2019

The cross-sectional and prospective associations between sleep characteristics and adiposity in toddlers: Results from the GET UP! Study

Zhiguang Zhang
University of Wollongong, zz886@uowmail.edu.au

Joao Rafael Rodrigues Pereira
University of Wollongong, jrrp505@uowmail.edu.au

Eduarda Manuela De Sousa Rodrigues de Sa
University of Wollongong, emdsr885@uowmail.edu.au

Anthony D. Okely
University of Wollongong, tokely@uow.edu.au

Xiaoqi Feng
University of Wollongong, xfeng@uow.edu.au

See next page for additional authors

The cross-sectional and prospective associations between sleep characteristics and adiposity in toddlers: Results from the GET UP! Study

Abstract

Background: The associations between sleep characteristics and adiposity in children under three years are not fully understood yet. Objective: The objective of the study is to examine the cross-sectional and prospective associations between sleep characteristics and adiposity in toddlers over a 12-month period. Methods: Participants were 202 toddlers from the GET-UP! Study. Sleep duration, sleep timing, and sleep variability were assessed using 24-hour accelerometry for seven consecutive days. Height and weight were measured, and BMI z scores were calculated. Linear mixed models were performed to examine the cross-sectional and prospective associations between sleep characteristics and adiposity, with adjustments for clustering effects and demographic factors. Results: Total sleep duration was negatively associated with higher adiposity cross-sectionally (B = −0.12; 95% CI: −0.23, −0.01;.033) but not prospectively (B = 0.01; 95% CI: −0.13, 0.10;.843). Nap duration was prospectively associated with higher levels of adiposity (B = 0.41; 95% CI: 0.14, 0.68;.003). Sleep variability and sleep timing were not associated with concurrent or subsequent adiposity. Conclusion: Although sleep duration is an important factor associated with obesity in toddlerhood, the potential effects of different types of sleep duration may vary. While longer total sleep duration may protect children from increasing adiposity, longer nap duration seems to be risk factor. As evidence in this age group is scarce, more research is needed to confirm this finding.

Disciplines

Education | Social and Behavioral Sciences

Publication Details

Zhang, Z., Pereira, J. R., Sousa-Sa, E., Okely, A. D., Feng, X. & Santos, R. (2019). The cross-sectional and prospective associations between sleep characteristics and adiposity in toddlers: Results from the GET UP! Study. Pediatric Obesity, 14 (11), e12557-1-e12557-8.

Authors

Zhiguang Zhang, Joao Rafael Rodrigues Pereira, Eduarda Manuela De Sousa Rodrigues de Sa, Anthony D. Okely, Xiaoqi Feng, and Rute Santos

Abstract

***Background*:** The associations between sleep characteristics and adiposity in children under three years are not fully understood yet.

***Objective*:** To examine the cross-sectional and prospective associations between sleep characteristics and adiposity in toddlers over a 12-month period.

***Methods*:** Participants were 202 toddlers from the GET-UP! Study. Sleep duration, sleep timing and sleep variability were assessed using 24-h accelerometry for 7 consecutive days. Height and weight were measured and BMI z-scores were calculated. Linear mixed models were performed to examine the cross-sectional and prospective associations between sleep characteristics and adiposity, with adjustments for clustering effects and demographic factors.

***Results*:** Total sleep duration was negatively associated with higher adiposity cross-sectionally (B=-0.12; 95%CI: -0.23,-0.01; p=0.033) but not prospectively (B=0.01; 95%CI: -0.13,0.10; p=0.843). Nap duration was prospectively associated with higher levels of adiposity (B=0.41; 95%CI: 0.14,0.68; p=0.003). Sleep variability and sleep timing were not associated with concurrent or subsequent adiposity.

***Conclusion*:** Although sleep duration is an important factor associated with obesity in toddlerhood, the potential effects of different types of sleep duration may vary. While longer total sleep duration may protect children from increasing adiposity, longer nap duration seems to be risk factor. As evidence in this age group is scarce, more research is needed to confirm this finding.

1. Introduction

The obesity epidemic among children has been a major public health concern, as it is linked to a number of adverse health (e.g., cardiovascular disease, diabetes and sleep apnoea) and socio-emotional consequences (e.g., low self-esteem and low self-confidence).[1] Early childhood is considered a critical period for obesity development, as obesity during this period can track into later childhood and even adulthood.[2] Therefore, it is vital to prevent excessive weight gain in the early years, making it important to understand the risk factors during this period.

A lack of adequate amount of sleep in school-aged children and adolescents has been described to be one contributing factor to obesity.[3] A recent systematic review in children under five years of age suggested that shorter sleep duration was associated with concurrent and later excess of adiposity in 20 (out of 31) studies.[4] However, most of those studies focused on pre-schoolers (3-5 years), whereas evidence in infancy and toddlerhood (prior to 3 years) is scarce and less consistent. In this review only six studies had examined the association between sleep duration and adiposity in children under three years, with predominantly null findings (in four studies).[4] Since total sleep duration decreases across the first three years of life,[5] understanding the nature of the association of sleep in this period would be important for preventing overweight and obesity.

Other sleep characteristics beyond sleep duration may also influence adiposity, although the associations remain relatively unexplored in children.[6] For example, it has been suggested that sleep timing (i.e., bedtime and wakeup time) may increase obesity risk in adults.[7] This is plausible as sleep timing may be related to social and

environmental factors that place individuals at greater risk for overweight and obesity by increasing opportunities to consume more energy, engage in more sedentary screen time, and by reducing opportunities for physical activity.[8] Also, abnormal sleep timing may alter circadian rhythms, which play an important role in circulating levels of nutrients (e.g., glucose, fatty acids and triglycerides) and various hormones (e.g., insulin, glucocorticoids and cortisol); as such, the alteration may lead to metabolic changes that may contribute to obesity.[9] Despite the limited number of studies in childhood,[5] preliminary evidence suggests that later bedtimes are associated with increased adiposity in both school-aged[6,10] and preschool-aged children.[11] However, whether such an association exists in children under the age of three remains unknown.

Sleep variability (i.e., intra-individual, night-to-night variability of sleep duration) is another characteristic that may be associated with adiposity. Previous evidence suggests that greater sleep variability is associated with higher body mass index (BMI) and weight gain in adults.[12] Sleep variability may be more common and relevant in childhood, due to the rapid growth and development, complex family and peer systems, as well as environmental demands during this period. However, its association with adiposity in children has not been fully understood yet. While the results from a study among 247 American adolescents showed a positive association between sleep variability and adiposity,[13] other studies with school-aged children[14] and in adolescents[14,15] suggest a null association. At the same time, even less studies have evaluated such an association among children under the age of five.[16]

Measures of sleep characteristics in most of the studies in early childhood have relied on parental report, with few providing the psychometric properties of those instruments,

making their validity questionable in young children.[17] It is also known that parent-reported sleep duration overestimates actual sleep duration compared with objective measures of sleep duration (e.g., actigraphy).[18] Therefore, assessing sleep characteristics with objective measures would be advantageous for clarifying the nature of the sleep-adiposity association in early childhood.[5]

To address these gaps in the literature, this study aimed (i) to examine the cross-sectional associations between sleep characteristics (sleep duration, sleep timing and sleep variability) and adiposity at baseline; and (ii) the prospective associations between these sleep characteristics at baseline and subsequent adiposity at 12-month follow-up, in a sample of Australian toddlers, using an objective measure of sleep characteristics.

2. Methods

2.1 Participants

Secondary analyses of data from the GET UP! Study were performed for this paper. The GET UP! Study was a 12-month cluster randomized controlled trial (RCT) examining the effects of reducing sitting time on cognitive development and executive functions in Australian toddlers. The complete description of this RCT have been previously reported.[19] Briefly, 30 Early Childhood Education and Care (ECEC) centres from the Illawarra region in New South Wales from a low- to medium- socio-economic areas were recruited. All children aged 12 to 26 months at baseline without any diagnosed medical or psychological impairment were eligible to participate if they attended the ECEC services full-time (i.e. >6 h/day) at least twice per week. Baseline data were collected from March 2016 and follow-up data were collected one year later.

The GET UP! Study included 335 toddlers aged 19.8±4.08 months at baseline; 202 had valid accelerometer data (i.e., at least ≥ 3 days of 24-hour periods) and adiposity data (i.e., z-BMI) at baseline; of these, 153 had valid adiposity data at the 1-year follow-up. As no intervention effect was found for the outcome of interest (adiposity variables, please see Table S1), in the current report we considered all children with valid data on the variables of interest (i.e. 202 at baseline and 153 at follow-up). Drop off analysis showed that there were no significant differences in baseline demographical variables (i.e., age, gender and socio-economic status) between children with adiposity data at follow-up and those without such data.

This study received approval by the Human Research Ethics Committee at the University of Wollongong's (HE15/236) and was registered in the Australian and New Zealand Clinical Trials Registry (ACTRN12616000471482, 11/04/ 2016, retrospectively registered). Informed written consents were obtained from the educators and children's parents or guardians.

2.2 Measures

Dependent variable

Adiposity

Body weight and height were measured according to standard procedures.[19] body height was measured to the nearest 0.1 cm in bare or stocking feet with the child standing upright against a portable stadiometer (Seca 254 Hamburg, Germany). Body weight was measured to the nearest 0.10 kg, lightly dressed (and without diapers) using a portable electronic weight scale (Seca 254 Hamburg, Germany).[19] BMI was calculated as weight(kg)/height(m2) and then BMI z-scores were then calculated by age and sex

using the formula [BMI z-score = (participant's value – mean value of the sample)/standard deviation].

Independent variables

Sleep duration, sleep variability and sleep timing

Sleep was assessed using accelerometery, which is a more objective measure than parent-proxy reported sleep behaviours and can be used to determine sleep-wake periods from differences in movement and non-movement for extended periods of time in a child's free-living environment. The waist-worn accelerometers (Actigraph GT3X+) have been validated and used to measure sleep time in children,[20,21] and this device has established validity and reliability to measure movement in toddlers.[22] Participants were asked to wear the accelerometer for 7 consecutive 24-hour periods, except for water-based activities. In addition, activity logs registered by parents and ECEC educators were used as complementary sources for the confirmation of nap(s) and nighttime sleep. Accelerometer data were collected using a sampling rate of 30 Hz and then integrated into 15-second epochs for analysis.[22] Children had to have at least three 24-h periods of accelerometer data to be considered valid for analysis.

As previously described,[23] accelerometer data were visually inspected minute by minute, in consultation with the activity logs, in order to identify nap(s), bedtimes(night) and wake-up times (morning). Nap onset/bedtime was initially located when a change in the accelerometer output from the sitting or standing position to the lying or off position was detected,[21] which should roughly agree with the nap onsets/bedtimes registered in the activity logs. Nap onset/bedtime was then identified as the first minute followed by at least 10 consecutive minutes with a vector magnitude

of 0 in the accelerometer data files. Nap offset/wake-up time was first located when a change in the inclinometer output from the lying or off position to the sitting or standing position was detected, which should roughly agree with the nap offsets/wake-up times registered in the activity logs. Nap offset/wake-up time was then identified as the first minute of at least 10 consecutive minutes with a vector magnitude of >0.

Nap(s) duration were defined as time between nap onset and nap offset. Nighttime sleep duration were defined as time between bedtime and wake-up time. Total sleep duration was calculated as the sum of the nighttime sleep duration and nap(s) duration. For the calculation of sleep duration, wake after sleep onset (WASO) was not included. Sleep variability was identified as the intra-subject standard deviation of the nighttime sleep duration over the days with valid data.

Following similar procedures in previous studies with children,[10,23] sleep timing (bedtime/wake-up time) was calculated as the mean over days with valid data. Using the median split for bedtime (19:54:26) of the sample at baseline, participants were classified into two groups: early bedtime group (below median) and late bedtime group (above median). Similarly, participants were also classified as either an early wake-up time group or late wake-up time group, according to the median value of the sample (06:52:55).

Covariates

Child age and gender

Child date of birth and gender were assessed by parental questionnaires.

Socio-economic status

Family socio-economic status of the children was assessed using postcode of residence and allocating from the corresponding value from the Australian Socio-Economic Indexes for Areas 2011 (SEIFA-Index of Relative Socio-Economic Disadvantage).[24] Using this index, deciles of deprivation ranging from 1 to 10 (higher decile indicates relatively less socio-economic disadvantages) are derived.[24] For description purpose, participants were categorized in three groups: low socio-economic status (deciles=1-3); middle socio-economic status (deciles=4-6); and high socio-economic status (deciles=7-10).

2.3 Statistical analysis

Descriptive characteristics of the sample at baseline and at follow-up were presented as means and standard deviations, median or percentages. The differences in sleep duration, sleep variability and sleep timing between baseline and follow up were examined using linear mixed models, with adjusted for time sequence, clustering effects, baseline age, gender and socio-economic status.

As the GET UP! Study was an RCT, the intervention effects on z-BMI were examined using linear regression models, and no intervention effects were found (Table S1), Therefore, we decided to perform the analyses with the whole sample to increase statistical power. We also performed a sensitivity analysis, considering only the control group, and the results remained the same (Table S2)

Linear mixed models were performed to examine the cross-sectional associations between the independent variables (i.e., total sleep duration, nightime sleep duration,

nap(s) duration, sleep timing or sleep variability) and the outcome (i.e., z-BMI) at baseline, with adjustments for centre-level clustering effects (modelled as a random intercept). Baseline age, gender and socio-economic status were subsequently included as covariates in the fully adjusted models. Linear mixed models were also performed to examine the prospective associations between sleep characteristics at baseline and adiposity at follow-up, accounting for centre-level clustering effects (modelled as random intercept). Baseline age, gender, socio-economic status and z-BMI were then included as covariates in the fully adjusted models.

Data were analysed using SPSS software (Version 24.0, IBM, USA). A P value < 0.05 was set as the significance level.

3. Results

The descriptive characteristics of the cross-sectional and prospective samples are presented in Table 1. Children's BMI and sleep duration (nap, nighttime sleep and total sleep duration) decreased over one year. Children's bedtime was almost 30 minutes later while they woke up around 20 minutes earlier at 12-month follow-up compared with baseline.

Insert Table 1 here

Cross-sectional associations between sleep characteristics and adiposity at baseline are reported in Table 2. In the fully adjusted model, total sleep duration was inversely associated with z-BMI. That is, an increase of 1-hour total sleep duration was associated with a decrease of 0.12 units of z-BMI (95% CI: -0.23, -0.01; p=0.033). Nap duration,

nightime sleep duration, sleep variability, bedtime or wakeup time were not associated with z-BMI.

Insert Table 2 here

Table 3 presents the prospective associations between sleep characteristics and adiposity. Nap duration at baseline was positively associated with z-BMI at 12-month follow-up even after accounting for centre-level clustering, baseline age, gender, socio-economic status and baseline z-BMI: an increase of 1-hour nap duration was associated with a gain of 0.41 unit of z-BMI (95%CI: 0.14, 0.68; p=0.003). There was no significant association between other sleep characteristics and z-BMI.

Insert Table 3 here

4. Discussion

4.1 Overall discussion

The present study shows that sleep duration was associated with adiposity in our sample of toddlers, although the associations between different types of sleep duration and adiposity varied. Total sleep duration was negatively associated with adiposity in cross-sectional analyses. Nap duration was prospectively but not cross-sectionally positively associated with adiposity. Sleep variability and sleep timing were not associated with concurrent or subsequent adiposity.

Our results suggest that shorter total sleep duration was cross-sectionally associated with higher adiposity in toddlers, which is consistent with a number of cross-sectional

findings in preschoolers[11,25,26] and in toddlers.[27,28] Indeed, short sleep duration has been suggested to influence the energy balance process through several biological and behavioural mechanisms, which in turn may increase adiposity.[5] Laboratory studies in adults have shown that short sleep duration could affect appetite regulation through relevant hormonal change, specifically leptin and ghrelin.[29] This may cause excessive food intake and eventually increase energy intake,[30] which has been found in epidemiological studies in both school-aged[10,31] and preschool-aged children.[16] On the other hand, short total sleep duration may also contribute to increased adiposity by reducing energy expenditure.[32] Evidence in adults suggests that total sleep deprivation could lead to lower resting and postprandial energy expenditure,[33] while chronic partial sleep deprivation could cause the feeling of fatigue,[34] which in turn may reduce physical activity and increase sedentary behaviour.[35] It has been reported in children that short sleep duration is associated with decreased physical activity[27,36] and increased screen time.[37]

Although longitudinal studies in preschool-aged children have predominantly suggested that total sleep duration is negatively associated with weight gain overtime or later adiposity,[11,17,25] in our study, there was no prospective association between total sleep duration and adiposity after 12 months. Our null-association finding is consistent with other two longitudinal studies in Australian (n=7,701)[38] and Danish toddlers (n=311).[39] A possible reason for the inconsistent findings between toddlers and pre-schoolers may be related to the developmental differences.[17] Since adiposity usually declines after the first year of life,[40] the potential effect of short sleep over time on adiposity in toddlerhood might be covered by this declining trend. It may be more likely to observe the potential effect in preschool-aged children as during this period the

decline in adiposity gradually becomes smaller before the adiposity rebound at around 5-7 years.[40] Moreover, it has been suggested that the adverse effect of short sleep duration on adiposity may be moderate during early childhood,[25] which is likely to manifest over time if the short sleep duration is prolonged. In that case, it may not be easily observed in a younger and healthier population like our sample.[4] Since pre-schoolers who have short sleep duration may also sleep less in their toddlerhood and infancy,[41] there may be stronger accumulative effects on adiposity and it may be easier to find significant associations, compared to toddlers. Therefore, future perspective studies with longer follow-up period are needed to examine the association between short sleep duration and adiposity in children under three years.

In our study, nap duration was prospectively associated with adiposity 12-month later in toddlers, indicating that the potential effects of nap(s) on adiposity may be different from that of total sleep duration. Our cross-sectional findings of no association between nap duration and adiposity in toddlers is consistent with previous studies in early childhood using cross-sectional designs.[42,43] In contrast to other prospective studies in young children,[44,45] we found a positive association between nap duration and adiposity. The differences in the measure of nap duration between those studies (by parental report) and our study (by accelerometry) may be one reason to explain the contrasting findings. Our results are consistent with studies examining nap time in adults with accelerometry, in which nap duration was associated with higher adiposity.[46,47] One underlying mechanism for the positive association between nap duration and adiposity could be the role that cortisol levels plays in obesity development. It is known in adults that sleep duration could influence cortisol levels, and an increased cortisol level may be associated with obesity.[48] Since evidence

suggested that toddler-aged children who have shorter nap duration tend to exhibit a matured cortisol pattern,[49] this may explain why longer nap duration was associated with higher subsequent adiposity in our study.

An alternative explanation for the prospective association between longer nap duration and higher adiposity may be the mediating effects of nighttime sleep. Previous evidence has suggested negative associations between nap duration and nighttime sleep duration in young children,[50] it is likely, therefore, that toddlers in our study who had longer nap duration would have shorter nighttime sleep duration. This may lead to an increase in adiposity, as it has been found that children with shortened nighttime sleep duration have higher subsequent adiposity.[44] While we did not find any prospective association between nighttime sleep duration and adiposity in our study, the cross-sectional association is close to significant ($p=0.05$). Therefore, nighttime sleep duration may be a mediator in the association between nap duration and adiposity in toddlers, which should be explored in future studies.

In spite of the positive association between nap duration and adiposity over time found in our study, we caution interpreting this as evidence to support limiting nap duration in toddlers, especially because nap(s) may be beneficial to other health and development outcomes, such as reduced stress levels,[51] improved motor skill learning[52] and better cognitive function.[53] Therefore, it may also be important for future studies to identify the ideal nap duration in young children for optimal health, growth and developmental outcomes.

In this study, the sleep variability in toddlers (around one hour at baseline) was much larger than the findings in a sample of 368 Danish pre-schoolers (around 0.5 hour),[16] which is most likely because children's sleep/wake system gradually mature with age.[54] Neither our study nor the Danish study found a significant association between sleep variability and adiposity, which agrees with most findings in children and adolecents.[14,15] Since the evidence is still limited, it may be premature to draw conclusions regarding this association. Previous studies suggest that greater sleep variability is independently associated with higher energy intake in preschool-aged children[16] and older children.[10,15] These findings indicate an underlying mechanism for a potential positive association between sleep variability and adiposity in children, which warrants examination in further epidemiologic studies.

In the current study, sleep timing (i.e., bedtime before around 8 pm or wakeup time before around 7 am) was not associated with concurrent or subsequent adiposity in toddlers. This finding is inconsistent with a recent study conducted of 8,950 American pre-schoolers, in which children who had later bedtimes (after 9 pm) were more likely to be obese and to gain weight over one year, compared with those who had earlier bedtimes (before 8 pm).[11] Despite the limited number of studies, sleep timing, especially late bedtime, has also been associated with obesity, independent of sleep duration, in school-aged children and adolescents.[6,10] A possible reasons for the inconsistency between our study and others may be due to our smaller sample size, the different stages of development and the difference in the measurement of sleep timing (objectively *vs* subjectively). Sleep timing was assessed by parental report in these studies, which may reduce accuracy.[16] Nevertheless, the association between sleep timing and adiposity in early childhood is feasible as evidence suggests that later

bedtimes are independently associated with higher energy intake at this age, which seems to be similar to the potential mechanism linking sleep variability with adiposity.[16] It is also likely that sleep timing could interact with sleep duration, which may contribute to the biological change linked with obesity risk.[5] In this light, findings in toddlers may need to be replicated in future studies to draw definitive conclusions.

4.2. Strengths and limitations

The current study, to the best of our knowledge, is the first to examine the prospective associations between objectively measured sleep duration, sleep timing and sleep variability and adiposity in toddlers. The prospective design of our study, the objective measurements of sleep variables and the ability to adjust for clustering effects and potential confounders related to demographics should be considered strengths of this study.

This study has several limitations. First, the Actigraph has not been validated directly against polysomnography in the assessment of sleep parameters in toddlers and there are currently no valid algorithms for sleep scoring available in this age group. To overcome this limitation, we identified sleep periods by visual inspection of the raw data, in consultation with the activity logs provided by the parents/educators. It has been shown that manually scoring wrist-worn accelerometer data with use of a sleep diary/log provided improved agreement with a polysomnography sleep-wake estimation[55]. Secondly, there may be rare cases when children's naps occurred with externally induced movements (e.g., nap occurring in a moving vehicle), and parents may not have accurately record these cases. This may have result in incorrect identification of a nap as another movement behaviour. Thirdly, there were several

factors that have confounded the relationship between sleep characteristics and adiposity and which we were unable to be adjusted in the statistical models, due to the availability of the data (e.g., dietary intake; nighttime awakenings) or the potential collinear issues (e.g., physical activity and sedentary behaviour). Finally, our relatively small sample size and only one follow-up point may limit the observations of true associations between sleep characteristics and adiposity in young children.

5. Conclusions

In this study, total sleep duration was negatively associated with higher concurrent adiposity but not subsequent adiposity in toddlers, whereas nap duration was positively associated with subsequent adiposity but not current adiposity. This indicates that the potential effects of total sleep duration may be different from that of nap duration at this age. Since sleep duration is modifiable, targeting this sleep characteristic may be an effective strategy to prevent overweight and obesity among young children. At the same time, sleep variability or sleep timing was not associated with concurrent or subsequent adiposity in our study. However, since relevant evidence in toddlerhood is still scarce, more research should to be replicated to confirm this finding.

Author Contribution

Miss Zhang conceptualized and designed the study, acquired the data, interpreted the data, drafted the initial manuscript, and reviewed and revised the manuscript. Mr Pereira and Miss Sousa-Sá acquired the data and critically reviewed and revised the manuscript. Dr Okely, Dr Feng and Dr Santos coordinated the design of the study and interpretation of the data and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Conflicts of interest

No conflict of interest was declared.

Funding

This study was supported by a Discovery Early Career Research Awards from the Australian Research Council (DE150101921).

Financial disclosure

Zhiguang Zhang is funded by a PhD scholarship from the China Scholarship Council and an International Postgraduate Tuition Award from University of Wollongong. Eduarda Sousa-Sá and Joao R. Pereira are funded by PhD scholarships from University of Wollongong. Xiaoqi Feng is funded by a National Health and Medical Research Council (NHMRC) Career Development Fellowship (#1140317) and an NHMRC project grant (#1101065). Rute Santos is supported by Portuguese Foundation for Science and Technology (CEECIND/01069/2017). The authors have no financial relationships relevant to this article to disclose.

Reference

1. Sahoo Krushnapriya, Sahoo Bishnupriya, Choudhury Ashok Kumar, Sofi Nighat Yasin, Kumar Raman, Bhadoria Ajeet Singh. Childhood obesity: causes and consequences. *Journal of family medicine and primary care.* 2015;4(2):187.
2. Druet Céline, Stettler Nicolas, Sharp Stephen, et al. Prediction of childhood obesity by infancy weight gain: an individual‐level meta‐analysis. *Paediatric and perinatal epidemiology.* 2012;26(1):19-26.
3. Chaput Jean-Philippe, Gray Casey E, Poitras Veronica J, et al. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. *Applied physiology, nutrition, and metabolism.* 2016;41(6):S266-S282.
4. Chaput Jean-Philippe, Gray Casey E, Poitras Veronica J, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0–4 years). *BMC Public Health.* 2017;17(5):855.
5. Miller Alison L, Lumeng Julie C, LeBourgeois Monique K. Sleep patterns and obesity in childhood. *Current opinion in endocrinology, diabetes, and obesity.* 2015;22(1):41.
6. Jarrin Denise C, McGrath Jennifer J, Drake Christopher L. Beyond sleep duration: distinct sleep dimensions are associated with obesity in children and adolescents. *International journal of obesity.* 2013;37(4):552.
7. Patel Sanjay R, Hayes Amanda L, Blackwell Terri, et al. The association between sleep patterns and obesity in older adults. *International journal of obesity.* 2014;38(9):1159.
8. Baron Kelly G, Reid Kathryn J, Kern Andrew S, Zee Phyllis C. Role of sleep timing in caloric intake and BMI. *Obesity.* 2011;19(7):1374-1381.
9. Froy Oren. Metabolism and circadian rhythms—implications for obesity. *Endocrine reviews.* 2009;31(1):1-24.
10. Golley Rebecca K, Maher Carol A, Matricciani L, Olds TS. Sleep duration or bedtime? Exploring the association between sleep timing behaviour, diet and BMI in children and adolescents. *International journal of obesity.* 2013;37(4):546.
11. Scharf Rebecca J, DeBoer Mark D. Sleep timing and longitudinal weight gain in 4‐and 5‐year‐old children. *Pediatric obesity.* 2015;10(2):141-148.
12. Bei Bei, Wiley Joshua F, Trinder John, Manber Rachel. Beyond the mean: A systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. *Sleep medicine reviews.* 2016;28:108-124.
13. Moore Melisa, Kirchner H Lester, Drotar Dennis, Johnson Nathan, Rosen Carol, Redline Susan. Correlates of adolescent sleep time and variability in sleep time: the role of individual and health related characteristics. *Sleep medicine.* 2011;12(3):239-245.
14. Spruyt Karen, Molfese Dennis L, Gozal David. Sleep duration, sleep regularity, body weight, and metabolic homeostasis in school-aged children. *Pediatrics.* 2011:peds. 2010-0497.
15. He Fan, Bixler Edward O, Berg Arthur, et al. Habitual sleep variability, not sleep duration, is associated with caloric intake in adolescents. *Sleep medicine.* 2015;16(7):856-861.

16. Rangan A, Zheng M, Olsen NJ, Rohde JF, Heitmann BL. Shorter sleep duration is associated with higher energy intake and an increase in BMI z-score in young children predisposed to overweight. *International Journal of Obesity.* 2018;42(1):59.
17. Carter Philippa J, Taylor Barry J, Williams Sheila M, Taylor Rachael W. Longitudinal analysis of sleep in relation to BMI and body fat in children: the FLAME study. *Bmj.* 2011;342:d2712.
18. Girschik Jennifer, Fritschi Lin, Heyworth Jane, Waters Flavie. Validation of self-reported sleep against actigraphy. *Journal of epidemiology.* 2012;22(5):462-468.
19. Santos Rute, Cliff Dylan P, Howard Steven J, et al. "GET-UP" study rationale and protocol: a cluster randomised controlled trial to evaluate the effects of reduced sitting on toddlers' cognitive development. *BMC pediatrics.* 2016;16(1):182.
20. Kinder Jennifer R, Lee Kathryn A, Thompson Hannah, Hicks Katherine, Topp Kimberly, Madsen Kristine A. Validation of a hip-worn accelerometer in measuring sleep time in children. *Journal of pediatric nursing.* 2012;27(2):127-133.
21. Tudor-Locke Catrine, Barreira Tiago V, Schuna Jr John M, Mire Emily F, Katzmarzyk Peter T. Fully automated waist-worn accelerometer algorithm for detecting children's sleep-period time separate from 24-h physical activity or sedentary behaviors. *Applied physiology, nutrition, and metabolism.* 2013;39(1):53-57.
22. Trost Stewart G, Fees Bronwyn S, Haar Sherry J, Murray Ann D, Crowe Linda K. Identification and validity of accelerometer cut‐points for toddlers. *Obesity.* 2012;20(11):2317-2319.
23. Zhang Zhiguang, Sousa-Sá Eduarda, Pereira João, et al. Correlates of nocturnal sleep duration, nocturnal sleep variability, and nocturnal sleep problems in toddlers: Results from the GET UP! Study. *Sleep Medicine.* 2018.
24. Pink Brian. Socio-economic indexes for areas (SEIFA). *Canberra: Australian Bureau of Statistics.* 2011.
25. Diethelm Katharina, Bolzenius Katja, Cheng Guo, Remer Thomas, Buyken Anette E. Longitudinal associations between reported sleep duration in early childhood and the development of body mass index, fat mass index and fat free mass index until age 7. *International Journal of Pediatric Obesity.* 2011;6(sup3):e114-123.
26. Ingram David G, Irish Leah A, Tomayko Emily J, et al. Overnight sleep duration and obesity in 2‐5 year‐old American Indian children. *Pediatric obesity.* 2018;13(7):406-412.
27. Hager Erin R, Calamaro Christina J, Bentley Lauren M, Hurley Kristen M, Wang Yan, Black Maureen M. Nighttime sleep duration and sleep behaviors among toddlers from low-income families: associations with obesogenic behaviors and obesity and the role of parenting. *Childhood Obesity.* 2016;12(5):392-400.
28. Wang Lu, Jansen Wilma, Boere‐Boonekamp Magda M, et al. Sleep and body mass index in infancy and early childhood (6‐36 mo): a longitudinal study. *Pediatric obesity.* 2019:e12506.

29. Spiegel Karine, Tasali Esra, Leproult Rachel, Van Cauter Eve. Effects of poor and short sleep on glucose metabolism and obesity risk. *Nature Reviews Endocrinology.* 2009;5(5):253.
30. Lundahl Alyssa, Nelson Timothy D. Sleep and food intake: A multisystem review of mechanisms in children and adults. *Journal of health psychology.* 2015;20(6):794-805.
31. Mi Sarah J, Kelly Nichole R, Brychta Robert J, et al. Associations of sleep patterns with metabolic syndrome indices, body composition, and energy intake in children and adolescents. *Pediatric obesity.* 2019:e12507.
32. Chaput Jean-Philippe. Sleep patterns, diet quality and energy balance. *Physiology & behavior.* 2014;134:86-91.
33. Benedict Christian, Hallschmid Manfred, Lassen Arne, et al. Acute sleep deprivation reduces energy expenditure in healthy men–. *The American journal of clinical nutrition.* 2011;93(6):1229-1236.
34. St-Onge Marie-Pierre, Roberts Amy L, Chen Jinya, et al. Short sleep duration increases energy intakes but does not change energy expenditure in normal-weight individuals–. *The American journal of clinical nutrition.* 2011;94(2):410-416.
35. Patel Sanjay R, Hu Frank B. Short sleep duration and weight gain: a systematic review. *Obesity.* 2008;16(3):643-653.
36. Yoong SL, Grady A, Stacey F, et al. A pilot randomized controlled trial examining the impact of a sleep intervention targeting home routines on young children's (3–6 years) physical activity. *Pediatric obesity.* 2018.
37. Hale Lauren, Guan Stanford. Screen time and sleep among school-aged children and adolescents: a systematic literature review. *Sleep medicine reviews.* 2015;21:50-58.
38. Hiscock Harriet, Scalzo Katherine, Canterford Louise, Wake Melissa. Sleep duration and body mass index in 0–7-year olds. *Archives of disease in childhood.* 2011;96(8):735-739.
39. Klingenberg Lars, Christensen Line Brinch, Hjorth Mads Fiil, et al. No relation between sleep duration and adiposity indicators in 9–36 months old children: the SKOT cohort. *Pediatric obesity.* 2013;8(1):e14-e18.
40. Rolland-Cachera MF, Deheeger M, Maillot M, Bellisle F. Early adiposity rebound: causes and consequences for obesity in children and adults. *International journal of obesity.* 2006;30(S4):S11.
41. Derks Ivonne PM, Kocevska Desana, Jaddoe Vincent WV, et al. Longitudinal associations of sleep duration in infancy and early childhood with body composition and cardiometabolic health at the age of 6 years: the generation R study. *Childhood Obesity.* 2017;13(5):400-408.
42. Kuzik Nicholas, Carson Valerie. The association between physical activity, sedentary behavior, sleep, and body mass index z-scores in different settings among toddlers and preschoolers. *BMC pediatrics.* 2016;16(1):100.
43. Louzada Maria Laura da Costa, Rauber Fernanda, Campagnolo Paula Dal Bó, Vitolo Márcia Regina. Sleep duration and body mass index among southern Brazilian preschoolers. *Arquivos brasileiros de cardiologia.* 2012;99(6):1156-1158.

44. Bell Janice F, Zimmerman Frederick J. Shortened nighttime sleep duration in early life and subsequent childhood obesity. *Archives of pediatrics & adolescent medicine.* 2010;164(9):840-845.
45. Bolijn R, Gubbels JS, Sleddens EFC, Kremers SPJ, Thijs C. Daytime sleep duration and the development of childhood overweight: the KOALA B irth C ohort S tudy. *Pediatric obesity.* 2016;11(5):e1-e5.
46. Devine Jaime K, Wolf Jutta M. Integrating nap and night‐time sleep into sleep patterns reveals differential links to health‐relevant outcomes. *Journal of sleep research.* 2016;25(2):225-233.
47. Owens Jane F, Buysse Daniel J, Hall Martica, et al. Napping, nighttime sleep, and cardiovascular risk factors in mid-life adults. *Journal of Clinical Sleep Medicine.* 2010;6(04):330-335.
48. Chan J, Sauve B, Tokmakejian S, Koren G, Van Uum S. Measurement of cortisol and testosterone in hair of obese and non-obese human subjects. *Experimental and Clinical Endocrinology & Diabetes.* 2014;122(06):356-362.
49. Watamura Sarah E, Donzella Bonny, Kertes Darlene A, Gunnar Megan R. Developmental changes in baseline cortisol activity in early childhood: Relations with napping and effortful control. *Developmental Psychobiology: The Journal of the International Society for Developmental Psychobiology.* 2004;45(3):125-133.
50. Thorpe Karen, Staton Sally, Sawyer Emily, Pattinson Cassandra, Haden Catherine, Smith Simon. Napping, development and health from 0 to 5 years: a systematic review. *Archives of Disease in Childhood.* 2015;100(7):615-622.
51. Atkinson L., Jamieson B., Khoury J., Ludmer J., Gonzalez A. Stress physiology in infancy and early childhood: Cortisol flexibility, attunement and coordination. *Journal of neuroendocrinology.* 2016;28(8).
52. Desrochers Phillip C., Kurdziel Laura B. F., Spencer Rebecca M. C. Delayed benefit of naps on motor learning in preschool children. *Experimental brain research.* 2016;234(3):763-772.
53. Giganti Fiorenza, Arzilli Cinzia, Conte Francesca, Toselli Monica, Viggiano Maria Pia, Ficca Gianluca. The effect of a daytime nap on priming and recognition tasks in preschool children. *Sleep.* 2014;37(6):1087-1093.
54. Bathory Eleanor, Tomopoulos Suzy. Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. *Current problems in pediatric and adolescent health care.* 2017;47(2):29-42.
55. Quante Mirja, Kaplan Emily R, Rueschman Michael, Cailler Michael, Buxton Orfeu M, Redline Susan. Practical considerations in using accelerometers to assess physical activity, sedentary behavior, and sleep. *Sleep health.* 2015;1(4):275-284.

TABLE 1 Descriptive characteristics of the participants

	Cross-Sectional Analysis (n = 202)	Prospective Analysis (n = 153)		
		Baseline	Follow-Up[a]	*P* Value[b]
Age, month, mean (SD)	19.62 (4.28)	19.56 (4.19)	31.90 (4.13)	-
Gender, % boys	49.5	50.3	50.3	-
Socioeconomic status, %				
Low	43.1	40.5	40.5	-
Middle	38.1	41.2	41.2	-
High	18.8	18.3	18.3	-
Body mass index, kg/m^2, mean (SD)	17.89 (1.70)	18.00 (1.63)	17.03 (1.24)	.000
Body mass index *z* score, mean (D)	0.04 (0.96)	0.10 (0.91)	0.06 (0.93)	.957
Sleep duration, h, mean (SD)				
Nap	1.48 (0.47)	1.52 (0.46)	1.38 (0.54)	.005
Night-time sleep	10.85 (1.15)	10.90 (1.08)	10.05 (1.93)	.000
Total sleep	12.33 (1.19)	12.41 (1.09)	11.41 (0.85)	.000
Sleep variability, h	1.08 (0.59)	1.00 (0.47)	1.01 (0.52)	1.000
Sleep timing (median)				
Bedtime	19:54:26	19:52:41	20:26:35	.000
Wake-up time	06:52:55	06:52:17	06:33:40	.000

[a]At follow-up, 111 children have valid sleep data (nap, night-time sleep, total sleep duration, sleep variability, bedtime, and wake-up time).

[b]Tested the change over 12 months using linear mixed models, adjusted for time sequence, clustering effects, baseline age, gender, and socioeconomic status. Sleep timing was transformed into minutes for test (eg, 19:52:41 = 1192.68 min).

TABLE 2 Cross-sectional associations between sleep characteristics and z-BMI (n = 202)

	Model 1[a]		Model 2[b]		Model 3[c]	
Sleep Characteristics	Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value
Total sleep duration, h	−0.12 (−0.23, −0.01)	0.037*	−0.12 (−0.23, −0.01)	0.038*	−0.12 (−0.23, −0.01)	0.033*
Nap duration, h	−0.06 (−0.35, 0.22)	0.667	−0.08 (−0.38, 0.22)	0.599	−0.08 (−0.37, 0.22)	0.616
Nighttime sleep duration, h	−0.12 (−0.23, −0.002)	0.047*	−0.12 (−0.23, 0.00)	0.050	−0.12 (−0.24, 0.00)	0.050
Sleep variability, h	−0.04 (−0.27, 0.18)	0.704	−0.03 (−0.27, 0.20)	0.786	−0.03 (−0.26, 0.20)	0.797
Bedtime						
Late	Reference		Reference		Reference	
Early	−0.02 (−0.28, 0.25)	0.898	−0.02 (−0.29, 0.25)	0.877	−0.02 (−0.29, 0.25)	0.886
Wake-up time						
Late	Reference		Reference		Reference	
Early	0.06 (−0.21, 0.32)	0.676	0.05 (−0.22, 0.32)	0.724	0.05 (−0.22, 0.32)	0.723

Abbreviation: CI, confidence interval.

*$P < 0.05$.

[a]Model 1 was adjusted for clustering effects.

[b]Model 2 was adjusted for clustering effects, age, gender, and socioeconomic status.

[c]Model 3 was adjusted for clustering effects, belonging or not to the intervention group, age, gender, and socioeconomic status.

TABLE 3 Prospective associations between sleep characteristics at baseline and z-BMI at 12-month follow-up (n = 153)

	Model 1[a]		Model 2[b]		Model 3[c]	
Sleep Variables	Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value
Total sleep duration, h	−0.06 (−0.20, 0.07)	0.367	−0.01 (−0.13, 0.10)	0.849	−0.01 (−0.13, 0.10)	0.843
Nap duration, h	0.34 (0.03, 0.66)	0.035*	0.41 (0.14, 0.68)	0.003*	0.41 (0.14, 0.68)	0.003*
Nighttime sleep duration, h	−0.13 (−0.26, 0.01)	0.069	−0.08 (−0.20, 0.03)	0.157	−0.08 (−0.20, 0.03)	0.159
Sleep variability, h	0.07 (−0.25, 0.39)	0.680	0.07 (−0.20, 0.34)	0.584	0.08 (−0.19, 0.35)	0.577
Bedtime						
Late	Reference		Reference			
Early	−0.23 (−0.52, 0.07)	0.136	−0.15 (−0.40, 0.10)	0.234	−0.15 (−0.40, 0.10)	0.236
Wake-up time						
Late	Reference		Reference			
Early	−0.17 (−0.47, 0.12)	0.252	−0.18 (−0.44, 0.07)	0.152	−0.18 (−0.44, 0.07)	0.154

Abbreviation: CI, confidence interval.

*$P < 0.05$.

[a]Model 1 was adjusted for clustering effects.

[b]Model 2 was adjusted for clustering effects, age, gender, socioeconomic status, and baseline z-BMI.

[c]Model 3 was adjusted for clustering effects, belonging or not to the intervention group, baseline age, gender, socioeconomic status, and baseline z-BMI.