Preventive Medicine 118 (2019) 159–165

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Associations between meeting combinations of 24-hour movement recommendations and dietary patterns of children: A 12-country study

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ARTICLE INFO

Keywords:
Physical activity
Screen time
Sleep
Diet
Food intake
Eating behavior
Pediatric

ABSTRACT

The purpose of this study was to examine whether meeting movement behavior recommendations (i.e., ≥60 min of moderate-to-vigorous physical activity [MVPA] per day, ≤2 h of recreational screen time per day, and between 9 and 11 h of nightly sleep), and combinations of these recommendations, are associated with dietary patterns of children. This cross-sectional study was conducted between 2011 and 2013 and included 5873 children 9–11 years of age from 12 countries around the world. MVPA and nightly sleep duration were measured using 24-hour waist-worn accelerometry. Screen time habits were assessed via self-report. A food frequency questionnaire was used to assess dietary patterns, and the whole diet was described by two components derived from principal component analysis: "healthy" and "unhealthy" dietary pattern scores. Covariates included in the multilevel statistical models included age, sex, highest parental education, and body mass index z-score. A healthier dietary pattern score was observed when more movement behavior recommendations were met. Among the three movement behaviors, limiting screen time habits to the recommended amount was most strongly associated with healthier dietary patterns. Similarly, a less unhealthy dietary pattern was observed when more movement behavior recommendations were met. Surprisingly, the highest unhealthy dietary pattern was associated with children meeting the MVPA recommendation alone. Combinations including ≤2 h of screen time per day were those most strongly associated with a less unhealthy dietary pattern. Findings were similar across study sites and in boys and girls. In conclusion, meeting more movement behavior recommendations is generally associated with better dietary patterns in children from around the world, with limiting screen time habits showing the strongest relationships.

1. Introduction

High physical activity, low screen time, and sufficient amounts of sleep (defined in this paper as "movement behaviors") are all important for overall health in children (Poitras et al., 2016; Carson et al., 2016a; Chaput et al., 2016). It is recommended that school-aged children spend ≥60 min per day in moderate-to-vigorous physical activity (MVPA), engage in ≤2 h per day of recreational screen time, and sleep between 9 and 11 h per night to promote health (Tremblay et al., 2016; World Health Organization, 2010; Hirshkowitz et al., 2015). We have recently shown that meeting all three recommendations of movement behaviors corresponds with the lowest odds ratio for obesity in children, while meeting two recommendations is better than meeting one, and meeting one is better than meeting none (Roman-Viñas et al., 2016). These

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https://doi.org/10.1016/j.ypmed.2018.10.025
Received 23 July 2018; Received in revised form 23 October 2018; Accepted 26 October 2018
Available online 27 October 2018

findings and others (Saunders et al., 2016; Carson et al., 2016b; Janssen et al., 2017) suggest that the whole day matters from a movement continuum perspective, and encouraging optimal levels of MVPA, limiting recreational screen time, and obtaining an adequate amount of sleep is important for the prevention of obesity in children.

Studies have reported that low levels of physical activity (Beaulieu et al., 2016), high levels of screen time (Thivel et al., 2013), and short sleep durations (Chaput, 2016) are all associated with increased food intake and poor diet quality in children. Thus, a key mechanism by which insufficient MVPA levels, high screen time levels, and insufficient sleep durations may lead to excess weight and obesity is through sub-optimal dietary patterns. Yet, it is largely unknown whether meeting all or certain combinations of the movement behavior recommendations is associated with better dietary patterns of children than meeting only single behaviors. This information is important for future interventions and clinical and public health guidelines aimed at preventing childhood obesity. The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is uniquely positioned to address this research question because it includes countries from around the world at differing levels of economic and human development. Indeed, data from ISCOLE permit us to test whether the associations among the behavioral recommendations are consistent across countries differing widely in human and economic development. Data establishing common associations among movement behaviors and eating patterns are important for the development of future interventions and clinical and public health guidelines.

The purpose of this study was to examine the associations between meeting recommendations for individual and combinations of 24-hour movement behaviors and dietary patterns of children from low- to high-income settings, and determine whether the associations vary by study site. We hypothesized that meeting a greater number of movement behavior recommendations would be associated with healthier (and less unhealthy) dietary patterns, irrespective of geographic location or country socioeconomic situation.

2. Methods

2.1. Study design and setting

ISCOLE is a multinational, cross-sectional study designed to examine the relationships between lifestyle behaviors and obesity in 12 countries from all inhabited continents of the world (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and United States). ISCOLE study sites were chosen because they represent a wide range of human development index, economic development, and income inequality. More information about the design and methods of ISCOLE can be found elsewhere (Katzmarzyk et al., 2013). Children from urban and suburban areas only (n = 256 schools in total) were recruited in ISCOLE in order to facilitate comparisons across sites and for logistical reasons. Data collection occurred between September 2011 and December 2013 and was conducted during the school year. A standardized protocol was followed for data collection to insure data quality, including rigorous training and certification of the personnel involved. The study was approved by the Pennington Biomedical Research Center Institutional Review Board as well as Institutional/Ethical Review Boards at each participating site. Parents/legal guardians gave their written informed consent, and child assent was also obtained.

2.2. Participants

ISCOLE included 9–11 year-old children, and each site aimed to recruit a sex-balanced sample of at least 500 children. Of the 7372 children who participated in ISCOLE, a total of 5873 remained in the present analytical sample. Reasons for exclusion included invalid accelerometry data (n = 1214) and missing information about screen time (n = 25), level of parental education (n = 255) and body mass index (BMI) z-scores (n = 5).

2.3. Measurements

2.3.1. Dietary patterns

A food frequency questionnaire (FFQ), adapted from the Health Behaviour in School-aged Children Survey (Currie et al., 2008; Mikkilä et al., 2015), was used to assess dietary patterns of children. The FFQ queried about usual consumption of 23 different food groups, with seven possible response options: "never", "less than once a week", "once a week", "2-4 days a week", "5-6 days a week", "once a day every day", and "more than once a day". The FFQ used in this study has been shown to be reliable (r = 0.52–0.82) in children (Vereecken and Maes, 2003). Dietary patterns of children were examined using principal components analyses (PCA) as reported previously (Mikkilä et al., 2015). The two strongest components were used for analysis: "healthy dietary pattern" (positive loadings for vegetables, fruit, whole grains, low-fat milk, etc.) and "unhealthy dietary pattern" (positive loadings for fast food, soft drinks, sweets, fried food etc.). The component scores were standardized to ensure normality, such that higher values represent either a "healthier" or "unhealthier" dietary pattern, respectively. It should be noted that each participant received a score for both components; hence, any combination of the healthy and unhealthy dietary pattern is possible. Country-specific component scores were used for this analysis.

2.3.2. Movement behaviors

MVPA was assessed with the use of an Actigraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL, USA) worn on the waist. Children were instructed to wear the device 24 h per day (except for water-related activities) and for a period of at least 7 days (including 2 weekend days). The average wear time in this study was 22.8 h per day. We included in our analyses only children with at least 4 days of waking wear time with at least 10 h per day (including at least one weekend day). Data were downloaded in 1-s epochs using the ActiLife software and were later reintegrated to 15-s epochs to determine MVPA levels.

Sleep duration was assessed using 60-s epochs and with the use of an automated algorithm validated for this study (Barreira et al., 2015). The algorithm has been shown to provide more precise estimates of sleep duration than previous ones based on 24-h accelerometry (Barreira et al., 2015; Tudor-Locke et al., 2014). To be included in this analysis (i.e., valid sleep duration), 3 days of valid sleep were required (≥160 min/night), including at least one weekend night. MVPA was then defined as ≥574 counts/15 s after the exclusion of sleep period time and awake non-wear time (defined as any sequence of ≥20 consecutive minutes of zero activity counts) (Evenson et al., 2008).

Screen time was self-reported by children using a lifestyle questionnaire (Katzmarzyk et al., 2013). Questions on screen time came from the US Youth Risk Behavior Surveillance System (U.S. Centers for Disease Control and Prevention, 2012) and asked about time watching TV, playing video games and using the computer on weekdays and weekends (response options: 0, < 1, 1, 2, 3, 4, and 5 or more hours). We calculated a daily average screen time score by weighting the responses (2/7 for weekend and 5/7 for weekday) and computing ' < 1' to '0.5' and '5 or more hours' to '5'. As previously reported, self-reported screen time assessments show acceptable validity and reliability in children (Lubans et al., 2011; Schmitz et al., 2004). Meeting the movement behavior recommendations was defined as ≥60 min/day for MVPA, ≤2 h/day for screen time, and between 9 and 11 h/night for sleep duration (Tremblay et al., 2016; World Health Organization, 2010; Hirshkowitz et al., 2015).

2.3.3. Covariates

Statistical models included age, sex, highest level of parental education, and BMI z-score as covariates. Age and sex were recorded on a questionnaire. Highest level of parental education was also self-reported and three categories were created: “did not complete high school”, “completed high school or some college”, or “completed bachelor's or postgraduate degree”. This was based on the highest level of education attained by either parent. Standing height and body weight were objectively measured using standardized procedures (Katzmarzyk et al., 2013) and BMI (kg/m^2) was calculated. Age- and sex-specific BMI z-scores were computed using the World Health Organization criteria (de Onis et al., 1997).

2.4. Statistical analysis

Descriptive characteristics (means and standard deviations) were computed by study site. Dietary patterns of children (healthy and unhealthy dietary pattern scores) were compared according to the combination of movement behaviors using an analysis of covariance with adjustment for covariates. Multilevel linear mixed model analysis (PROC MIXED) was used to investigate the differences in dietary patterns between children who meet and those who do not meet the different combinations of recommendations (fixed effects for study sites and random effects for schools). The Kenward and Roger approximation method (Kenward and Roger, 1997) was used to calculate denominator degrees of freedom for statistical tests pertaining to fixed effects. The level of significance was set at $p < 0.05$. Statistical analyses were conducted using JMP version 14 and SAS version 9.4 (SAS Institute, Cary, NC, USA).

3. Results

Table 1 shows descriptive characteristics of the children. On average children spent 60.2 min/day in MVPA (from 44.8 min/day in China to 72.0 min/day in Kenya), 2.9 h/day in screen time (from 2.0 h/day in India to 3.9 h/day in Brazil), and 8.8 h/night in sleep (from 8.3 h/night in Portugal to 9.5 h/night in the United Kingdom). We have not reported dietary pattern scores in the table as they are meaningless for descriptive purposes (by definition they have an overall mean of 0.00 ± 1.00 SD).

Findings from the multilevel models indicated that the largest proportion of total variance in healthy dietary pattern scores happened at the individual level (89%), followed by school (4%) and site (7%) levels. Similar findings were observed for unhealthy dietary pattern scores (individual, school, site: 63%; 11%; 26%). Overall, 19% of children met none of the recommendations, 44% met the MVPA recommendation, 39% met the screen time recommendation, 42% met the sleep recommendation, 17% met the MVPA + screen time combination, 18% met MVPA + sleep, 17% met screen time + sleep, and only 7% met all three movement behavior recommendations. We did not find significant sex interactions in the associations between combinations of movement behaviors and dietary patterns of children across sites. Boys and girls were therefore pooled together for analysis.

Fig. 1 shows mean dietary pattern scores of children who meet the different combinations of movement behaviors in the full study sample. Overall, a healthier dietary pattern was observed with more movement behavior recommendations met (Fig. 1A). Among the three single movement behavior recommendations, engaging in no > 2 h of screen time per day was the one more strongly associated with a healthier dietary pattern (even more so than meeting the MVPA + sleep duration recommendations together). With regard to unhealthy dietary patterns (e.g., fast food, fried foods, sweets, soft drinks), surprisingly, the unhealthiest dietary pattern was associated with meeting the MVPA recommendation alone, even more so than meeting none of the recommendations (Fig. 1B). Of the three movement behavior recommendations, here again, meeting the screen time recommendation was most strongly associated with a better dietary pattern (i.e., less unhealthy dietary pattern).

Fig. 2 also shows mean dietary pattern scores of children who meet the different combinations of movement behaviors in the full study sample, but using a bivariate graph. This figure allows showing the relative movement from the undesirable lower right quadrant (unhealthier dietary pattern) to the desirable upper left quadrant (healthier dietary pattern). This also shows how MVPA drags the scores to the unhealthy quadrant. Of interest, patterns of associations between dietary patterns and adherence with movement behavior recommendations were not different across study sites or by grouping of economic development (low, middle and high-income countries) (data not shown). This was also confirmed by the fact that there were no significant site interactions in the associations between movement behaviors and dietary patterns.

Table 2 shows dietary pattern scores in children meeting versus not meeting the movement behavior recommendations (and combinations), in the full ISCOLE sample. Children who met the screen time recommendation, the MVPA + screen time recommendation, the screen time + sleep recommendation, and all three recommendations had healthier dietary patterns than children not meeting these recommendations. The strongest association was seen when children met all three movement behavior recommendations, and limiting screen time habits to the recommended amount was most strongly associated with healthy dietary patterns. The unhealthiest dietary patterns were observed in children meeting the MVPA recommendation alone, while any combinations including limiting screen time habits

Table 1
Descriptive characteristics of participants stratified by study site (n = 5873).

Country (site)	Participants (n, % males)	Age (years)	MVPA (min/day)	Screen time (h/day)	Sleep duration (h/night)
Australia (Adelaide)	439 (46.5)	10.8 (0.4)	65.7 (23.1)	3.0 (1.6)	9.4 (0.7)
Brazil (Sao Paulo)	435 (48.5)	10.5 (0.5)	59.3 (26.3)	3.9 (2.1)	8.6 (0.8)
Canada (Ottawa)	502 (40.8)	10.5 (0.4)	58.5 (19.5)	2.8 (1.8)	9.1 (0.8)
China (Tianjin)	463 (51.6)	9.9 (0.5)	44.8 (15.7)	2.2 (1.5)	8.8 (0.6)
Colombia (Bogotá)	821 (49.1)	10.5 (0.6)	68.2 (24.9)	3.0 (1.5)	8.8 (0.8)
Finland (Helsinki, Espoo and Vantaa)	434 (45.2)	10.5 (0.4)	70.4 (26.7)	3.0 (1.5)	8.5 (0.9)
India (Bangalore)	526 (45.1)	10.5 (0.5)	48.5 (20.7)	2.0 (1.2)	8.6 (0.7)
Kenya (Nairobi)	458 (45.4)	10.3 (0.7)	72.0 (31.3)	2.5 (1.7)	8.6 (0.9)
Portugal (Porto)	578 (41.7)	10.5 (0.3)	55.3 (21.6)	2.5 (1.4)	8.3 (0.9)
South Africa (Cape Town)	391 (39.3)	10.3 (0.7)	63.4 (25.4)	3.3 (2.0)	9.2 (0.7)
UK (Bath and North East Somerset)	377 (43.0)	10.9 (0.5)	64.6 (22.8)	3.2 (1.6)	9.5 (0.7)
USA (Baton Rouge)	449 (40.1)	9.9 (0.6)	50.1 (18.8)	3.4 (2.2)	8.9 (0.9)
All sites	5873 (45.0)	10.4 (0.6)	60.2 (24.9)	2.9 (1.7)	8.8 (0.9)

MVPA, moderate-to-vigorous physical activity.
Data are shown as mean (standard deviation) unless otherwise indicated.
MVPA and sleep duration were based on accelerometer data and screen time was self-reported.
The study was conducted between 2011 and 2013.

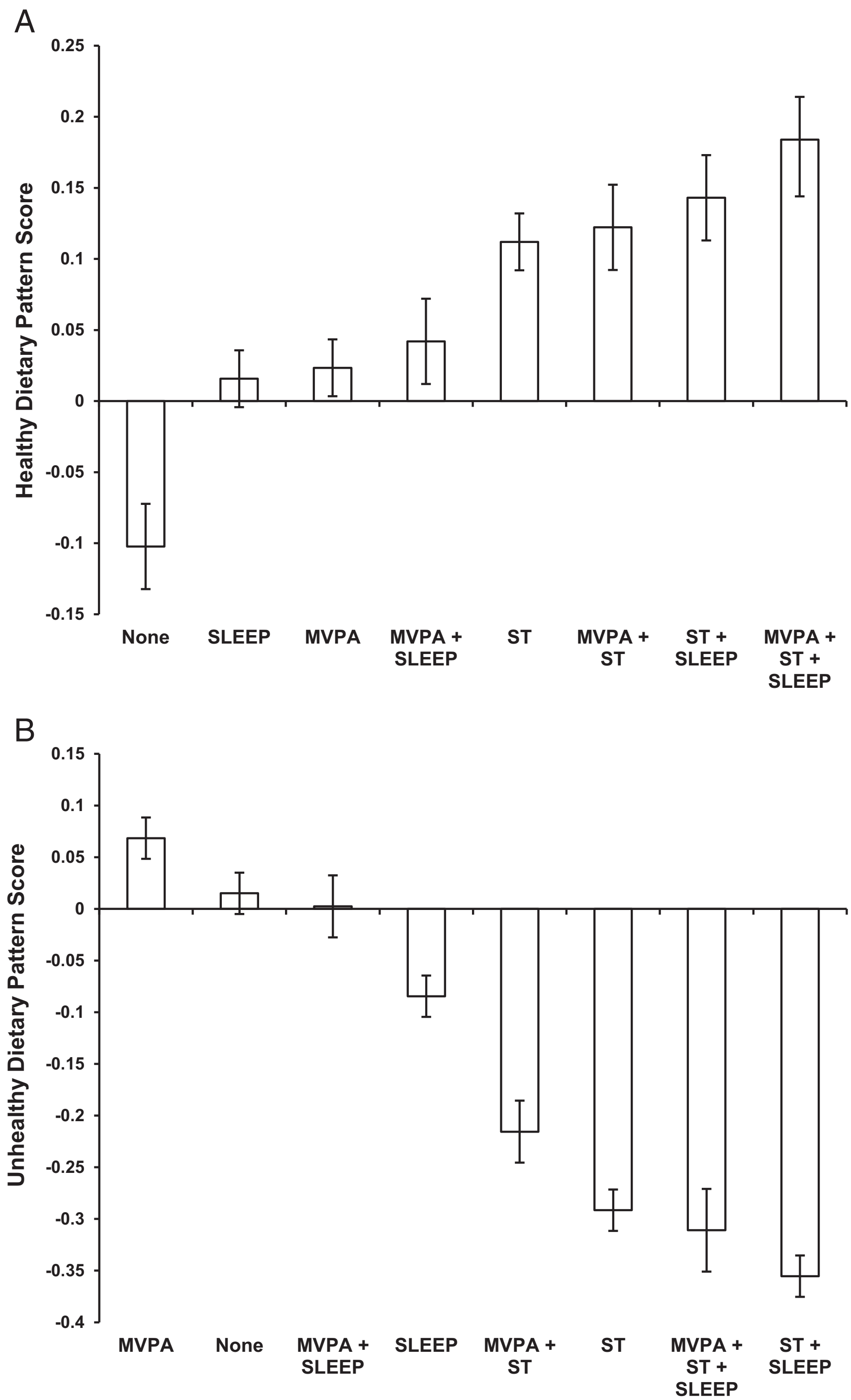

Fig. 1. Healthy dietary pattern scores (Fig. 1A) and unhealthy dietary pattern scores (Fig. 1B) in children meeting the different combinations of movement behaviors in the full study sample (n = 5873). Data are shown as adjusted means and standard errors of the mean. Means are adjusted for age, sex, highest level of parental education, and body mass index z-score. A significant main effect ($p < 0.01$) was observed between meeting combinations of movement behaviors and dietary patterns. MVPA, moderate-to-vigorous physical activity; ST, screen time; SLEEP, sleep duration. Meeting the recommendations is defined as accumulating ≥60 min/day of MVPA, limiting recreational screen time habits to ≤2 h/day, and getting between 9 and 11 h/night of sleep. The study was conducted between 2011 and 2013.

were those more strongly associated with less unhealthy dietary patterns (i.e., children less frequently ate unhealthy foods if they met the screen time recommendation). Findings were also similar across study sites (data not shown).

4. Discussion

To our knowledge, this study was the first to investigate the relationships between meeting various combinations of movement behaviors and dietary patterns in children from around the world. Collectively, we found that meeting more movement behaviors was generally associated with better dietary patterns of children. Among the three movement behaviors, meeting the screen time recommendation was the one most strongly associated with better dietary patterns. Similar associations between 24-hour movement behaviors and dietary patterns were found across sites and for boys and girls, suggesting that the present findings may apply broadly across different settings.

Our findings support current public health approaches by showing that meeting a combination of 24-hour movement guidelines is more likely to provide dividends than meeting single recommendations (Roman-Viñas et al., 2016; Saunders et al., 2016; Carson et al., 2016b; Janssen et al., 2017). However, when looking at the associations with dietary patterns in children, the present findings suggest that limiting screen time habits to the recommended amount of no more than 2 h per day is particularly important. This observation is in line with current evidence demonstrating that screen media exposure leads to obesity in

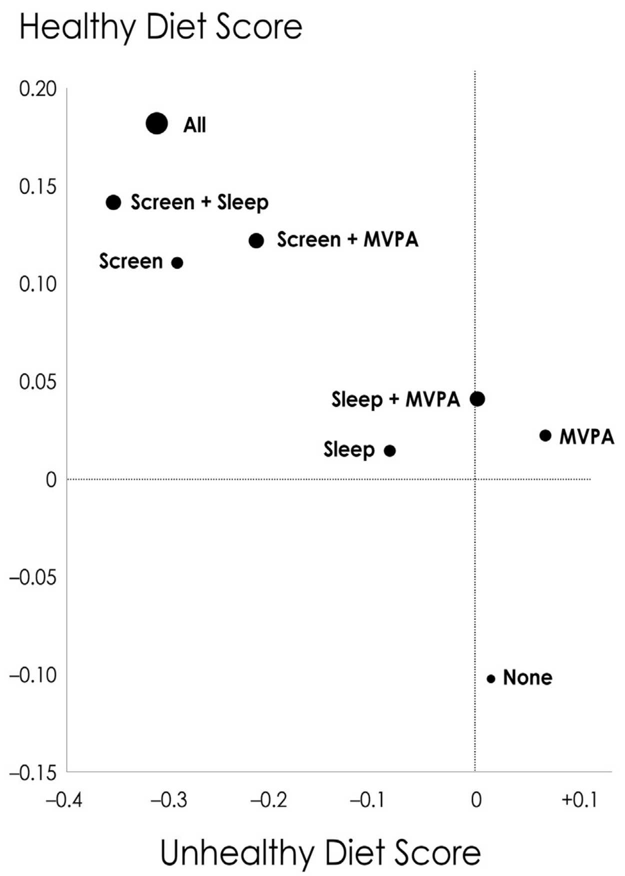

Fig. 2. Bivariate graph showing adjusted means of healthy (y-axis) and unhealthy (x-axis) dietary pattern scores of children meeting the different combinations of movement behaviors in the full study sample (n = 5873). Means are adjusted for age, sex, highest level of parental education, and body mass index z-score. MVPA, moderate-to-vigorous physical activity; ST, screen time; SLEEP, sleep duration. Meeting the recommendations is defined as accumulating ≥60 min/day of MVPA, limiting recreational screen time habits to ≤2 h/day, and getting between 9 and 11 h/night of sleep. The study was conducted between 2011 and 2013.

Table 2
Differences in dietary pattern scores between children meeting versus not meeting the moderate-to-vigorous physical activity, screen time, and sleep duration recommendations and combinations of these recommendations in the full study sample (n = 5873).

	Healthy dietary pattern score		Unhealthy dietary pattern score	
	Mean	SD	Mean	SD
MVPA				
Meet	0.0235	1.0209	0.0684*	1.0693
Do not meet	−0.0124	0.9790	−0.1350	0.8912
ST				
Meet	0.1121*	1.0185	−0.2915*	0.8377
Do not meet	−0.0671	0.9778	0.1147	1.0297
SLEEP				
Meet	0.0157	0.9965	−0.0845*	0.9474
Do not meet	−0.0054	0.9987	−0.0170	1.0003
MVPA + ST				
Meet	0.1222*	1.0528	−0.2155*	0.9114
Do not meet	−0.0201	0.9849	−0.0114	0.9884
MVPA + SLEEP				
Meet	0.0420	1.0018	0.0024	1.0359
Do not meet	−0.0052	0.9968	−0.0560	0.9655
ST + SLEEP				
Meet	0.1423*	1.0240	−0.3553*	0.7866
Do not meet	−0.0244	0.9902	0.0170	1.0018
All three recommendations				
Meet	0.1844*	1.0071	−0.3109*	0.8563
Do not meet	−0.0108	0.9958	−0.0243	0.9850

MVPA, moderate-to-vigorous physical activity; ST, screen time; SLEEP, sleep duration; SD, standard deviation.
Meeting the recommendations is defined as ≥60 min/day for MVPA, ≤2 h/day for recreational screen time, and between 9 and 11 h/night for sleep duration.
Models are adjusted for age, sex, highest level of parental education, and body mass index z-score.
Data are shown as mean (SD) of dietary pattern scores.
MVPA and sleep duration were accelerometer-determined while screen time was self-reported.
The study was conducted between 2011 and 2013.
* $p < 0.001$ versus do not meet the recommendation.

children via unhealthy eating behaviors while viewing (Robinson et al., 2017). Additionally, randomized controlled trials in community settings have shown that reducing screen time reduced weight gain in children, mainly via a change in eating behaviors (Robinson et al., 2017). It is thus not so surprising that eating behaviors of children would be better with less screen exposure in the present study. The greater challenge is to find ways to help the 61% of children exceeding the screen time recommendation, as found in our study. This is especially difficult in a context where screens have become so ubiquitous in today's world (Leblanc et al., 2017). Effective interventions could include removing the TV and other screen-based devices from the bedroom of the children, setting limits on personal screen interactions, and actively engaging children in alternative behaviors (Leblanc et al., 2017).

An interesting finding of this study is the observation that MVPA was the movement behavior more strongly associated with an unhealthy dietary pattern in children from across the globe. This suggests that children engaging in ≥60 min of MVPA daily are more likely to eat unhealthy foods (e.g., fried foods, fast food, soft drinks) than children not meeting this recommendation. It is increasingly recognized that the relationship between physical activity and eating behavior is complex and shows a large inter-individual variability (Blundell et al., 2015; Thivel et al., 2016). In some individuals, physical activity increases hunger and drives up food intake thereby offsetting the energy burnt through activity (Blundell et al., 2015). Some may even over-compensate in food (reward-driven eating behavior) for physical activities (Blundell et al., 2015). Unfortunately, the present findings cannot provide information about possible underlying mechanisms (only associations). However, it is not that surprising that active children eat more of everything (both healthy and unhealthy foods), because of their higher energy expenditure if they want to maintain energy balance.

Getting a sufficient amount of nightly sleep was the second movement behavior most strongly associated with better dietary patterns in this study. There is accumulating evidence for the idea that lack of sleep is a contributor to weight gain in children and that the main mediator is an increase in food intake (Chaput, 2016; Chaput, 2014). Recent experimental studies also show that extending sleep duration in short sleepers facilitates appetite control and helps controlling body weight (Chaput and Dutil, 2016). The present findings are consistent with this idea by showing that meeting the sleep duration recommendations was associated with better dietary patterns in children. The sleep + screen time combination was the one more strongly associated with less unhealthy dietary patterns. There is an important interrelationship between these two behaviors; screen time before bed has been shown to impact sleep and short sleepers are more likely to engage in screen time behaviors (Chaput, 2016).

The present study included sites from countries having wide variation in levels of economic development, human development, and geographic dispersion. We did not find different patterns of associations between sites, suggesting that the reported findings may apply broadly to children from around the world. We also observed that the relationships between meeting combinations of movement behaviors and dietary patterns were not different between boys and girls. This suggests that interventions aimed at increasing adherence to 24-hour movement guidelines (Tremblay et al., 2016), at least as it relates to dietary patterns of children, could be generalized across different settings and demographic subgroups of the population.

Some strengths and limitations deserve attention. Important strengths comprise the large multinational sample of children, the wide geographic representation, the use of objective measurements whenever possible, and the highly standardized measurement protocol and rigorous quality control program (Katzmarzyk et al., 2013). The main limitations comprise the cross-sectional study design that precludes inferences about causality and temporality, the use of self-reported measures for dietary patterns and screen time, the lack of information about energy intake (kcal/day) or context, the limited generalizability of our findings to urban and suburban areas, and the possibility of residual confounding by variables not measured in ISCOLE such as mental health.

5. Conclusions

Findings from this large multinational study of children show that meeting more movement behaviors was associated with better dietary patterns. In particular, meeting the screen time recommendation is the one most strongly associated with desirable dietary patterns of children. Findings were similar in boys and girls and across study sites, strengthening the generalizability of our findings. Future work should aim to find innovative ways to reduce screen time of children or to mitigate the suboptimal eating behaviors linked with screen media use.

Financial support

This work was supported by The Coca-Cola Company. With the exception of requiring that the study be global in nature, the funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Conflicts of interest

None.

Authorship

D.T. and J.-P.C. conceptualized and designed the study, carried out the statistical analyses, and drafted the manuscript. M.S.T., P.T.K., M.F., G.H., C.M., J.M., T.O., O.L.S., M.S., C.T.-L. and J.-P.C. conceptualized and designed the study. P.T.K. obtained funding. All authors critically revised the manuscript, approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Acknowledgments

We wish to thank the ISCOLE External Advisory Board and the ISCOLE participants and their families who made this study possible. The ISCOLE Research Group includes: **Coordinating Center**, **Pennington Biomedical Research Center**: Peter T. Katzmarzyk, PhD (Co-PI), Timothy S. Church, MD, PhD (Co-PI), Denise G. Lambert, RN (Project Manager), Tiago Barreira, PhD, Stephanie Broyles, PhD, Ben Butitta, BS, Catherine Champagne, PhD, RD, Shannon Cocreham, MBA, Kara D. Denstel, MPH, Katy Drazba, MPH, Deirdre Harrington, PhD, William Johnson, PhD, Dione Milauskas, MS, Emily Mire, MS, Allison Tohme, MPH, Ruben Rodarte MS, MBA; **Data Management Center**, **Wake Forest University**: Bobby Amoroso, BS, John Luopa, BS, Rebecca Neiberg, MS, Scott Rushing, BS; **Australia**, **University of South Australia**: Timothy Olds, PhD (Site Co-PI), Carol Maher, PhD (Site Co-PI), Lucy Lewis, PhD, Katia Ferrar, B Physio (Hon), Effie Georgiadis, BPsych, Rebecca Stanley, BAppSc (OT) Hon; **Brazil**, **Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul** (**CELAFISCS**): Victor Keihan Rodrigues Matsudo, MD, PhD (Site PI), Sandra Matsudo, MD, PhD, Timoteo Araujo, MSc, Luis Carlos de Oliveira, MSc, Luis Fabiano, BSc, Diogo Bezerra, BSc, Gerson Ferrari, MSc; **Canada**, **Children's Hospital of Eastern Ontario Research Institute**: Mark S. Tremblay, PhD (Site Co-PI), Jean-Philippe Chaput, PhD (Site Co-PI), Priscilla Bélanger, MA, Mike Borghese, MSc, Charles Boyer, MA, Allana LeBlanc, PhD, Claire Francis, MSc, Geneviève Leduc, PhD; **China**, **Tianjin Women's and Children's Health Center**: Pei Zhao, MD (Site Co-PI), Gang Hu, MD, PhD (Site Co-PI), Chengming Diao, MD, Wei Li, MD, Weiqin Li, MSc, Enqing Liu, MD, Gongshu Liu, MD, Hongyan Liu, MD, Jian Ma, MD, Yijuan Qiao, MD, Huiguang Tian, PhD, Yue Wang, MD, Tao Zhang, MSc, Fuxia Zhang, MD; **Colombia**, **Universidad de los Andes**: Olga Sarmiento, MD, PhD (Site PI), Julio Acosta, Yalta Alvira, BS, Maria Paula Diaz, Rocio Gamez, BS, Maria Paula Garcia, Luis Guillermo Gómez, Lisseth Gonzalez, Silvia Gonzalez, RD, Carlos Grijalba, MD, Leidys Gutierrez, David Leal, Nicolas Lemus, Etelvina Mahecha, BS, Maria Paula Mahecha, Rosalba Mahecha, BS, Andrea Ramirez, MD, Paola Rios, MD, Andres Suarez, Camilo Triana; **Finland**, **University of Helsinki**: Mikael Fogelholm, ScD (Site-PI), Elli Hovi, BS, Jemina Kivelä, Sari Räsänen, BS, Sanna Roito, BS, Taru Saloheimo, MS, Leena Valta; **India**, **St. Johns Research Institute**: Anura Kurpad, MD, PhD (Site Co-PI), Rebecca Kuriyan, PhD (Site Co-PI), Deepa P. Lokesh, BSc, Michelle Stephanie D'Almeida, BSc, Annie Mattilda R, MSc, Lygia Correa, BSc, Vijay Dakshina Murthy, BSc; **Kenya**, **Kenyatta University**: Vincent Onywera, PhD (Site Co-PI), Mark S. Tremblay, PhD (Site Co-PI), Lucy-Joy Wachira, PhD, Stella Muthuri, PhD; **Portugal**, **University of Porto**: Jose Maia, PhD (Site PI), Alessandra da Silva Borges, BA, Sofia Oliveira Sá Cachada, Msc, Raquel Nichele de Chaves, MSc, Thayse Natacha Queiroz Ferreira Gomes, PhD, MSc, Sara Isabel Sampaio Pereira, BA, Daniel Monteiro de Vilhena e Santos, PhD, Fernanda Karina dos Santos, MSc, Pedro Gil Rodrigues da Silva, BA, Michele Caroline de Souza, MSc; **South Africa**, **University of Cape Town**: Vicki Lambert, PhD (Site PI), Matthew April, BSc (Hons), Monika Uys, BSc (Hons), Nirmala Naidoo, MSc, Nandi Synyanya, Madelaine Carstens, BSc (Hons); **United Kingdom**, **University of Bath**: Martyn Standage, PhD (Site PI), Sean Cumming, PhD, Clemens Drenowatz, PhD, Lydia Emm, MSc, Fiona Gillison, PhD, Julia Zakrzewski, PhD; **United States**, **Pennington Biomedical Research Center**: Catrine Tudor-Locke, PhD (Site-PI), Ashley Braud, Sheletta Donatto, MS, LDN, RD, Corbin Lemon, BS, Ana Jackson, BA, Ashunti Pearson, MS, Gina Pennington, BS, LDN, RD, Daniel Ragus, BS, Ryan Roubion, John Schuna, Jr., PhD; Derek Wiltz. **The ISCOLE External Advisory Board includes** Alan Batterham, PhD, Teesside University, Jacqueline Kerr, PhD, University of California, San Diego; Michael Pratt, MD, Centers for Disease Control and Prevention, Angelo Pietrobelli, MD, Verona University Medical School.

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