Sleep Patterns and Sugar-Sweetened Beverage Consumption among Children from Around the World

Short Title: Sleep patterns and sugary drinks

Jean-Philippe Chaput[1,2,*], Mark S. Tremblay[1,2], Peter T. Katzmarzyk[3], Mikael Fogelholm[4], Gang Hu[3], Carol Maher[5], Jose Maia[6], Timothy Olds[5], Vincent Onywera[7], Olga L. Sarmiento[8], Martyn Standage[9], Catrine Tudor-Locke[3,10] and Hugues Sampasa-Kanyinga[2]
for the ISCOLE Research Group

[1]Children's Hospital of Eastern Ontario Research Institute, Ottawa, Canada
[2]University of Ottawa, Ottawa, Canada
[3]Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA
[4]University of Helsinki, Helsinki, Finland
[5]University of South Australia, Adelaide, Australia
[6]CIFI2D, University of Porto, Porto, Portugal
[7]Kenyatta University, Nairobi, Kenya
[8]Universidad de los Andes, Bogota, Colombia
[9]University of Bath, Bath, United Kingdom
[10]University of Massachusetts Amherst, Amherst, USA

***Corresponding Author:** Jean-Philippe Chaput, Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Road, Ottawa, Ontario, Canada, K1H 8L1. Phone: +1 613 737 7600 ext. 3683. Fax: +1 613 738 4800. E-mail: jpchaput@cheo.on.ca

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Conflict of Interest

None

Authorship

JPC and HSK conceived the paper. JPC performed the statistical analyses. JPC wrote the first draft of the article. All authors critically reviewed the manuscript, provided feedback, and approved the final submission.

Ethical Standards Disclosure

This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The Pennington Biomedical Research Center Institutional Review Board as well as Institutional/Ethical Review Boards at each site approved the study. Written informed consent was obtained from parents/legal guardians, and child assent was also obtained.

Abstract

Objective: To examine the relationships between objectively-measured sleep patterns (sleep duration, sleep efficiency, and bedtime) and sugar-sweetened beverage (SSB) consumption (regular soft drinks, energy drinks, sports drinks, and fruit juice) among children from all inhabited continents of the world.

Design: Multinational, cross-sectional study.

Setting: The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE).

Subjects: 5873 children 9-11 years of age.

Results: Sleep duration was 12 minutes per night shorter in children who reported consuming regular soft drinks "at least once a day" compared to those who reported consuming "never" or "less than once a week". Children were more likely to sleep the recommended 9-11 hours per night if they reported lower regular soft drink consumption or higher sports drinks consumption. Children who reported consuming energy drinks "once a week or more" reported a 25-minute earlier bedtime compared with those who reported never consuming energy drinks. Children who reported consuming sports drinks "2-4 days a week or more" also reported a 25-minute earlier bedtime compared to those who reported never consuming sports drinks. The associations between sleep efficiency and SSB consumption were not significant. Similar associations between sleep patterns and SSB consumption were observed across all 12 study sites.

Conclusions: Shorter sleep duration was associated with higher intake of regular soft drinks, while earlier bedtimes were associated with lower intake of regular soft drinks and higher intake of energy drinks and sports drinks in this international study of children. Future work is needed to establish causality and to investigate underlying mechanisms.

Keywords: sleep, sugary drinks, soft drinks, energy drinks, sports drinks, cola, pediatric

Introduction

Sugar-sweetened beverages (SSBs), defined as any liquids that are sweetened with various forms of added sugars, contribute 10-15% of children's energy intake and are the primary source of added sugar in their diet [(1)]. SSB consumption is associated with adverse health outcomes including obesity, type 2 diabetes, and cardiovascular disease [(2-4)]. Putative underlying mechanisms comprise incomplete compensation for liquid calories, adverse glycemic effects, and increased hepatic metabolism of fructose leading to *de novo* lipogenesis, production of uric acid, and accumulation of visceral and ectopic fat [(5)]. Recent evidence has stimulated public health efforts to reduce SSB consumption as a means of improving childhood weight status and related health outcomes [(6)].

Factors associated with SSB consumption in children are numerous [(7)], and a better understanding of these correlates can inform the development of effective interventions to reduce SSB intake. One factor that has received little attention is the role of sleep, despite accumulating evidence linking insufficient sleep (i.e., short sleep duration and/or poor sleep quality) with obesity and other adverse health outcomes [(8,9)]. The main mechanism linking insufficient sleep to weight gain is through an increase in food intake, especially energy-dense foods [(10)]. Thus, it is plausible that insufficient sleep would be associated with greater intake of SSBs in children. Alternatively, SSB consumption may also be associated with insufficient sleep due to the stimulating properties of caffeine that, when consumed near bedtime, may negatively influence sleep.

Studies examining the associations between sleep and SSB consumption are sparse. Prather et al.[11] recently showed that short self-reported sleep duration in adults (≤5 and 6 hours per night) was associated with greater intake of sugared caffeinated sodas. Franckle et al.[12] reported that children who reported sleeping <10 hours/day consumed soda more frequently compared to children who reported ≥10 hours/day of sleep. However, to our knowledge, no studies to date have examined whether objectively-measured sleep patterns (i.e., sleep duration, sleep efficiency, and bedtime) are associated with SSB consumption in children from around the world. Understanding how sleep patterns may be linked to SSB consumption across countries at different levels of economic and human development is important to inform public health policies and tailor interventions that are context and setting-specific.

The objective of this study was to investigate the relationships between objectively-measured sleep patterns and SSB consumption among a large cross-sectional sample of children from all inhabited continents of the world. We hypothesized that sleep patterns characterized by shorter sleep durations, poorer sleep efficiencies, and later bedtimes would be associated with a higher frequency of SSB consumption.

Methods

Study Design and Setting

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to examine the relationships between lifestyle behaviours 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 (composite statistic of life expectancy, education, and per capita income indicators used to rank countries into four tiers of human development; 0.509 in Kenya to 0.929 in Australia), and inequality (Gini index of 26.9 in Finland to 63.1 in South Africa) [(13)]. The rationale, design and methods of ISCOLE have previously been published elsewhere [(13)]. The primary sampling frame was schools, which was typically stratified by an indicator of socioeconomic status (SES) to maximize variability within sites. A standardized protocol was used to collect data across all sites, and all study personnel underwent rigorous training and certification to ensure data quality. Data were collected during the school year at each study site and occurred between September 2011 and December 2013. This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The Pennington Biomedical Research Center Institutional Review Board as well as Institutional/Ethical Review Boards at each site approved the study. Written informed consent was obtained from parents/legal guardians, and child assent was also obtained.

Participants

ISCOLE targeted grade levels/classes likely to ensure minimal variability around a mean age of 10 years. All children within the targeted grade level/class in a sampled school were eligible to participate; hence, the sample included 9-11 year-old children. Based on *a priori* sample size and power calculations [(13)], 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 dataset after excluding participants without valid sleep data (n=1054), reported level of parental education (n=273), physical activity data (n=151), body mass index (BMI) z-scores (n=5), and SSB consumption (n=16). Exclusion of participants for invalid sleep data was mainly due to a wear time of <3 nights. Except for significantly higher BMI z-scores, the descriptive characteristics of children who were excluded for missing data did not significantly differ from those who were included in the present analysis.

Measurements

Sleep Patterns

Sleep duration, sleep efficiency, and bedtime 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-based activities) for at least 7 days, including 2 weekend days. 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, and reintegrated to 60-s epochs for analysis. Sleep duration (h/night) was estimated using a fully automated algorithm for 24-h waist-worn accelerometers that was developed and validated for ISCOLE [14,15]. This algorithm produces more precise estimates of sleep duration than previous algorithms and captures total sleep time from sleep onset to sleep offset, including all epochs and wakefulness after onset [14,15]. The weekly sleep duration averages were calculated using only days where valid sleep was accumulated (i.e., total sleep period time ≥160 min/night and >90% estimated wear time) 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 (%, defined as total sleep episode time divided by sleep period time) and bedtime (h:min, defined as first 5 consecutive minutes scored as sleep) [14-16].

SSB Consumption

Information on SSB consumption was obtained using a food frequency questionnaire (FFQ) adapted from the Health Behaviour in School-aged Children Survey [13,17]. The FFQ asked children to report their consumption of “Regular cola or soft drinks that contain sugar”, “Energy drinks (Red Bull, Rock Star, Guru, etc.”, “Sports drinks (Gatorade, Powerade, etc.)”, and “Fruit juice”, with response options of “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 “every day, more than once”. Some categories were combined together for analysis due to small sample sizes. A recent study reported a reliability correlation of 0.61 for regular soft drinks, 0.68 for energy drinks, 0.78 for sports drinks, and 0.64 for fruit juice among 321 children who repeated this FFQ after an average of 4.9 weeks [18]. Given the difficulties in accurately assessing total energy intake in children, we did not measure it in ISCOLE.

Covariates

Age, sex, highest level of parental education, physical activity level, and BMI z-scores were included as covariates in statistical models given their association with sleep patterns and/or SSB consumption. Age was computed from birth and observation dates and sex was recorded on a demographic and family questionnaire. Highest level of parental education was parent-reported and coded into three categories based on the highest level of education attained by either parent: “did not complete high school”, “completed high school or some college”, or “completed bachelor’s or postgraduate degree”. Physical activity data were obtained following a 24-h protocol using waist-worn accelerometers. After removal of sleep period time from the data file using a published algorithm [14,15], awake non-wear time was defined as at least 20 consecutive minutes of zero activity counts and excluded [19], and moderate-to-vigorous physical activity (MVPA) was defined as all activity ≥574 counts per 15 s [20]. Furthermore, the minimal amount of daytime data that was considered acceptable for inclusion of physical activity data was at least 4 days with at least 10 h of wear time per day, including at least 1 weekend day. Based on the average of the monitored days, children were classified as physically active (≥60 min/day on average) or inactive (<60 min/day on average), according to the recommendations of the WHO [(21)]. Finally, height and body weight were objectively measured using standardized procedures by trained and certified study personnel [(13)]. BMI (kg/m^2) was calculated and age- and sex-specific BMI z-scores were computed using reference data from the World Health Organization [(22)]. Of note, biological maturity was estimated using the maturity offset method; however, because age and weight were included in the maturity offset calculation, biological maturity was not included as a covariate in our analyses.

Statistical Analysis

Statistical analyses were performed using JMP version 12 and SAS version 9.4 (SAS Institute, Cary, NC, USA). Multilevel mixed-effects models accounting for clustering at the school and study site levels were used to examine the relationships between sleep patterns and SSB consumption. Study sites were considered to have fixed effects, and school 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 [(23)]. Age, sex, highest level of parental education, meeting WHO physical activity recommendations, and BMI z-scores were included as covariates in statistical models. Bonferonni corrections were used to account for multiple comparisons. Sleep duration was also dichotomized as <9 h/night (sleeping less than recommended) vs. 9-11 h/night (meeting the sleep recommendations; reference category), in agreement with current sleep duration guidelines [(24,25)], to calculate the odds of meeting the sleep duration recommendations for each of the four SSB consumption variables (treated as categorical variables). A total of 37 children slept more than 11 hours per night (long sleepers) and were thus excluded from this analysis. However, keeping them or excluding them did not impact the results found. We also examined associations between sleep patterns and SSB consumption according to country-level World Bank classification of economic development [(26)]. P-values of less than 0.05 were considered statistically significant.

Results

Table 1 presents descriptive characteristics of the sample. The average sleep duration was 8.8 hours per night (with Portugal having the shortest sleep duration of the countries examined [8.3 hours] and the United Kingdom the longest [9.5 hours]), and 58% of children slept less than the recommended 9-11 hours per night. Children were very sleep efficient (96.2% sleep efficiency on average) and had a mean bedtime of 22:18 (latest mean bedtime in Portugal [23:15] and earliest in Kenya [21:41]). A total of 11.6% of children reported that they consumed regular cola or soft drinks once a day or more (ranging from 1.1% reporting consuming regular soda or soft drinks once a day or more in Finland to 31.6% in South Africa). Approximately three quarters of children reported never consuming energy drinks (ranging from 46% reporting "never" consuming energy drinks in South Africa to 95% in Finland). Approximately 45% of the sample reported that they never consumed sports drinks (ranging from 9% reporting "never" consuming sports drinks in the United States to 80% in Finland). Finally, 22.4% of children reported drinking fruit juice more than once a day (ranging from 6% reporting drinking fruit juice more than once a day in China to 47% in Colombia).

We did not find significant sex interactions in the associations between sleep patterns and SSB consumption across study sites; therefore, results were pooled for presentation. Figures 1-3 show sleep patterns across levels of consumption of SSBs in this sample of children. There was a significant negative trend in sleep duration across levels of consumption of regular soft drinks (Figure 1A). Sleep duration was 12 minutes shorter in children who reported consuming regular soft drinks “at least once a day” compared with those who reported consuming regular soft drinks “never” or “less than once a week”. We also observed significant positive trends between bedtime and consumption of regular soft drinks (Figure 3A), and significant negative trends between bedtime and consumption of energy drinks (Figure 3B) and sports drinks (Figure 3C). In particular, we observed a 25-minute earlier bedtime in children who reported consuming energy drinks “once a week or more” compared with those who reported never consuming energy drinks. Likewise, we found a 25-minute earlier bedtime in children who reported consuming sports drinks “2-4 days a week or more” compared to those reporting “never”. The other associations between sleep patterns and SSB consumption were not significant. We also did not find a significant World Bank classification of economic development-by-sleep pattern interaction for SSB consumption, suggesting that the associations did not differ between sites (e.g., low vs. high-income countries).

Table 2 presents the odds ratios of meeting the sleep duration recommendation of 9-11 hours/night (reference category) for each of the four SSB consumption variables. The cut-points for the SSB consumption variables were chosen based on the distribution of the data in order to maximize power. Children who reported drinking regular soft drinks “once a week or more” were less likely to sleep the recommended amount (OR = 0.79, 95% CI 0.71-0.88) compared to those who reported consuming regular soft drinks “never or less than once a week”. In contrast, higher odds of meeting the sleep duration recommendation were observed in children reporting consuming sports drinks “less than once a week or more” (OR = 1.26, 95% CI 1.13-1.39) compared to those reporting never consuming sports drinks. Finally, children reporting drinking fruit juice “once a week or more” had higher odds of meeting the sleep duration recommendation (OR = 1.23, 95% CI 1.08-1.40) than those indicating drinking fruit juice “never or less than once a week”.

Discussion

To our knowledge, the present study was the first to examine the relationships between sleep patterns and SSB consumption in children from 12 countries varying widely in levels of economic and human development. Collectively, we observed shorter sleep durations with higher consumption of regular soft drinks. Children were also more likely to sleep the recommended 9-11 hours per night if they reported lower regular soft drink consumption or higher sports drinks or fruit juice consumption. We also observed that later bedtimes were associated with higher consumption of regular soft drinks. Conversely, later bedtimes were also associated with lower consumption of energy drinks and sports drinks. There was no association between sleep efficiency and SSB consumption. Similar associations between sleep patterns and SSB consumption were observed across all 12 study sites.

The present findings are in line with previous studies that have reported a significant relationship between sleep duration and SSB consumption. For example, short self-reported sleep duration (≤5 and 6 hours per night) has been shown to be associated with higher intake of sugared caffeinated sodas among adults in the United States [11]. In children, Franckle et al.[12]

reported that students in two Massachusetts communities who reported sleeping <10 hours/day consumed soda more frequently compared to students who reported ≥10 hours of sleep per day. However, no significant association was reported with fruit juice in their study, in agreement with the present work. Similarly, Pérez-Farinós et al. [27] reported that short sleep duration (<9.9 h/day) was associated with a greater frequency of consumption of soft drinks containing sugar but not with fruit juice in Spanish children. No studies have looked at the association between sleep quality or sleep timing (e.g., bedtime or chronotype) with SSB consumption in children.

Among the three sleep characteristics examined in the present study, bedtime was most strongly associated with SSB consumption. Similar to short sleep duration, later bedtimes were associated with greater consumption of regular soft drinks. Yet, earlier bedtimes were also associated with greater consumption of energy drinks and sports drinks. Although this may seem counter-intuitive, a greater frequency of consumption of energy and sports drinks may be a proxy for a healthier lifestyle in general. For instance, it is possible that active children go to bed earlier and may consume energy and sports drinks more frequently during the day for their physical activities (or other reasons). Energy and sports drinks may be seen as “good” by children and parents despite the fact they are not healthy options according to public health authorities. Sampasa-Kanyinga and Chaput have recently reported that female adolescents who meet the physical activity recommendation of ≥60 minutes of MVPA per day are more likely to report consuming energy drinks than those who do not meet this recommendation [28]. Conversely, late bedtimes are generally associated with more screen time and energy-dense food snacking [29,30]. The present data suggest that a greater consumption of sugar-sweetened soft drinks is linked to later bedtimes in children from around the world.

Reverse causation is always a possibility with cross-sectional study designs. Thus, it is possible that SSB consumption may also impact sleep patterns, especially due to the stimulating properties of caffeine that can disrupt sleep. Although caffeine use is well-known to reduce sleep quality (especially when consumed in the hours before bedtime), we did not find a significant association between sleep efficiency and SSB consumption in the present study. One explanation is the ceiling effect observed for sleep efficiency in this sample of children (average value of 96%). It is indeed difficult to find significant associations with small inter-individual variations in the data. Although children have high sleep efficiency values in general (e.g., compared to adults), the waist-worn accelerometer protocol used in ISCOLE tends to also overestimate sleep efficiency compared with wrist-worn devices [(31)]. Future studies using more sensitive measures of sleep quality are thus required to confirm our findings. Longitudinal studies will also be needed in order to determine the directionality in the findings, including information about when children routinely consume the different SSBs (e.g., during the day or near bedtime).

This study included sites from countries varying widely in levels of economic and human development. However, we did not find a significant World Bank classification of economic development-by-sleep pattern interaction for SSB consumption, suggesting that the associations were similar across study sites. Although limited, the current evidence on sleep patterns as it relates to SSB consumption is mainly from high-income countries. It is thus reassuring to observe herein the same associations all over the world, thereby making future intervention strategies more generalizable. However, ISCOLE did not contain nationally-representative data, so it would be prudent to design interventions that are context and setting-specific to optimize success.

Determinants of SSB consumption in children are numerous and include things such as child's preference for SSBs, screen time and snack consumption, lower parental socioeconomic status, parental role modeling, using food as a reward, or living near a fast food/convenience store [7]. Likewise, reasons for having inadequate sleep patterns are diverse and can include a lack of parental monitoring or rules about bedtime in the household, artificial light exposure before bedtime, electronic devices in the bedroom, unfavorable sleep environment, cultural factors etc. Sleep duration of school-aged children is also largely influenced by the start of the school day, and bedtime is therefore a key determinant of total sleep duration in such a context. A better understanding of the determinants of SSB consumption and sleep patterns is important to inform the development of effective interventions aimed at reducing SSB consumption and improving sleep hygiene of children.

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 sleep measurements, and a rigorous quality control program to ensure high-quality data across all sites [13]. However, our results need to be interpreted in light of the following limitations. First, the cross-sectional nature of the data precludes inferences about causality or temporality. Second, accelerometers may be limited in their ability to properly distinguish between sleep and wake states, as they are based on movement detection, and waist-worn accelerometers have been shown to overestimate absolute sleep duration and sleep efficiency compared with wrist-worn devices [31]. Third, ISCOLE was not designed to provide nationally representative data and therefore the degree to which the results are generalizable to the studied countries is not known. Fourth, the narrow age range limits our ability to infer our findings to other age groups and it is possible that different patterns would be observed in adolescents or adults for example. Fifth, only the frequency of SSB consumption was reported and information on energy intake (kcal) was not captured in ISCOLE. Reliability correlation coefficients of 0.61 (regular soft drinks), 0.68 (energy drinks), 0.78 (sports drinks), and 0.64 (fruit juice) have been reported in children who repeated this FFQ after an average of 4.9 weeks. Also, the FFQ used did not distinguish between fruit juice with or without added sugar. Finally, the potential confounding effects of unmeasured variables cannot be discounted.

In conclusion, findings from this study show that shorter sleep duration was associated with higher intake of regular soft drinks, while earlier bedtimes were associated with lower intake of regular soft drinks and higher intake of energy drinks and sports drinks in this large multinational study of children. Further studies using longitudinal research designs are needed to better understand the prospective associations among sleep patterns and SSB consumption in children.

References

1. Hu FB & Malik VS (2010) Sugar-sweetened beverages and risk of obesity and type 2 diabetes: Epidemiologic evidence. *Physiol Behav* **100**, 47-54.
2. Scharf RJ & DeBoer MD (2016) Sugar-sweetened beverages and children's health. *Annu Rev Public Health* **37**, 273-293.
3. Bes-Rastrollo M, Sayon-Orea C, Ruiz-Canela M *et al.* (2016) Impact of sugars and sugar taxation on body weight control: A comprehensive literature review. *Obesity (Silver Spring)* **24**, 1410-1426.
4. Keller A & Bucher Della Torre S (2015) Sugar-sweetened beverages and obesity among children and adolescents: a review of systematic literature reviews. *Child Obes* **11**, 338-346.
5. Malik VS & Hu FB (2015) Fructose and cardiometabolic health: What the evidence from sugar-sweetened beverages tells us. *J Am Coll Cardiol* **66**, 1615-1624.
6. Le Bodo Y, Paquette MC, Vallières M *et al.* (2015) Is sugar the new tobacco? Insights from laboratory studies, consumer surveys and public health. *Curr Obes Rep* **4**, 111-121.
7. Mazarello Paes V, Hesketh K, O'Malley C *et al.* (2015) Determinants of sugar-sweetened beverage consumption in young children: a systematic review. *Obes Rev* **16**, 903-913.
8. Chaput JP, Gray CE, Poitras VJ *et al.* (2016) Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab* **41**, S266-282.
9. Chaput JP (2016) Is sleep deprivation a contributor to obesity in children? *Eat Weight Disord* **21**, 5-11.

10. Chaput JP (2014) Sleep patterns, diet quality and energy balance. *Physiol Behav* **134**, 86-91.

11. Prather AA, Leung CW, Adler NE *et al.* (2016) Short and sweet: Associations between self-reported sleep duration and sugar-sweetened beverage consumption among adults in the United States. *Sleep Health* **2**, 272-276.

12. Franckle RL, Falbe J, Gortmaker S *et al.* (2015) Insufficient sleep among elementary and middle school students is linked with elevated soda consumption and other unhealthy dietary behaviors. *Prev Med* **74**, 36-41.

13. Katzmarzyk PT, Barreira TV, Broyles ST *et al.* (2013) The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE): design and methods. *BMC Public Health* **13**, 900.

14. Tudor-Locke C, Barreira TV, Schuna Jr JM *et al.* (2014) Fully automated waist-worn accelerometer algorithm for detecting children's sleep-period time separate from 24-h physical activity or sedentary behaviors. *Appl Physiol Nutr Metab* **39**, 53-57.

15. Barreira TV, Schuna Jr JM, Mire EF *et al.* (2015) Identifying children's nocturnal sleep using a 24-h waist accelerometry. *Med Sci Sports Exerc* **47**, 937-943.

16. Tudor-Locke C, Mire EF, Barreira TV *et al.* (2015) Nocturnal sleep-related variables from 24-f free-living waist-worn accelerometry: International Study of Childhood Obesity, Lifestyle and the Environment. *Int J Obes Suppl* **5**, S47-S52.

17. Currie C, Gabhainn SN, Godeau E *et al.* (2008) Inequalities in Children's Health: HBSC International Report from the 2005/2006 Survey. Health Policy for Children and Adolescents, No. 5; WHO Regional Office for Europe: Copenhagen, Denmark.

18. Saloheimo T, Gonzalez SA, Erkkola M *et al.* (2015) The reliability and validity of a short food frequency questionnaire among 9-11-year old: A multinational study on three middle-income and high-income countries. *Int J Obes Suppl* **5**, S22-S28.

19. Mark AE & Janssen I (2008) Dose-response relation between physical activity and blood pressure in youth. *Med Sci Sports Exerc* **40**, 1007-1012.

20. Evenson KR, Catellier DJ, Gill K *et al.* (2008) Calibration of two objective measures of physical activity for children. *J Sports Sci* 26, 1557-1565.

21. World Health Organization (2010) Global Recommendations on Physical Activity for Health. World Health Organization: Geneva, Switzerland, p.58.

22. de Onis M, Onyango AW, Borghi E *et al.* (2007) Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* **85**, 660-667.

23. Kenward MG & Roger JH (1997) Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics* **53**, 983-997.

24. Hirshkowitz M, Whiton K, Albert SM *et al.* (2015) National Sleep Foundation's updated sleep duration recommendations: final report. *Sleep Health* **1**, 233-243.

25. Tremblay MS, Carson V, Chaput JP *et al.* (2016) Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep. *Appl Physiol Nutr Metab* **41**, S311-S327.

26. World Bank (2012) World Development Indicators. The World Bank: Washington, DC, USA.

27. Pérez-Farinós N, Villar-Villalba C, López Sobaler AM *et al.* (2017) The relationship between hours of sleep, screen time and frequency of food and drink consumption in

Spain in the 2011 and 2013 ALADINO: a cross-sectional study. *BMC Public Health* **17**, 33.

28. Sampasa-Kanyinga H & Chaput JP (2017) Consumption of sugar-sweetened beverages and energy drinks and adherence to physical activity and screen time recommendations among adolescents. *Int J Adolesc Med Health* **29**, 20150098.
29. Adamo KB, Wilson S, Belanger K *et al.* (2013) Later bedtime is associated with greater daily energy intake and screen time in obese adolescents independent of sleep duration. *J Sleep Disord Ther* **2**, 126.
30. Thivel D, Tremblay MS, Chaput JP (2013) Modern sedentary behaviors favor energy consumption in children and adolescents. *Curr Obes Rep* **2**, 50-57.
31. Hjorth MF, Chaput JP, Damsgaard CT *et al.* (2012) Measure of sleep and physical activity by a single accelerometer: can a waist-worn Actigraph adequately measure sleep in children? *Sleep Biol Rythms* **10**, 328-335.

Table 1. Descriptive characteristics of participants (*N*=5873).

Age (year)	10.4 (0.6)
Sex (%)	
Boys	45.1
Girls	54.9
BMI (kg/m^2)	18.4 (3.4)
Obesity (%)[1]	12.2
Highest parental education (%)	
Did not complete high school	19.7
Completed high school or some college	42.5
Completed bachelor's or postgraduate degree	37.8
Meeting physical activity guidelines (%)	45.8
Sleep duration (h/night)	8.8 (0.9)
Sleep efficiency (%)	96.2 (1.4)
Bedtime (h:min)	22:18
Consumption of regular cola or soft drinks (%)	
Never	15.1
Less than once a week	27.2
Once a week	23.4
2-4 days a week	16.5
5-6 days a week	6.2
Once a day or more	11.6
Consumption of energy drinks (%)	
Never	75.9
Less than once a week	9.6
Once a week or more	14.5

Consumption of sports drinks (%)	
Never	45.1
Less than once a week	21.0
Once a week	12.0
2-4 days a week or more	21.9
Consumption of fruit juice (%)	
Never or less than once a week	19.7
Once a week	14.0
2-4 days a week	16.7
5-6 days a week	11.9
Once a day every day	15.3
Every day, more than once	22.4

BMI, body mass index.

[1]Obesity defined according to the World Health Organization criteria [22].

Data are shown as mean (standard deviation) unless otherwise indicated.

Table 2. Odds ratios for meeting the sleep duration recommendation of 9-11 hours per night (compared with <9 h/night) for each of the sugar-sweetened beverage consumption variables.

SSB variable	OR (95% CI)
Regular cola or soft drinks	
Never or less than once a week	1
Once a week or more	0.79 (0.71-0.88)*
Energy drinks	
Never	1
Less than once a week or more	1.08 (0.96-1.21)
Sports drinks	
Never	1
Less than once a week or more	1.26 (1.13-1.39)*
Fruit juice	
Never or less than once a week	1
Once a week or more	1.23 (1.08-1.40)*

SSB, sugar-sweetened beverage; OR, odds ratio; CI, confidence interval.

*P<0.05.

Age, sex, highest level of parental education, meeting physical activity guidelines, and body mass index z-scores were included as covariates in statistical models.

N=5836.

Figure Legends

Figure 1. Sleep duration across levels of consumption of (A) regular cola or soft drinks, (B) energy drinks, (C) sports drinks, and (D) fruit juice. Data are presented as mean values and standard deviations. Age, sex, highest level of parental education, meeting physical activity guidelines, and body mass index z-scores were included as covariates. N=5873.

Figure 2. Sleep efficiency across levels of consumption of (A) regular cola or soft drinks, (B) energy drinks, (C) sports drinks, and (D) fruit juice. Data are presented as mean values and standard deviations. Age, sex, highest level of parental education, meeting physical activity guidelines, and body mass index z-scores were included as covariates. N=5873.

Figure 3. Bedtime across levels of consumption of (A) regular cola or soft drinks, (B) energy drinks, (C) sports drinks, and (D) fruit juice. Data are presented as mean values and standard deviations. Age, sex, highest level of parental education, meeting physical activity guidelines, and body mass index z-scores were included as covariates. N=5873.

Figure 1A

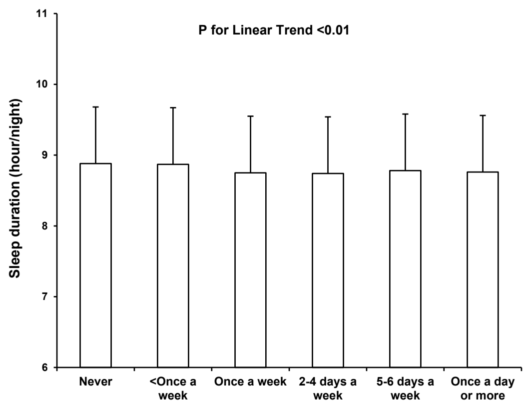

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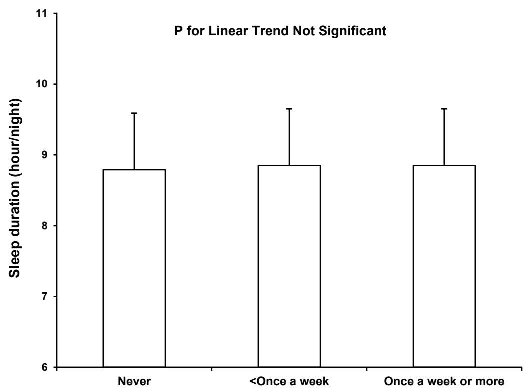
Figure 1B



P for Linear Trend Not Significant
Sleep duration (hour/night)
11
10
9
8
7
6
Never
<Once a week
Once a week or more

Figure 1C

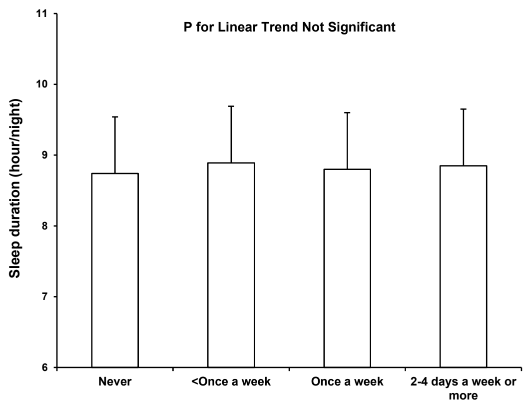

P for Linear Trend Not Significant
Sleep duration (hour/night)
11
10
9
8
7
6
Never
<Once a week
Once a week
2-4 days a week or more

Figure 1D

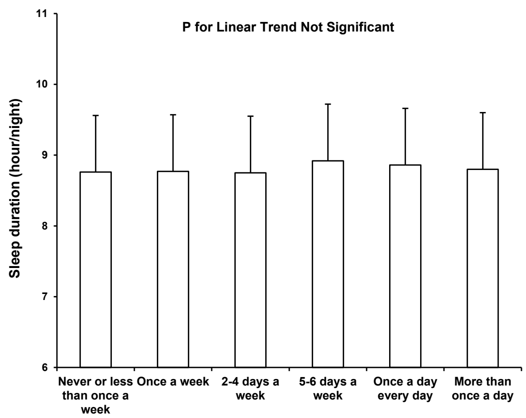

P for Linear Trend Not Significant
Sleep duration (hour/night)
11
10
9
8
7
6
Never or less than once a week
Once a week
2-4 days a week
5-6 days a week
Once a day every day
More than once a day

Figure 2A

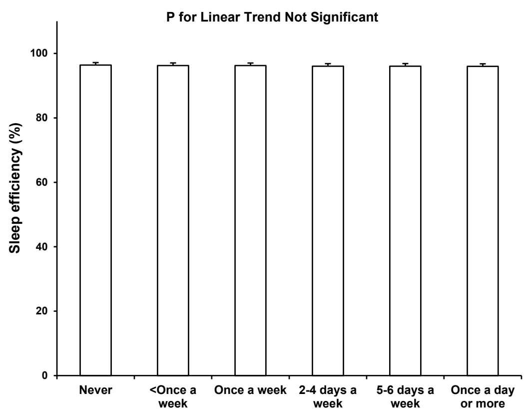
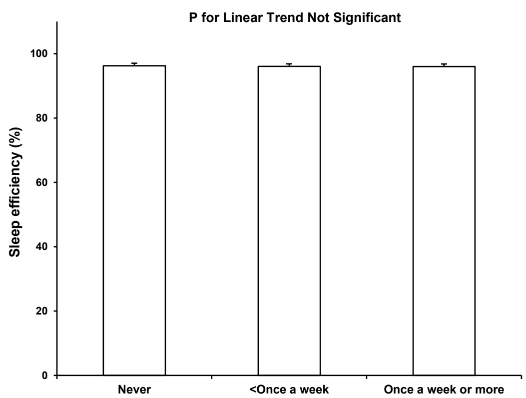

P for Linear Trend Not Significant
Sleep efficiency (%)
100
80
60
40
20
0
Never
<Once a week
Once a week
2-4 days a week
5-6 days a week
Once a day or more

Figure 2B



P for Linear Trend Not Significant
Sleep efficiency (%)
0
20
40
60
80
100
Never
<Once a week
Once a week or more

Figure 2C

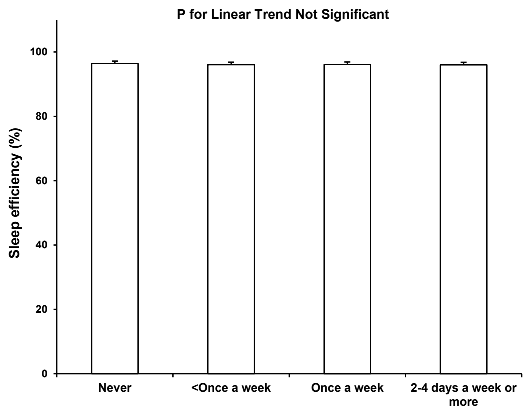

P for Linear Trend Not Significant
Sleep efficiency (%)
0
20
40
60
80
100
Never
<Once a week
Once a week
2-4 days a week or more

Figure 2D

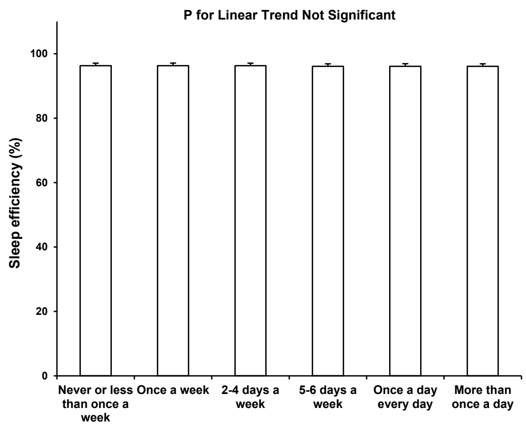

P for Linear Trend Not Significant
Sleep efficiency (%)
0
20
40
60
80
100
Never or less than once a week
Once a week
2-4 days a week
5-6 days a week
Once a day every day
More than once a day

Figure 3A

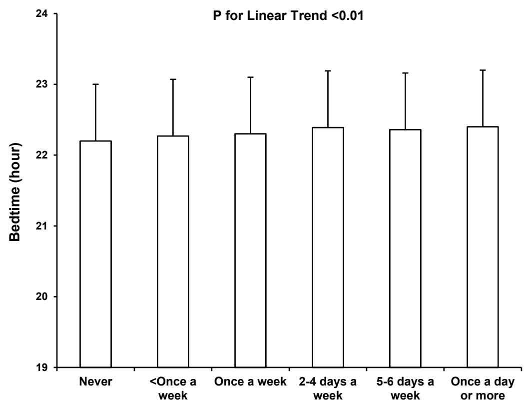

P for Linear Trend <0.01
Bedtime (hour)
24
23
22
21
20
19
Never
<Once a week
Once a week
2-4 days a week
5-6 days a week
Once a day or more

Figure 3B

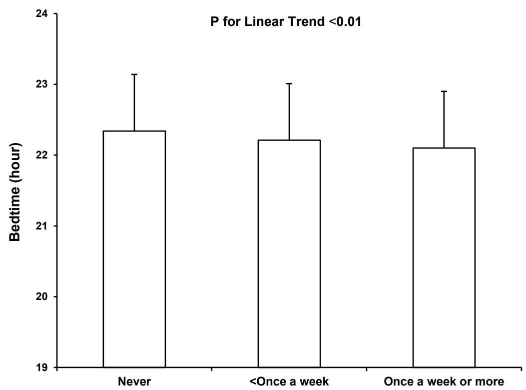

P for Linear Trend <0.01
Bedtime (hour)
24
23
22
21
20
19
Never
<Once a week
Once a week or more

Figure 3C

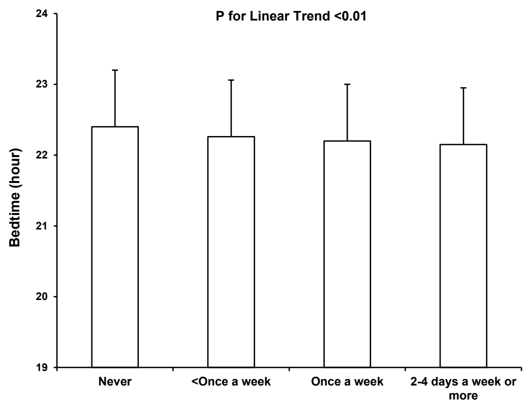
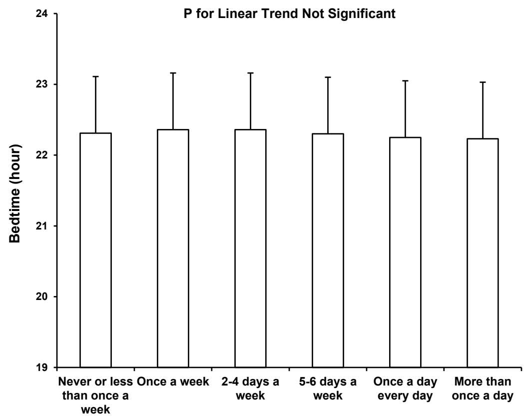

P for Linear Trend <0.01
Bedtime (hour)
24
23
22
21
20
19
Never
<Once a week
Once a week
2-4 days a week or more

Figure 3D



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