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Isotemporal substitution analysis for sedentary behavior and body mass index

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Abstract

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

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

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

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

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

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

INTRODUCTION

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

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

Despite recent applications of isotemporal substitution analysis in physical activity research, current understanding of time allocation is limited to the effects of reallocating sedentary time (either objectively assessed or self-reported TV time) with MVPA and/or LPA. Furthermore, no studies conducted in youth have considered sleep. Other than screen time, specific sedentary behaviors have seldom been investigated in relation to obesity. A study conducted with Chinese children found that both studying time and screen time were positively associated with BMI among boys (37); however, the mechanism for this relationship remains unclear. Some studies have suggested that dietary intake is responsible for the observed association between screen time and adiposity (8, 13); others have indicated it is partly mediated by the displacement of MVPA (4). Whether sedentary behavior, other than screen time, yields different effects on obesity risk is little known. Such issues may be particularly important with respect to Chinese children because doing academic-related activities occupy large amounts of their discretionary time (16). Therefore, the purpose of this study was to examine the prospective associations of substituting different types of sedentary behavior, LPA, MVPA and sleep with BMI by using isotemporal substitution analysis. It was hypothesized that statistically displacing screen time with an equal amount of physical activity or other types of sedentary behaviors would lead to a 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

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

Anthropometric measurements

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

Sedentary behavior and sleep

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

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

Physical activity assessment

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

variables.

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

Other covariates

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

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

Statistical analysis

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

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

RESULTS

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 isotemporal 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

each other.

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

For sedentary behavior other than screen-based activities, little is known on their associations with adiposity. It is surprising to find that in the current study, replacement of 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

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

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

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

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

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

Conflict of Interest

The authors declare that they have no conflict of interest.

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Table 1. Baseline characteristics of the participants

	Baseline sample[#] (n = 1,020)	**≥ 1 time points* (n = 672)**
Number of boys (%)	548 (53.7%)	359 (53.4%)
Age (yrs)	7.6 (1.0)	7.6 (1.0)
BMI ($kg \cdot m^2$)	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 ($min \cdot d^{-1}$)	114.5 (96.0)	116.5 (96.2)
Academic-related activities ($min \cdot d^{-1}$)	123.6 (91.5)	125.8 (91.7)
Other sedentary activities ($min \cdot d^{-1}$)	54.6 (56.5)	59.1 (59.5)
Sleep duration ($min \cdot d^{-1}$)	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.

[#]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

	MVPA	**LPA**	**Screen time**	**Academic -related activities**	**Other sedentary behavior**	**Sleep**
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 isotemporal substitution models of associations between 30 min/day change in MVPA, LPA, different types of sedentary behavior, sleep and BMI[a]

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