International Journal of Obesity Supplements (2015) 5, S59–S65

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REVIEW

Associations between sleep patterns and lifestyle behaviors in children: an international comparison

J-P Chaput[1], PT Katzmarzyk[2], AG LeBlanc[1,3], MS Tremblay[1], TV Barreira[2,4], ST Broyles[2], M Fogelholm[5], G Hu[2], R Kuriyan[6], A Kurpad[6], EV Lambert[7], DE Rae[7], C Maher[8], J Maia[9], V Matsudo[10], V Onywera[11], OL Sarmiento[12], M Standage[13], C Tudor-Locke[2,14], P Zhao[15] and T Olds[8] for the ISCOLE Research Group

OBJECTIVES: Although evidence is accumulating on the importance of a good night's sleep for healthy eating and activity behaviors, existing research has mainly been conducted in high-income, developed countries with limited sociocultural variability. This study is the first to examine the associations between sleep patterns and lifestyle behaviors in children from 12 countries in five major geographic regions of the world.

METHODS: This observational, multinational cross-sectional study included 5777 children aged 9–11 years from sites in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the United Kingdom and the United States. Nocturnal sleep duration (hours per night), sleep efficiency (%) and bedtime (h:min) were monitored over 7 consecutive days using an accelerometer. Lifestyle behaviors included moderate-to-vigorous physical activity (MVPA), total sedentary time (SED), self-reported screen time (ST) and healthy/unhealthy diet patterns (HDP/UDP). Multilevel modeling analyses were used to account for the hierarchical nature of the data.

RESULTS: Overall, participants averaged 8.8 (s.d. 0.9) hours of sleep with 96.2% (s.d. 1.4) sleep efficiency and a mean bedtime of 2218 hours. After adjustment for age, sex, highest parental education and BMI *z*-score, results showed that (i) sleep duration was negatively associated with MVPA, SED and UDP score; (ii) sleep efficiency was negatively associated with MVPA and UDP score, and positively associated with SED; and (iii) later bedtime was positively associated with SED, ST and UDP score, and negatively associated with MVPA and HDP score. Results using categories of sleep patterns were consistent with the linear associations. Results also revealed that associations between sleep patterns and MVPA, SED and ST were significantly different between study sites, with stronger associations in high-income countries compared with low/middle-income countries.

CONCLUSIONS: Sleep characteristics are important correlates of lifestyle behaviors in children. Differences between countries suggest that interventions aimed at improving sleep and lifestyle behaviors should be culturally adapted.

International Journal of Obesity Supplements (2015) **5,** S59–S65; doi:10.1038/ijosup.2015.21

INTRODUCTION

Insufficient sleep (short sleep duration and/or poor sleep quality) has become pervasive in contemporary societies with 24/7 availability of commodities.[1,2] School-aged children and adolescents generally sleep less now compared with decades ago,[3,4] and factors responsible for this secular decline in sleep duration are generally ascribed to the modern way of living (that is, artificial light, late-night screen time (ST) and no bedtime rules in the household).[5] Insufficient sleep has consistently been shown to exert wide-ranging adverse effects on a variety of body systems,[6] and epidemiological evidence shows that curtailed sleep is associated with a higher risk of chronic diseases including obesity.[7–9]

Beyond sleep duration and quality, sleep timing (combination of bedtime and wake-up time) is gaining recognition as an important additional factor to consider for the promotion of good health outcomes and behaviors.[10–12] A recent cross-sectional study in Australian children showed that a combination of late bedtimes and late wake-up times was associated with a higher risk of obesity and poorer diet quality, independent of sleep duration, physical activity level and sociodemographic characteristics.[13] Likewise, children with late bedtimes/wake-up times have been reported to engage in less moderate-to-vigorous physical activity (MVPA) and more ST compared with a group of children with early bedtimes/wake-up times, despite having similar sleep durations.[14]

Although empirical evidence is accumulating on the importance of a good night's sleep for adequate eating and activity behaviors, existing research has mainly been conducted in high-income, developed countries with limited sociocultural variability.[15] The present multinational study is unique in its international diversity and provides an opportunity to determine whether the relationships between sleep characteristics and

[1]Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada; [2]Pennington Biomedical Research Center, Baton Rouge, LA, USA; [3]University of Ottawa, Ottawa, Ontario, Canada; [4]Department of Exercise Science, University of Syracuse, Syracuse, NY, USA; [5]Department of Food and Environmental Sciences, University of Helsinki, Helsinki, Finland; [6]St. Johns Research Institute, Bangalore, India; [7]Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa; [8]Alliance for Research in Exercise Nutrition and Activity (ARENA), School of Health Sciences, University of South Australia, Adelaide, South Australia, Australia; [9]CIFI2D, Faculdade de Desporto, University of Porto, Porto, Portugal; [10]Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul (CELAFISCS), Sao Paulo, Brazil; [11]Department of Recreation Management and Exercise Science, Kenyatta University, Nairobi, Kenya; [12]School of Medicine Universidad de los Andes, Bogota, Colombia; [13]Department for Health, University of Bath, Bath, UK; [14]Department of Kinesiology, University of Massachusetts Amherst, Amherst, MA, USA and [15]Tianjin Women's and Children's Health Center, Tianjin, China. Correspondence: Dr J-P Chaput, Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Road, Ottawa, Ontario, Canada K1H 8L1.
E-mail: jpchaput@cheo.on.ca

lifestyle behaviors differ across countries and across different environmental and sociocultural settings. Such information is key to informing the development of interventions that can be culturally adapted for implementation around the world.

The objective of this study was thus to examine the associations between sleep characteristics (duration, efficiency and bedtime) and lifestyle behaviors (physical activity, sedentary behavior and eating patterns) in children from 12 countries representing a wide range of geographic and sociocultural variability. We hypothesized that shorter sleep duration, poorer sleep efficiency and later bedtimes would be associated with unfavorable lifestyle behaviors. We also hypothesized that the associations between sleep characteristics and lifestyle behaviors would differ across study sites.

MATERIALS AND METHODS

Setting

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to determine the relationships between lifestyle behaviors and obesity in 12 study sites located in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the United Kingdom and the United States. These countries represent a wide range of economic development (low to high income), Human Development Index (0.509 in Kenya to 0.929 in Australia) and inequality (GINI coefficient).[16] The design and methods have been published in detail elsewhere.[16] By design, the within-site samples were not intended to be nationally representative. Rather, the primary sampling frame was schools, which was typically stratified by an indicator of socioeconomic status to maximize variability within sites.[16] A standard protocol was used to collect data across all sites, and all study personnel underwent rigorous training and certification before and during the data collection to ensure the quality of data collected.[16] The Institutional Review Board at the Pennington Biomedical Research Center in Baton Rouge, USA (coordinating center) approved the ISCOLE protocol, and the Ethical Review Boards at each participating institution also approved the local protocol. Written informed consent was obtained from parents or legal guardians, and child assent was also obtained as required by local Ethical Review Boards before participation in the study. Data were collected from September 2011 to December 2013.

Participants

The sample included 9–11-year-old children from the 12 ISCOLE sites. The recruitment goal was to enroll at least 500 children per site. A total of 7372 children participated in ISCOLE, of which 5777 remained in the present analytic data set after excluding participants without valid accelerometry ($n=1214$), information on ST ($n=2$), diet ($n=127$), parental education ($n=247$) or BMI z-score ($n=5$). Participants who were excluded due to missing data did not differ in their descriptive characteristics (except for BMI z-scores, which were significantly higher) compared with those who were included in the analysis.

Measurement of sleep patterns and lifestyle behaviors

Sleep patterns (nocturnal sleep time, sleep efficiency and bedtime), MVPA and total sedentary time (SED) were all objectively assessed using 24-h, waist-worn accelerometry. An Actigraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL, USA) was worn at the waist on an elasticized belt at the right mid-axillary line. Participants were encouraged to wear the accelerometer 24 h per day (removing only for water-related activities) for at least 7 days, including 2 weekends. The minimal amount of daytime data that was considered acceptable for inclusion in the sample was at least 4 days with at least 10 h of wake wear time per day, including at least 1 weekend day. Data were collected at a sampling rate of 80 Hz, downloaded in 1-s epochs with the low-frequency extension filter using the ActiLife software version 5.6 or higher (ActiGraph LLC, Pensacola, FL, USA). Data were later reintegrated to 15- and 60-s epochs for the different analyses. Nocturnal sleep duration was estimated from the accelerometry data using 60-s epochs and a fully automated algorithm for 24-h waist-worn accelerometers that was recently validated for ISCOLE.[17] This new algorithm produces more precise estimates of sleep duration than previous algorithms and captures total sleep time from sleep onset to the end of sleep, including all epochs and wakefulness after onset.[17,18] The weekly total sleep time averages were calculated using only days where valid sleep was accumulated (total sleep period time $\geqslant$ 160 min) and only for participants with at least 3 nights of valid sleep, including 1 weekend night (Friday or Saturday). The same device was used to determine sleep efficiency (total sleep episode time divided by sleep period time) and bedtime (first 5 consecutive minutes defined as sleep).[17,18] After exclusion of total sleep time and awake non-wear time (any sequence of $\geqslant$ 20 consecutive minutes of 0 activity counts), MVPA was defined as all activity $\geqslant$ 574 counts per 15 s and total SED as all movement $\leqslant$ 25 counts per 15 s, consistent with the widely used Evenson cutoffs.[19] After testing for normality, MVPA was log-transformed for analysis.

Child-reported ST was determined from a lifestyle questionnaire,[16] and questions were obtained from the US Youth Risk Behavior Surveillance System.[20] Children were asked how many hours they typically watched TV, and how many hours they played video games and/or used the computer per week day, and per weekend. Response options were 0, <1, 1, 2, 3, 4 and 5 or more hours per day. A daily average score was computed by recording '<1' to '1' and '5 or more hours' to '5', and weighting the responses (2/7 for weekend; 5/7 for weekday). For analysis, this is presented as a ST score, rather than total hours of ST, as after 5 h per day, we could not ascertain the participant's actual amount of ST. Self-report methods of quantifying ST have been reported to have acceptable reliability and validity in children.[21,22] After testing for normality, ST was log-transformed and analyzed as a continuous variable.

Finally, dietary patterns were assessed using a food frequency questionnaire (FFQ) adapted from the Health Behavior in School-aged Children Survey.[23] The FFQ asks the participant about 'usual' consumption of 23 different food groups, with response categories including never, less than once per week, once per week, 2–4 days per week, 5–6 days per week, once a day every day and more than once a day. A version of this FFQ has been shown to be reliable ($r=0.52$–0.82) for ranking the frequency of consumption of food items in children.[24] Dietary patterns were investigated by employing principal components analyses to identify derived variables (factors). Reported frequencies were converted into portions per week. The analyses were performed first using the total data set and second for each country separately. Eigenvalues and a scree plot analysis were used as the criteria for deciding the number of factors extracted. The two criteria led to similar conclusions and two factors were chosen for analysis. The factors were then rotated using an orthogonal varimax transformation to force non-correlation of the factors and to enhance the interpretation. The two factors represented an 'unhealthy diet pattern' (UDP, with positive loadings for fast food, hamburgers, soft drinks, sweets, fried food and so on) and a 'healthy diet pattern' (HDP, with positive loadings for vegetables, fruit, whole grains, low-fat milk and so on). The factor scores computed for each participant for both eating patterns were standardized to ensure normality, and higher values for each score represent either an 'unhealthier' or 'healthier' eating pattern, respectively. Most of the food items in both factors were common

Table 1. Descriptive characteristics of participants stratified by study site ($n = 5777$)

Country (site)	*Participants (n, % males)*	*Age (years)*	*MVPA (minutes per day)*	*SED (hours per day)*	*Screen time score*	*Sleep duration (hours per day)*	*Sleep efficiency (%)*	*Bedtime (h:min)*
Australia (Adelaide)	433 (46.7)	10.7 (0.4)	65.6 (23.0)	8.0 (1.0)	2.8 (1.7)	9.4 (0.7)	95.4 (1.3)	21:53
Brazil (Sao Paulo)	435 (48.5)	10.5 (0.5)	59.3 (26.3)	8.4 (1.1)	3.7 (2.2)	8.6 (0.8)	95.5 (1.3)	23:10
Canada (Ottawa)	496 (40.9)	10.5 (0.4)	58.5 (19.5)	8.6 (1.0)	2.5 (1.9)	9.1 (0.8)	96.1 (1.3)	22:10
China (Tianjin)	459 (51.6)	9.9 (0.5)	44.8 (15.7)	9.5 (1.1)	1.9 (1.6)	8.8 (0.6)	96.5 (1.2)	22:03
Colombia (Bogotá)	820 (49.2)	10.5 (0.6)	68.2 (24.9)	8.4 (1.1)	2.9 (1.5)	8.8 (0.8)	95.9 (1.2)	21:53
Finland (Helsinki, Espoo and Vantaa)	526 (45.3)	10.4 (0.5)	70.5 (26.7)	8.6 (1.1)	1.8 (1.3)	8.6 (0.7)	96.6 (1.2)	22:46
India (Bangalore)	433 (45.1)	10.5 (0.4)	48.5 (20.7)	8.9 (1.1)	2.8 (1.7)	8.5 (0.9)	96.8 (1.1)	22:35
Kenya (Nairobi)	452 (45.4)	10.2 (0.7)	72.1 (31.4)	8.3 (1.1)	2.4 (1.7)	8.6 (0.9)	95.9 (1.4)	21:42
Portugal (Porto)	563 (41.6)	10.4 (0.3)	55.1 (21.5)	9.3 (1.0)	2.3 (1.5)	8.3 (0.9)	97.2 (0.9)	23:17
South Africa (Cape Town)	452 (38.6)	10.2 (0.7)	63.4 (25.4)	8.2 (1.1)	3.1 (2.1)	9.2 (0.7)	96.1 (1.4)	21:47
UK (Bath and North East Somerset)	374 (42.8)	10.9 (0.4)	64.4 (22.7)	8.3 (0.9)	3.0 (1.7)	9.5 (0.7)	95.7 (1.4)	22:03
USA (Baton Rouge)	421 (40.4)	9.9 (0.6)	50.0 (19.0)	8.7 (1.0)	3.2 (2.3)	8.9 (0.9)	96.0 (1.2)	22:12
All sites	5777 (45.0)	10.4 (0.6)	60.2 (24.9)	8.6 (1.1)	2.7 (1.8)	8.8 (0.9)	96.2 (1.4)	22:18

Abbreviations: MVPA, moderate-to-vigorous physical activity; SED, sedentary time. Data are shown as mean (s.d.) unless otherwise indicated.

for all 12 countries. For this analysis, we have chosen to use the country-specific factor scores to be more representative of each site, although the difference between these and the factor scores from the pooled data were small.

Covariates

Age, sex, highest parental education and body mass index (BMI) *z*-score were included as covariates in statistical models. Age was computed from birth, and observation dates and sex were recorded on a questionnaire. The highest level of parental education (with options ranging from less than high school to graduate degree) was reported by the parent or guardian and three categories were created to facilitate analysis across sites (that is, did not complete high school, completed high school or some college and bachelor's or postgraduate degree). Overall, 594 participants (10%) were missing data on household income so education was used instead as a proxy for socioeconomic status. Body weight and height were measured according to the standardized procedures by trained ISCOLE staff.[16] BMI ($kg\ m^{-2}$) was calculated, and BMI *z*-scores were computed using age- and sex-specific reference data from the World Health Organization.[25] Of note, biological maturity was estimated using the maturity offset method in ISCOLE; however, because age and weight are included in the maturity offset calculation, biological maturity could not be included as a covariate in our analyses.

Statistical analysis

Statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC, USA). Means and s.d.'s of descriptive characteristics were computed by study site. Multilevel multi-variable linear regression (PROC MIXED) was used to examine the associations between sleep patterns and lifestyle behaviors. Age, sex, highest parental education and BMI *z*-score were included as covariates in the models. Multilevel modeling analyses were used to properly account for the hierarchical nature of the data. Study sites were considered to have fixed effects, and schools nested within study sites were viewed as having random effects. The denominator degrees of freedom for statistical tests pertaining to fixed effects were calculated using the Kenward and Roger approximation.[26] Trends in lifestyle behaviors were examined across ordered sex-specific quintile categories for each of the sleep variables, with adjustments for age, highest parental education and BMI *z*-score. Differences across sites in the associations were examined using interaction terms; site-by-sleep interactions were retained when $P < 0.05$. The level of significance was set at $P < 0.05$.

RESULTS

Descriptive characteristics of the sample are shown in Table 1. The average sleep duration was 8.8 ± 0.9 h per night, below the National Sleep Foundation's recommendation[27] of 9–11 h of sleep per day for school-aged children (58% of kids were below this threshold). Children were very sleep efficient ($96.2 \pm 1.4\%$) and had a mean bedtime of 2218 hours. Data on HDP and UDP are not reported in the table as they are meaningless for descriptive purposes, as by definition they have an overall mean of 0.00 ± 1.00 s.d.

On the basis of the results from the multilevel models, the largest fraction of the total variance in lifestyle behaviors occurred at the individual level (from 62.1% for MVPA to 96.0% for UDP), followed by schools (from 4.0% for HDP to 24.3% for MVPA) and sites (from 0% for HDP/UDP to 18.1% for SED). After adjustment for covariates, (i) sleep duration was negatively associated with MVPA, SED and UDP score; (ii) sleep efficiency was negatively associated with MVPA and UDP score, and positively associated with SED; and (iii) bedtime was positively associated with SED, ST and UDP score, and negatively associated with MVPA and HDP score (Table 2). Additional adjustments for sleep duration and bedtime (when not already in the model) did not affect the strength of associations (data not shown). Also, expressing MVPA and SED as a percentage of the wake time (as opposed to hours per day) did not affect the relationships with sleep patterns (data not shown).

Results also revealed that associations between sleep patterns (duration, efficiency and bedtime) and MVPA, SED and ST were different between study sites (that is, site-by-sleep interactions were found in the adjusted models; data not shown). Interestingly, results showed that the associations between sleep patterns and these lifestyle behaviors were significantly stronger in high-income countries (especially the United Kingdom, the United States and Australia) compared with low/middle-income countries (especially Kenya and India; data not shown). However, the relationships between sleep patterns and HDP/UDP were similar across sites (P for interaction between 0.11 and 0.86).

Figures 1–3 present trends in lifestyle behaviors across quintiles of sleep duration (Figure 1), sleep efficiency (Figure 2) and bedtime (Figure 3). Findings observed while categorizing sleep patterns are generally consistent with the linear associations

Table 2. Associations between sleep patterns and lifestyle behaviors in 5777 9–11-year-old children

	MVPA (minutes per day)			*SED (hours per day)*			*Screen time score*			*Healthy diet pattern*			*Unhealthy diet pattern*		
	β	*95% CI*	P	β	*95% CI*	P	β	*95% CI*	P	β	*95% CI*	P	β	*95% CI*	P
Sleep duration (hours per night)															
Model 1	−1.15	−1.19; −1.11	< 0.0001	−0.38	−0.41; −0.34	< 0.0001	−1.01	−1.05; 1.03	0.63	0.01	−0.03; 0.04	0.75	−0.05	−0.09; −0.02	< 0.01
Model 2	−1.13	−1.16; −1.09	< 0.0001	−0.37	−0.41; −0.34	< 0.0001	1.03	−1.01; 1.54	0.16	0.001	−0.03; 0.04	0.97	−0.04	−0.07; −0.01	0.04
Sleep efficiency (%)															
Model 1	−3.63	−4.40; −2.87	< 0.0001	8.45	6.33; 10.57	< 0.0001	−10.47	−96.81; −1.13	0.04	−0.15	−2.21; 1.91	0.89	−4.37	−6.37; −2.37	< 0.0001
Model 2	−2.65	−3.36; −1.94	< 0.0001	8.03	5.92; 10.14	< 0.0001	1.03	−8.84; 9.30	0.98	−0.46	−2.54; 1.61	0.66	−3.47	−5.47; −1.47	< 0.001
Bedtime (h:min)															
Model 1	−1.1	−1.15; −1.05	< 0.0001	0.36	0.31; 0.41	< 0.0001	1.2	1.14; 1.26	< 0.0001	−0.07	−0.11; −0.02	< 0.01	0.08	0.03; 0.12	< 0.001
Model 2	−1.08	−1.13; −1.03	< 0.0001	0.36	0.31; 0.41	< 0.0001	1.19	1.14; 1.25	< 0.0001	−0.07	−0.11; −0.02	< 0.01	0.08	0.04; 0.13	< 0.001

Abbreviations: CI, confidence interval; MVPA, moderate-to-vigorous physical activity; SED, sedentary time. Model 1: unadjusted. Model 2: adjusted for age, sex, highest parental education and body mass index z-score. Unstandardized beta coefficients are presented; data for MVPA and screen time have been back transformed to their original units.

found in Table 2 and do not suggest U-shaped relationships with the outcomes variables.

DISCUSSION

The present study was the first to examine the associations between sleep patterns and lifestyle behaviors in children across five major geographic regions of the world (Europe, Africa, the Americas, South-East Asia and the Western Pacific) representing a wide range of sociocultural variability. Findings from this study revealed that sleep characteristics (duration, efficiency and bedtime) are important correlates of lifestyle behaviors in children. Relationships between sleep patterns and MVPA, SED and ST were also found to significantly differ among study sites, with stronger associations in high-income countries compared with low/middle-income countries. Collectively, these findings suggest that interventions aimed at improving sleep and lifestyle behaviors should be culturally adapted to maximize success. More sleep studies in low/middle-income countries are also needed to understand and determine whether the connection between sleep patterns and lifestyle behaviors differs compared with high-income countries.

The observation that short sleep duration and poor sleep efficiency were associated with higher levels of MVPA contradicts our hypothesis and the idea that fatigue and tiredness generally associated with inadequate sleep could result in reduced voluntary physical activity in some individuals.[28] However, studies investigating the association between sleep and physical activity are far from being consistent and report large interindividual variations.[29] Our results agree with other cross-sectional studies showing that children who are more physically active during the day have shorter total sleep time than less active children.[14,30,31] Several theories may explain this finding, including the fact that there are only a certain number of hours in the day and sleeping longer produces an overall time deficit thereby reducing time in other activities.[32] Also, the fact that sleep and MVPA were measured over a week with average values used in the analyses means that days with high MVPA are not compared with sleep that night. In other words, it is possible that days with high MVPA are days with longer sleep durations, but this is washed out when behaviors are averaged. In contrast, results obtained with bedtime as the exposure variable are in line with our hypothesis and previous evidence showing that later bedtimes are associated with lower MVPA in children.[14,33,34]

The associations between sleep timing and SED/ST are consistent with our hypothesis and previous research showing that later bedtimes are associated with greater sedentary behaviors.[14,15,34,35] Likewise, short sleep duration was associated with more SED. However, in contrast to our hypothesis, good sleep efficiency was associated with longer SED. Reasons behind this finding are unknown and warrant further investigation. Given the cross-sectional nature of the data, the temporal sequence of events cannot be inferred, and one must be cautious in the interpretation of this observation.

Relationships between sleep patterns and eating patterns are in line with our hypothesis and previous evidence in the field.[12,36,37] We found that shorter sleep duration, poorer sleep efficiency and later bedtimes were associated with unhealthy eating patterns in this sample of children. There is accumulating evidence showing that sleep has an influence on eating behaviors. Inadequate sleep habits have been reported to increase snacking, the number of meals eaten per day and the preference for energy-dense foods.[15] Proposed mechanisms by which insufficient sleep may increase energy intake include: more time and opportunities for eating, psychological distress, greater sensitivity to food reward, disinhibited eating, more energy needed to sustain extended wakefulness and changes in appetite hormones.[15]

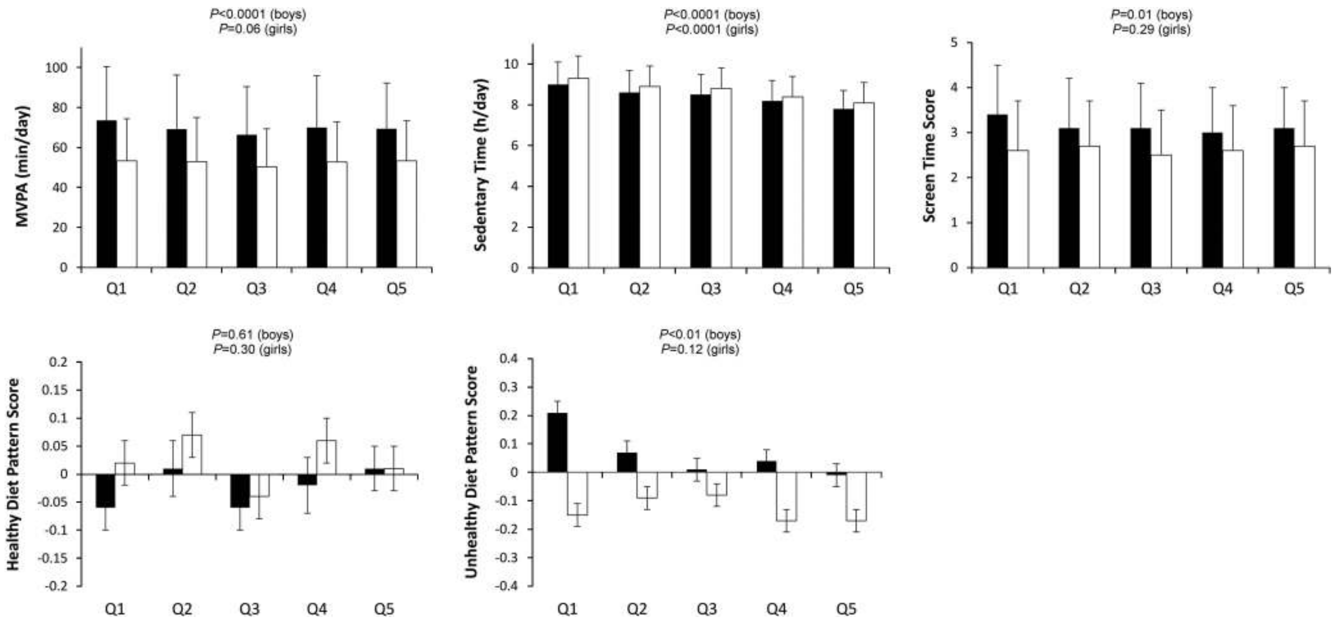

Figure 1. Trends in lifestyle behaviors across quintiles of nocturnal sleep duration in boys (black bars) and girls (white bars). Error bars represent s.d.'s for moderate-to-vigorous physical activity (MVPA), sedentary time and screen time score. S.e.'s are represented for healthy/unhealthy diet pattern scores. *P*-values for linear trends across quintiles in both boys and girls are shown in the figure. The models are adjusted for age, highest parental education and BMI *z*-score.

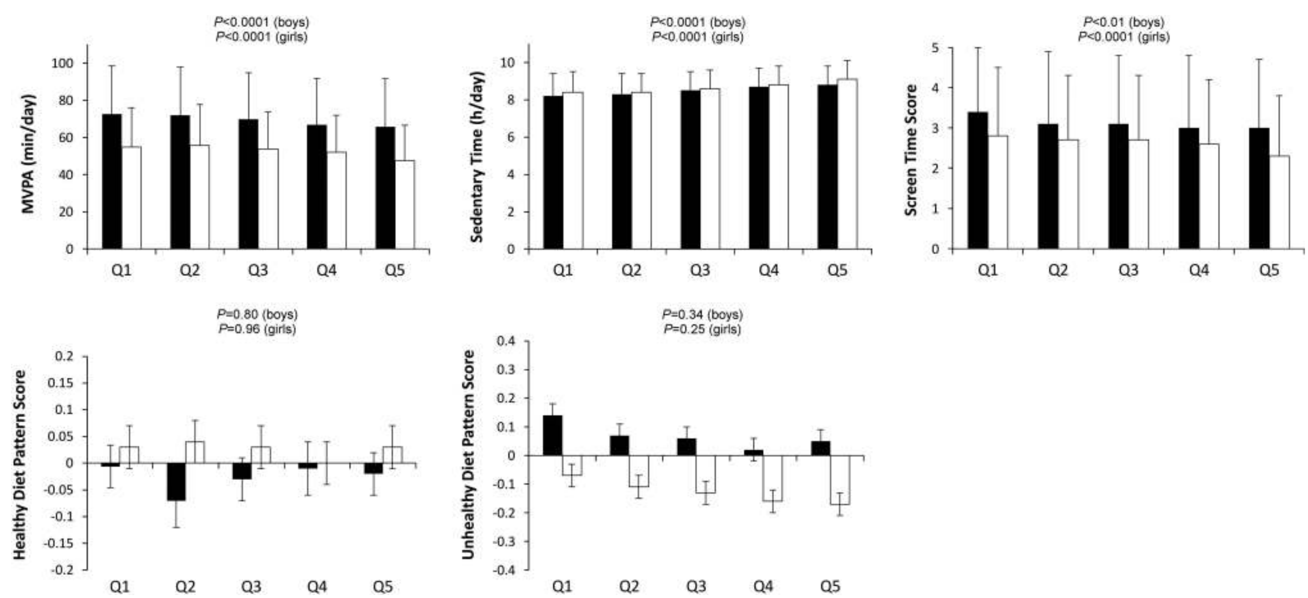

Figure 2. Trends in lifestyle behaviors across quintiles of nocturnal sleep efficiency in boys (black bars) and girls (white bars). Error bars represent s.d.'s for moderate-to-vigorous physical activity (MVPA), sedentary time and screen time score. S.e.'s are represented for healthy/unhealthy diet pattern scores. *P*-values for linear trends across quintiles in both boys and girls are shown in the figure. The models are adjusted for age, highest parental education and BMI *z*-score.

Although the multilevel analysis used in the present study does not provide estimates of the effect size for the reported associations, Figures 1–3 reveal that some of the relationships are clinically meaningful from a public health standpoint. For example, children in the highest quintile of sleep duration (that is, longer sleep) averaged 1.2 h less SED than those in the opposite quintile (that is, shorter sleep). Likewise, children with later bedtimes averaged 1 h more SED than those with earlier bedtimes (for both boys and girls). At the very least, these findings remind us that multiple connections exist between sleep patterns and lifestyle behaviors. Sleep should not be overlooked by healthcare practitioners and should also be part of the lifestyle package that traditionally has focused on diet and exercise.[5,7]

The fact that the associations between sleep patterns and MVPA, SED and ST were significantly different between study sites also reminds us that strategies aimed at improving sleep and lifestyle behaviors should be culturally adapted to optimize results of interventions. It is possible that children's days are more structured or regulated in high-income countries and that there is more flexibility and discretionary time in low-income countries. Not only can the associations between sleep and lifestyle habits be influenced by numerous factors at the individual level (for

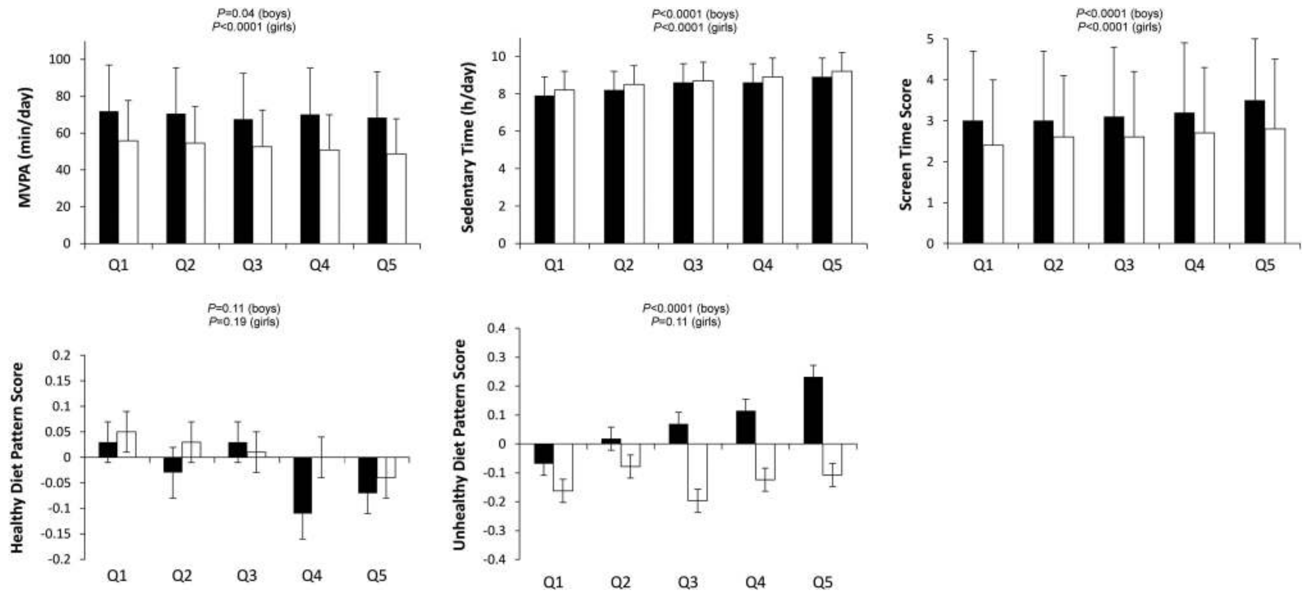

Figure 3. Trends in lifestyle behaviors across quintiles of nocturnal bedtime in boys (black bars) and girls (white bars). Error bars represent s.d.'s for moderate-to-vigorous physical activity (MVPA), sedentary time and screen time score. S.e.'s are represented for healthy/unhealthy diet pattern scores. *P*-values for linear trends across quintiles in both boys and girls are shown in the figure. The models are adjusted for age, highest parental education and BMI *z*-score.

example, age, sex, socioeconomic status, body size and so on) but interventions that have shown success in one country may not necessarily be replicated in another setting. The observation that stronger associations were found in high-income countries compared with low/middle-income countries highlights the need for a better understanding of the link between sleep and lifestyle behaviors in underdeveloped and developing countries before generalizing findings in this area of research. Also, the fact that similar and stronger associations were found in high-income countries in which the obesogenic environment is more prevalent suggests that increased efforts may be needed in these countries to reduce the adverse effects of clustering unhealthy lifestyle behaviors.

This study has several strengths and limitations that warrant discussion. An important strength is the large multinational sample of children from low- to high-income countries across several regions of the world. We also used a highly standardized measurement protocol, the use of objective measurements whenever possible, and a rigorous quality control program to ensure high-quality data across all sites.[16] However, our results need to be interpreted in light of the following limitations. First, the direction of causality cannot be determined from cross-sectional data. Second, accelerometers may be limited in their ability to properly distinguish between sleep and waking state, as they are based on movement detection. Furthermore, waist-worn accelerometers have been shown to overestimate absolute sleep duration and sleep efficiency compared with wrist-worn devices,[38] which may in part explain the high sleep efficiency values observed in this cohort. However, the use of one single device to assess both sleep and MVPA/SED is less cumbersome for children and still provides valid proxy measurements of sleep.[38] Third, we relied on self-reported estimates of ST and eating patterns, which are challenging behaviors to measure in young children. However, we used validated and reliable scales to measure these behaviors in an effort to minimize error and bias. Fourth, ISCOLE was not designed to provide nationally representative data and therefore the degree to which the results are generalizable are not known. Finally, residual confounding by unmeasured variables is always a possibility in observational studies.

CONCLUSION

The present study provides evidence that waist-worn 24-h accelerometer-determined nocturnal sleep patterns are associated with several lifestyle behaviors in children selected from around the world. Differences in the reported relationships between study sites suggest that the geographic area in the world and sociocultural variability are important factors to consider. Future work in low/middle-income countries is needed to better understand whether sleep is associated with lifestyle behaviors in these countries and further elucidate this possible discrepancy between settings.

CONFLICT OF INTEREST

MF has received a research grant from Fazer Finland and has received an honorarium for speaking for Merck. AK has been a member of the Advisory Boards of Dupont and McCain Foods. RK has received a research grant from Abbott Nutrition Research and Development. VM is a member of the Scientific Advisory Board of Actigraph and has received an honorarium for speaking for The Coca-Cola Company. TO has received an honorarium for speaking for The Coca-Cola Company. The remaining authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank the ISCOLE External Advisory Board and the ISCOLE participants and their families who made this study possible. A membership list of the ISCOLE Research Group and External Advisory Board is included in Katzmarzyk *et al.* (this issue). ISCOLE was funded by The Coca-Cola Company.

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