163 adjustment of other behavior variables. Partition models estimated the effects of each  
164 individual behavior on BMI while holding the duration of each of the other behavior  
165 variables constant. All the behavior variables were entered into the partition models  
166 simultaneously. The coefficients for the partition models represented the effect of  
167 statistically adding 30 min/day of one behavior type. Isotemporal substitution models were  
168 performed by holding the total behavior time (total behavior time = MVPA + LPA + screen  
169 time + academic-related activities + other sedentary activities + sleep) constant.  
170 Accelerometer assessed sedentary time was excluded in order to avoid duplication. The  
171 coefficients for the isotemporal models demonstrated the estimated effects of displacing 30  
172 minutes of one behavior (the dropped one in the models) with an equal duration in another  
173 while holding the total behavior time constant. All the analyses were conducted using SPSS  
174 version 22.

175

## 176 **RESULTS**

177 Of the 1,020 children from whom parental approval was sought for wearing the

178 accelerometer, 359 boys and 313 girls provided valid accelerometer data for at least 1  
179 assessment time point and returned a parental questionnaire (Table 1). No differences were  
180 found in general characteristics of children and sedentary behavior reported by parents  
181 between children who provided valid accelerometer data and those who did not. On average,  
182 children were 7.6 years old at baseline. They spent approximately 2 hr/day watching TV and  
183 doing academic-related activities, respectively. Sleep duration was approximately 9 hr/day.  
184 The percentage of a snacking habit (reporting ‘sometimes’ and ‘often’) was 25% while doing  
185 homework and 27% during screen time. Low correlations were observed between the  
186 different behavioral variables, although significant positive associations were found between  
187 LPA and MVPA, and between screen time and the other two types of sedentary behaviors  
188 (Table 2).

189

190 Table 3 shows single, partition and isothermal substitution models for the associations  
191 between the behavior variables and children’s BMI. In single models, screen time tended to  
192 be positively associated with BMI ( $B = 0.03$ ; 95% CI,  $-0.01$  to  $0.07$ ), whereas other  
193 sedentary behaviors ( $B = -0.07$ ; 95% CI,  $-0.13$  to  $-0.01$ ), LPA ( $B = -0.06$ ; 95% CI,  $-0.12$   
194 to  $-0.00$ ) and MVPA ( $B = -0.42$ ; 95% CI,  $-0.60$  to  $-0.25$ ) were negatively associated with  
195 BMI. In the partition models, statistically adding an additional 30 min/day of each  
196 activity/sedentary behavior type while holding the other variables constant only changed the

197 associations between LPA and BMI (not significant). In the isotemporal substitution models,  
198 replacing 30 min/day of MVPA with each of the other behavior variables resulted in an  
199 increase in children's BMI. Replacing 30 min/day of other sedentary behavior (e.g. sitting  
200 and talking) with screen time ( $B = 0.12$ ; 95% CI, 0.04 to 0.20) or academic-related activities  
201 ( $B = 0.13$ ; 95% CI, 0.04 to 0.21) resulted in higher BMI.

202

## 203 **DISCUSSION**

204 This study applied an isotemporal substitution model approach to examine time allocation  
205 effects on BMI in Chinese children. Although this novel technique has previously been used  
206 in physical activity research in both adults (15, 35) and children (1, 20), this study extends  
207 previous findings by examining substitution effects of different types of sedentary behavior  
208 in children. The results suggest that the substituting of 30 min/day of other types of  
209 sedentary behavior (e.g. sitting and talking) with an equivalent amount of screen time or  
210 academic-related activities was associated with an increased BMI according to statistical  
211 modelling. The findings are also in line with previous studies that show that MVPA is  
212 favorably associated with children's BMI as it was found that displacing any of the other  
213 behavior variables, including LPA, with MVPA resulted in a lower modelled BMI. As the  
214 isotemporal substitution models controlled for the total behavior time, the observed  
215 associations between individual behavior types and BMI are expected to be independent of

216 each other.

217

218 This study found that the three types of sedentary behavior had different associations with  
219 BMI which seemed to be independent of MVPA. That is, the overall impact of 30 minutes  
220 of screen time on BMI in Chinese children may depend on what kinds of sedentary behavior  
221 it displaces. Current evidence linking sedentary behavior with adiposity is equivocal.  
222 Studies primarily focusing on TV viewing or screen time have consistently found  
223 associations between these activities and higher risks of obesity (10, 30), whereas evidence  
224 of association between objectively assessed overall sedentary time (not examined in the  
225 current study because of the different outcome of interest) and cardiometabolic risk factors  
226 is inconsistent (9, 12, 14). Our finding that screen time was no longer associated with BMI  
227 in single and partition models after adjusting for snacking habit is in line with the notion  
228 that the association of screen time with obesity could be partially explained by dietary  
229 intake (8, 13). It has been also supported by preliminary evidence from experimental studies  
230 that screen-based behaviors can increase acute energy intake in children and youth (22).

231

232 For sedentary behavior other than screen-based activities, little is known on their  
233 associations with adiposity. It is surprising to find that in the current study, replacement of  
234 academic-related activities with screen time did not yield any differences in BMI. The only

235 study reporting a positive relationship between studying time and BMI was conducted on  
236 6-11 year old Chinese boys, but snacking habits were not examined (37). High-energy  
237 snacks are commonly accessible to children in Hong Kong (18). In the current study, one  
238 fourth of the Chinese children had a habit of snacking while doing academic-related  
239 activities, which is a similar percentage to those who reported eating snacks during screen  
240 time. The opportunity for using the Internet to do homework is increasing for school-aged  
241 children nowadays. It is possible that exposure to the screen *per se* may increase the  
242 likelihood of food intake; no matter it is for homework or entertainment purpose.  
243 Nevertheless, it is important to note that although frequency of snacking habit was  
244 controlled, whether other dietary variables, such as energy intake of the snacks, were  
245 different or not remains unknown. The other unexpected finding is the negative association  
246 between other sedentary behavior (e.g. sitting and talking, listening to music) and BMI.  
247 Consistent with previous work among Chinese children (16, 37), other sedentary pursuits  
248 were less prevalent compared with screen time and academic-related activities. Furthermore,  
249 we found that screen time and academic-related activities were negatively associated with  
250 time in MVPA, whereas, other sedentary behavior was not. It is possible that these activities  
251 are less likely to be combined with snacking or they may be indicative of a healthier  
252 lifestyle in general. Some laboratory studies have shown that teenagers consumed less  
253 energy from drinks and/or solid foods while listening to music or sitting in groups,



254 compared with when the TV was on (25, 27). However, longer term effects of different  
255 types of sedentary behavior on adiposity need to be investigated by well-designed  
256 experimental or cohort studies.

257

258 No beneficial effects of reallocating time from sedentary behavior to LPA or sleep on BMI  
259 for Chinese children were generally consistent with the previous studies using an  
260 isotemporal substitution approach for adults (15) and children (1, 20). The observation that  
261 sleep duration was not associated with BMI contrasts with previous reviews that suggest  
262 that sleep duration is inversely related to obesity (7, 26). However, Chinese children  
263 observed in this study slept on average for approximately 9 hr/night which may be  
264 considered to be adequate. Given that, in this study the strongest associations were found  
265 between MVPA and BMI in all of the three types of model, it seems that MVPA remains the  
266 most potent behavior along the activity spectrum in relation to children's BMI. This  
267 suggests that the maximal benefits on BMI will be achieved if MVPA can be reallocated  
268 from screen time or academic-related activities. Practically, however, the actual amount of  
269 time in MVPA that can be reallocated from other physical activities or sedentary behavior  
270 may be limited. It will be particularly difficult to limit time spent in academic-related  
271 activities for Chinese children because of the academic pressure in Chinese society (16).  
272 However, promoting healthy snacking habits or limiting energy intake while engaging in

273 sedentary behavior warrants attention in future interventions. Taken together, these findings  
274 support current advocacy in promoting health-enhancing physical activity and reducing  
275 screen-based behaviors to maintain a healthy body weight (21, 29).

276

277 The strengths of this study lie in its longitudinal design and its focus on substitution effects  
278 of different types of sedentary behavior. Thus, the associations observed between sedentary  
279 behavior and BMI reflect a prospective relationship and are independent of MVPA. Future  
280 studies may consider using an objective device that detects postural transition, e.g. activPAL,  
281 to distinguish between sitting and LPA in children (2, 28). A potential bias of using  
282 subjective measures of sedentary behavior is acknowledged. Although sedentary time could  
283 be calculated based on the ActiGraph data, the outcome of interest in this study was on the  
284 different types of sedentary behavior. As a result, the sum of the three types of reported  
285 sedentary behavior instead of accelerometer assessed sedentary time was computed in the  
286 isotemporal models. The questionnaire was developed and validated for Chinese children in  
287 Hong Kong (17) and high correlations were found between parent-reported total sedentary  
288 behavior and objectively measured sedentary time ( $r$  ranged from 0.64 to 0.73 at the three  
289 assessment waves, data not shown). In order to maximize the analytical sample, having  
290 valid accelerometer data on at least a weekend day was not considered as a requirement.  
291 However, 87% of the children who were included in the final data analyses did provide

292 valid accelerometer data on more than 3 days including a weekend day. In addition, mixed  
293 effects models excluding those children who provided valid data on weekdays only did not  
294 yield different findings.

295

296 In summary, this study provides preliminary evidence of the different impacts of various  
297 types of sedentary behavior on children's BMI. Reallocating screen time or  
298 academic-related activities with other types of sedentary behavior or MVPA was associated  
299 with lower BMI. It is possible that the unfavorable effects of sedentary behavior on  
300 adiposity may be mediated not only by replacing MVPA but also by increasing other  
301 unhealthy behavior, such as snacking. While screen time reduction continues to be a potent  
302 component of health-enhancing interventions, future studies may consider providing  
303 instructions on alternative activities and targeting other unhealthy behavior while engaging  
304 in screen-based behavior and academic-related activities in Chinese children.

305

### 306 **Acknowledgements**

307 The UCAN study was supported by the General Research Fund (GRF) from the Research  
308 Grants Council (RGC) of the Government of the Hong Kong Special Administrative Region,  
309 China (GRF 451308). The authors are grateful to all the children and their parents who  
310 participated in this study, along with the school teachers and student helpers who assisted in

311 the UCAN project. JS is supported by a Principal Research Fellowship from the Australian  
312 National Health and Medical Research Council (APP1026216).

313 The results of the present study do not constitute endorsement by the American College of  
314 Sports Medicine.

315

### 316 **Conflict of Interest**

317 The authors declare that they have no conflict of interest.

318

### 319 **References**

320 1. Aggio D, Smith L, Hamer M. Effects of Reallocating Time in Different Activity  
321 Intensities on Health and Fitness: A Cross Sectional Study. *Int J Behav Nutr Phys*  
322 *Act.* 2015;12:83.

323 2. Aminian S, Hinckson EA. Examining the Validity of the Activpal Monitor in  
324 Measuring Posture and Ambulatory Movement in Children. *Int J Behav Nutr Phys*  
325 *Act.* 2012;9:119.

326 3. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-Year  
327 Changes in Afterschool Physical Activity and Sedentary Behavior. *Am J Prev Med.*  
328 2013;44(6):605-11.

329 4. Berentzen NE, Smit HA, van Rossem L et al. Screen Time, Adiposity and

- 330 Cardiometabolic Markers: Mediation by Physical Activity, Not Snacking, among  
331 11-Year-Old Children. *Int J Obes (Lond)*. 2014;38(10):1317-23.
- 332 5. Brooke HL, Atkin AJ, Corder K, Ekelund U, van Sluijs EM. Changes in  
333 Time-Segment Specific Physical Activity between Ages 10 and 14 Years: A  
334 Longitudinal Observational Study. *J Sci Med Sport*. 2016;19(1):29-34.
- 335 6. Buman MP, Winkler EA, Kurka JM et al. Reallocating Time to Sleep, Sedentary  
336 Behaviors, or Active Behaviors: Associations with Cardiovascular Disease Risk  
337 Biomarkers, Nhanes 2005-2006. *Am J Epidemiol*. 2014;179(3):323-34.
- 338 7. Cappuccio FP, Taggart FM, Kandala NB et al. Meta-Analysis of Short Sleep  
339 Duration and Obesity in Children and Adults. *Sleep*. 2008;31(5):619-26.
- 340 8. Chaput JP, Klingenberg L, Astrup A, Sjodin AM. Modern Sedentary Activities  
341 Promote Overconsumption of Food in Our Current Obesogenic Environment. *Obes*  
342 *Rev*. 2011;12(5):e12-20.
- 343 9. Colley RC, Garriguet D, Janssen I et al. The Association between  
344 Accelerometer-Measured Patterns of Sedentary Time and Health Risk in Children  
345 and Youth: Results from the Canadian Health Measures Survey. *BMC Public Health*.  
346 2013;13:200.
- 347 10. Coombs NA, Stamatakis E. Associations between Objectively Assessed and  
348 Questionnaire-Based Sedentary Behaviour with Bmi-Defined Obesity among

- 349 General Population Children and Adolescents Living in England. *BMJ Open*.  
350 2015;5(6):e007172.
- 351 11. Corder K, Sharp SJ, Atkin AJ et al. Change in Objectively Measured Physical  
352 Activity During the Transition to Adolescence. *Br J Sports Med*. 2015;49(11):730-6.
- 353 12. Ekelund U, Luan J, Sherar LB, Esliger DW, Griew P, Cooper A. Moderate to  
354 Vigorous Physical Activity and Sedentary Time and Cardiometabolic Risk Factors in  
355 Children and Adolescents. *JAMA*. 2012;307(7):704-12.
- 356 13. Falbe J, Rosner B, Willett WC, Sonnevile KR, Hu FB, Field AE. Adiposity and  
357 Different Types of Screen Time. *Pediatrics*. 2013;132(6):e1497-505.
- 358 14. Froberg A, Raustorp A. Objectively Measured Sedentary Behaviour and  
359 Cardio-Metabolic Risk in Youth: A Review of Evidence. *Eur J Pediatr*.  
360 2014;173(7):845-60.
- 361 15. Hamer M, Stamatakis E, Steptoe A. Effects of Substituting Sedentary Time with  
362 Physical Activity on Metabolic Risk. *Med Sci Sports Exerc*. 2014;46(10):1946-50.
- 363 16. Huang WY, Wong SH. Time Use Clusters in Children and Their Associations with  
364 Sociodemographic Factors. *Journal of Public Health*. 2015;  
365 doi:10.1093/pubmed/fdv088.
- 366 17. Huang YJ, Wong SH, Salmon J. Reliability and Validity of the Modified Chinese  
367 Version of the Children's Leisure Activities Study Survey (Class) Questionnaire in

- 368           Assessing Physical Activity among Hong Kong Children. *Pedia Exerc Sci.*  
369           2009;21(3):339-53.
- 370 18.   Hui LL, Nelson E. Dietary Characteristics of Hong Kong Young Children:  
371           Implications for Nutrition Education. *HK J Paediatr.* 2006;11:255-62.
- 372 19.   Jimenez-Pavon D, Kelly J, Reilly JJ. Associations between Objectively Measured  
373           Habitual Physical Activity and Adiposity in Children and Adolescents: Systematic  
374           Review. *Int J Pediatr Obes.* 2010;5(1):3-18.
- 375 20.   Loprinzi PD, Cardinal BJ, Lee H, Tudor-Locke C. Markers of Adiposity among  
376           Children and Adolescents: Implications of the Isotemporal Substitution Paradigm  
377           with Sedentary Behavior and Physical Activity Patterns. *J Diabetes Metab Disord.*  
378           2015;14:46.
- 379 21.   Lynch BM, Owen N. Too Much Sitting and Chronic Disease Risk: Steps to Move  
380           the Science Forward. *Ann Intern Med.* 2015;162(2):146-7.
- 381 22.   Marsh S, Ni Mhurchu C, Maddison R. The Non-Advertising Effects of  
382           Screen-Based Sedentary Activities on Acute Eating Behaviours in Children,  
383           Adolescents, and Young Adults. A Systematic Review. *Appetite.* 2013;71:259-73.
- 384 23.   Mekary RA, Lucas M, Pan A et al. Isotemporal Substitution Analysis for Physical  
385           Activity, Television Watching, and Risk of Depression. *Am J Epidemiol.*  
386           2013;178(3):474-83.

- 387 24. Mekary RA, Willett WC, Hu FB, Ding EL. Isotemporal Substitution Paradigm for  
388 Physical Activity Epidemiology and Weight Change. *Am J Epidemiol.*  
389 2009;170(4):519-27.
- 390 25. Mekhmoukh A, Chapelot D, Bellisle F. Influence of Environmental Factors on Meal  
391 Intake in Overweight and Normal-Weight Male Adolescents. A Laboratory Study.  
392 *Appetite.* 2012;59(1):90-5.
- 393 26. Nielsen LS, Danielsen KV, Sorensen TI. Short Sleep Duration as a Possible Cause of  
394 Obesity: Critical Analysis of the Epidemiological Evidence. *Obes Rev.*  
395 2011;12(2):78-92.
- 396 27. Peneau S, Mekhmoukh A, Chapelot D et al. Influence of Environmental Factors on  
397 Food Intake and Choice of Beverage During Meals in Teenagers: A Laboratory  
398 Study. *Br J Nutr.* 2009;102(12):1854-9.
- 399 28. Ridgers ND, Salmon J, Ridley K, O'Connell E, Arundell L, Timperio A. Agreement  
400 between ActiPal and Actigraph for Assessing Children's Sedentary Time. *Int J*  
401 *Behav Nutr Phys Act.* 2012;9:15.
- 402 29. Tremblay MS. Major Initiatives Related to Childhood Obesity and Physical  
403 Inactivity in Canada: The Year in Review. *Can J Public Health.* 2012;103(3):164-9.
- 404 30. Tremblay MS, LeBlanc AG, Kho ME et al. Systematic Review of Sedentary  
405 Behaviour and Health Indicators in School-Aged Children and Youth. *Int J Behav*



- 406           *Nutr Phys Act.* 2011;8:98.
- 407   31.   Tremblay MS, Warburton DE, Janssen I et al. New Canadian Physical Activity  
408           Guidelines. *Appl Physiol Nutr Metab.* 2011;36(1):36-46; 7-58.
- 409   32.   Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical  
410           Activity in the United States Measured by Accelerometer. *Med Sci Sports Exerc.*  
411           2008;40(1):181-8.
- 412   33.   Trost SG, Pate RR, Sallis JF et al. Age and Gender Differences in Objectively  
413           Measured Physical Activity in Youth. *Med Sci Sports Exerc.* 2002;34(2):350-5.
- 414   34.   U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines*  
415           *for Americans.* Washington, DC: Department of Health and Human Services; 2008.  
416           15-18p.
- 417   35.   Wellburn S, Ryan CG, Azevedo LB et al. Displacing Sedentary Time: Association  
418           with Cardiovascular Disease Prevalence. *Med Sci Sports Exerc.* 2016;48(4):641-7.
- 419   36.   Wong SH, Huang WY, He G. Longitudinal Changes in Objectively Measured  
420           Physical Activity Differ for Weekdays and Weekends among Chinese Children in  
421           Hong Kong. *BMC Public Health.* 2015;15(1):1310.
- 422   37.   Zhang J, Seo DC, Kolbe L, Middlestadt S, Zhao W. Associated Trends in Sedentary  
423           Behavior and Bmi among Chinese School Children and Adolescents in Seven  
424           Diverse Chinese Provinces. *Int J Behav Med.* 2012;19(3):342-50.

Table 1. Baseline characteristics of the participants

	<b>Baseline sample<sup>#</sup></b> <b>(n = 1,020)</b>	<b>≥ 1 time points*</b> <b>(n = 672)</b>
Number of boys (%)	548 (53.7%)	359 (53.4%)
Age (yrs)	7.6 (1.0)	7.6 (1.0)
BMI (kg·m <sup>2</sup> )	17.1 (3.0)	17.1 (3.0)
Parental age (yrs)	38.9 (6.6)	38.8 (6.8)
Parental education (%)		
Lower secondary or less	32.2	33.3
Completed secondary	49.7	49.9
Tertiary	18.1	16.8
Parental BMI	22.3 (3.2)	22.5 (3.2)
Marital status (% single parent)	10.2%	10.6 %
Screen time (min·d <sup>-1</sup> )	114.5 (96.0)	116.5 (96.2)
Academic-related activities (min·d <sup>-1</sup> )	123.6 (91.5)	125.8 (91.7)
Other sedentary activities (min·d <sup>-1</sup> )	54.6 (56.5)	59.1 (59.5)
Sleep duration (min·d <sup>-1</sup> )	533.7 (42.4)	535.7 (42.9)

BMI, body mass index

Data are presented as mean (standard deviation, SD) unless otherwise specified. All the demographic information was reported by the parents except for the anthropometric measurements.

<sup>#</sup>for children who agreed to wear an accelerometer at baseline

\*for children who provided valid accelerometer data for at least one assessment wave

Screen time includes watching TV, playing electronic games and using the Internet (for leisure purpose); academic-related activities include doing homework, attending tutorial class and using the Internet for academic-related purposes; other sedentary behavior includes reading, sitting and talking, listening to music, and etc.

Table 2. Correlation matrix for behavior variables

	<b>MVPA</b>	<b>LPA</b>	<b>Screen time</b>	<b>Academic-related activities</b>	<b>Other sedentary behavior</b>	<b>Sleep</b>
MVPA	1					
LPA	0.35**	1				
Screen time	-0.11**	0.01	1			
Academic-related activities	-0.06*	-0.02	0.33**	1		
Other sedentary behavior	0.03	0.02	0.29**	0.38**	1	
Sleep	0.05*	-0.04	-0.07**	-0.08**	-0.00	1

\*p<0.05;\*\*p<0.01

MVPA, moderate-to-vigorous physical activity; LPA, light-intensity physical activity

Screen time includes watching TV, playing electronic games and using the Internet (for leisure purpose);

academic-related activities include doing homework, attending tutorial class and using the Internet for

academic-related purposes; other sedentary behavior includes reading, sitting and talking, listening to

music, and etc.

Table 3. Single, partition, and isothermal substitution models of associations between 30 min/day change in MVPA, LPA, different types of sedentary behavior, sleep and BMI<sup>a</sup>

<b>Models</b>	<b>Screen time</b>	<b>Academic-related activities</b>	<b>Other sedentary behavior</b>	<b>Sleep</b>	<b>LPA</b>	<b>MVPA</b>
Single model	0.03 (-0.01, 0.07)	0.01 (-0.02, 0.05)	<b>-0.07 (-0.13, -0.01)</b>	-0.03 (-0.12, 0.07)	<b>-0.06 (-0.12, -0.00)</b>	<b>-0.42 (-0.60, -0.25)</b>
Partition model	0.03 (-0.01, 0.06)	0.02 (-0.02, 0.06)	<b>-0.10 (-0.17, -0.03)</b>	-0.01 (-0.10, 0.08)	-0.03 (-0.09, 0.03)	<b>-0.39 (-0.57, -0.22)</b>
Isotemporal models						
Replace screen time	Dropped	-0.00 (-0.06, 0.06)	<b>-0.12 (-0.20, -0.04)</b>	-0.03 (-0.13, 0.06)	-0.05 (-0.12, 0.02)	<b>-0.42 (-0.59, -0.24)</b>
Replace academic-related activities	0.00 (-0.06, 0.06)	Dropped	<b>-0.13 (-0.21, -0.04)</b>	-0.04 (-0.14, 0.06)	-0.05 (-0.12, 0.02)	<b>-0.42 (-0.60, -0.24)</b>
Replace other sedentary behavior	<b>0.12 (0.04, 0.20)</b>	<b>0.13 (0.04, 0.21)</b>	Dropped	0.09 (-0.03, 0.20)	0.07 (-0.02, 0.16)	<b>-0.30 (-0.49, -0.10)</b>