Pediatric RESEARCH

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BASIC SCIENCE ARTICLE

A longitudinal study of sleep, weight status, and weight-related behaviors: Childhood Obesity Study in China Mega-cities

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BACKGROUND: The aim of the study was to examine correlates of sleep and assess its associations with weight status and related behaviors.

METHODS: Data were collected in 2015–2017 for 3298 children aged 6–17 years and their parents in 5 Chinese mega-cities. One thousand six hundred and ninety-one children with measured weight, height, and waist circumference in ≥2 surveys were included for longitudinal data analyses. Sleep and behaviors were self-reported.

RESULTS: Cross-sectional data analyses found that older ($\beta = -0.29$, 95% CI: −0.32, −0.27) and secondary school children ($\beta = -1.22$, 95% CI: −1.31, −1.13) reported shorter sleep than their counterparts. Children with ≥college-educated (vs <college) fathers ($\beta = 0.17$, 95% CI: 0.04, 0.31) or mothers ($\beta = 0.16$, 95% CI: 0.04, 0.29) reported longer sleep. Longer sleep was longitudinally associated with less sugar-sweetened beverage intake ($\beta = -0.12$ days/h sleep, 95% CI: −0.20, −0.03), more healthy snacks intake ($\beta = 0.13$ days/h sleep, 95% CI: 0.02, 0.25) and having breakfast ($\beta = 0.07$ days/h sleep, 95% CI: 0.04, 0.11), and shorter total screen time ($\beta = -0.22$ h/h sleep, 95% CI: −0.65, −0.21) and surfing the internet/computer time ($\beta = -0.06$ h/h sleep, 95% CI: −0.09, −0.04) among all children. Longer sleep reduced the risk of central obesity (OR = 0.46, 95% CI: 0.25, 0.85) for girls.

CONCLUSIONS: Sleep among urban Chinese children varies by demographic factors. Longer sleep is associated with healthier weight-related behaviors and lower central obesity risk.

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IMPACT:

- Longer sleep was observed in younger, primary school children and children with college-educated parents.
- Longer sleep increased healthier weight-related behaviors and reduced general and central obesity risk.
- Provides data on the correlates of sleep duration of children.
- Gives insights on longitudinal relationships of sleep duration with weight-related behaviors and obesity risk.
- Findings help inform sleep interventions to increase sleep duration to prevent childhood obesity and unhealthy weight-related behaviors in urban settings of developing countries.

INTRODUCTION

Sleep is an essential behavior for optimal child health.[1] However, a global, secular decline of 0.75 min per year in child sleep duration has been observed over the past 100 years with greatest rates of decline seen in Asia.[2] In China, >15% of school-aged children are estimated to not get enough sleep.[3] This is in part attributable to the high educational aspirations and demands placed on Chinese children by schools and parents due to the rapid social changes and implementation of the one-child policy since the 1980s; the atmosphere of heightened academic competition and expectation often leaves children more vulnerable to insufficient sleep.[2,3]

The prevalence of insufficient sleep is even higher in mega-cities in China. In 2010, 62.9% of children aged 9–18 years were reported to sleep ≤8 h per day in Chinese urban areas;[4] these estimates have not been updated despite continued growth. Indeed, mega-cities, which have led China's economic development over the past decades, are where the fastest changes in environment and urbanization in China have occurred. Closer examination of change in sleep duration and its potential determinants among children in these locales are critical for understanding the sleep health of Chinese urban children.

Sleep duration in children may be influenced by child and parental socio-demographic factors. For example, older ages[5] and higher school grades[6] have been found to be risk factors for shorter sleep duration. There exist contradictory findings as to whether boys or girls sleep more.[7] Parental education level has

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also been shown to be associated with children's sleep duration.[7] However, factors impacting children's sleep duration have not been well studied in Chinese mega-cities.

Insufficient sleep may increase the risk of overweight and obesity[8] and engaging in unhealthy weight-related behaviors [e.g., consumption of sugar-sweetened beverages (SSBs) and using screens].[9] In Chinese children, the prevalence of all these factors was very high. For example, the prevalence of overweight and obesity was 28.2% in 2014,[10,11] 66.6% of Chinese children consumed SSBs weekly,[12] and 21.6% spent ≥2 h/day using screens.[13] While several cross-sectional studies have observed associations between shorter sleep duration with increased overweight and obesity risk[14] and frequency of unhealthy behaviors in children,[9] no large prospective studies have examined how children's sleep duration may affect weight status and related behaviors in Chinese mega-cities.[8]

To fill these knowledge gaps, this study utilized longitudinal data collected from five mega-cities (city population >8 million) in China in 2015–2017 and examined (1) overall and sex-specific correlates of children's sleep duration and (2) overall and sex-specific associations of children's sleep duration with body weight status and related behaviors. Shorter sleep duration was hypothesized to increase risk of overweight and obesity (including central obesity) and be associated with more unhealthy weight-related behaviors.

METHODS AND MATERIALS

Ethics statement

This study was conducted in compliance with the Declaration of Helsinki and with the approval of the ethics committees of the State University of New York at Buffalo and the Chinese Center for Disease Control and Prevention in China. Informed consent was obtained from a parent and/or legal guardian for children's participation in this study.

Study design and participants

The Childhood Obesity Study in China Mega-cities (COCM) was a U.S. NIH-funded longitudinal study aiming to examine the etiology of childhood obesity and chronic diseases in China. This study uniquely captures health trends related to lifestyle behaviors changes occurring at the forefront of China's economic growth. Initially, four major cities across China were included in 2015 at baseline: Beijing in the North, the capital; Shanghai in the Southeast, China's largest and most economically developed city; Nanjing in the Southeast, China's old capital before 1949 and capital of Jiangsu province; and Xi'an in the Northwest, a dynastic capital of China and capital of Shanxi province. In 2016, Chengdu, in the Southwest and capital of Sichuan province, was added. A cluster randomized sampling design was applied. The sampling method has been described in detail in previous publications.[15,16]

This study used data collected annually in 2015–2017 via Chinese language surveys on child and parental characteristics, sleep duration, and weight and related behaviors. This study utilized an open cohort design so some students completed the survey only once while others completed the survey multiple times, as students graduated, and new students also joined. For cross-sectional data analyses, we used each child's first observation from pooled data during 2015–2017 ($n = 3298$; mean age ± SD: 11.5 ± 2.0 years, range: 6.5–17.5 years). For longitudinal analyses, children were included if their eating and drinking behaviors, screen time behaviors, body weight and height, and/or waist circumference had been recorded at least twice in the 2015–2017 period ($n = 1691$, mean age ± SD: 11.2 ± 1.9 years, range: 6.5–16 years).

Key study variables and measurements

Outcome variables

Overweight and obesity: Students' body mass index was calculated as weight (kg) divided by height squared (m^2). Height was measured using Seca 213 Portable Stadiometer Height-Rods (Seca China, Zhejiang, China) with a precision of 0.1 cm. Body weight was measured using Seca 877 electronic flat scales (Seca China, Zhejiang, China) with a precision of 0.1 kg. Height and weight were measured by trained health professionals. Overweight and obesity were defined using age- and sex-specific BMI cutoff points issued by the National Health Commission of the People's Republic of China.[17]

Central obesity: Waist circumference was measured using a non-stretchable tape with a precision of 0.1 cm. Central obesity was defined as having a waist-to-height ratio ≥0.48[18] and taken as a dichotomous dependent variable in mixed-effects models.

Eating behaviors: Children were asked to report average (in days) weekly consumption of the following during the previous 3 months: breakfast, SSBs (common examples were listed), and healthy snacks (i.e., fruits, eggs, milk, other dairy and dairy products, beans and beans products, and nuts). A healthy snacks composite score was calculated by summing and averaging the consumption frequencies of the six specified snacks. These three eating behaviors were treated as continuous dependent variables in mixed-effects models.

Screen time: Children were asked to self-report total time spent per week using screens in general (e.g., cell phones, iPads, computers, and TV, and excluding time related to school or studying) and time spent per day specifically surfing the internet/using the computer or watching TV. For these latter two behaviors, participants were asked how many times they used the computer/internet or watched TV in the past 7 days and about how long they spent doing so each time. The three screen time variables were used as continuous dependent variables in mixed-effects models.

Exposure variables

Sleep duration: Sleep was assessed by one question "On average, how many hours and minutes did you sleep (including naps) on a typical day during the past 7 days?" This item has been used extensively in previous studies among children in China.[19,20] The reported duration was categorized according to sex-specific sleep duration cutoffs previously used in children,[21] given age-related shifts in children's sleep needs and circadian rhythms.[22] For children aged <10 years, the recommended sleep duration, shorter duration, and shortest duration were ≥10 h/day, 8–10 h/day, and <8 h/day, respectively. For children aged ≥10 years, the recommended sleep duration, shorter duration, and shortest duration were ≥9 h/day, 7–9 h/day, and <7 h/day, respectively.[22] The shorter and shortest sleep duration were defined as insufficient sleep. Sleep was used as both a continuous (h and min and a categorical variable in mixed-effects models.

Covariates. A host of variables were included in mixed-effects models predicting students' weight status and related behaviors. The potential associations of these variables with children's sleep duration were also examined. These variables included: age (in years), sex, city of residence (Beijing, Shanghai, Nanjing, Xi'an, or Chengdu), baseline weight status, baseline eating and drinking behaviors, baseline screen times, school level (primary or secondary), and highest paternal and maternal education levels (≤middle school, high and vocational schools, or ≥college).

Statistical analysis

First, descriptive statistics were calculated. Chi-square tests (for categorical variables) and *t* tests (for continuous variables) were conducted to test for sex differences in children and parental characteristics using pooled, cross-sectional data.

Second, linear and logistic mixed-effects models were used to examine the following: (1) potential child and parental correlates of children's sleep duration via pooled, cross-sectional data, including age, sex, school type, city of residence, children's primary caregiver, and highest paternal and maternal education; and (2) the longitudinal associations of sleep duration with children's weight status and related behaviors. Linear models were used for sleep duration as a continuous variable and logistic for sleep as a binary variable. Models adjusted for random effects arising from cities of residence and schools, as well as other covariates including age and sex, baseline eating and drinking behaviors, baseline weight status, and paternal and maternal education levels. Sex-stratified analyses were conducted to explore potential differences in these associations. In such analyses, all covariates except for sex were adjusted for.

Potential interaction effects of sleep duration and age (both mean-centered) on eating and drinking behaviors, screen time, and weight status were also examined and tested in linear or logistic mixed-effects models. Effect sizes were presented either as beta coefficients with standard error or odds ratios (ORs) with a 95% confidence interval (95% CI). Analyses were performed using Stata 14 (StataCorp, College Station, TX). Statistical significance was set at $p < 0.05$.

RESULTS

Characteristics of the children

Children self-reported an average sleep duration of 8.5 h/day. The prevalence of insufficient sleep duration was 56.9%; no significant sex differences were found. The combined prevalence of overweight/obesity and central obesity were 31.4 and 2.3%, respectively. Boys were more likely to have overweight/obesity (39.2 vs 23.4%, $p < 0.001$) and centrally obesity (3.1 vs 1.4%, $p = 0.001$) than girls. Average total screen time was 6.3 h/week overall. Boys reported longer total screen time than girls (7.1 vs 5.5 h/week, $p < 0.001$) and also spent more time surfing the internet/using the computer (0.6 vs 0.4 h/day, $p < 0.001$) and watching TV (0.6 vs 0.4 h/day, $p < 0.001$) (Table 1).

Cross-sectional data analysis: possible correlates of sleep duration

Shorter sleep duration was observed with age ($\beta = -0.29$, 95% CI: -0.32, 0.27) and in secondary school children ($\beta = -1.22$, 95% CI: -1.31, -1.13); no sex differences were found. All adolescents in Shanghai ($\beta = 0.29$, 95% CI: 0.15, 0.44), Nanjing ($\beta = 0.20$, 95% CI: 0.04, 0.36), Xi'an ($\beta = 0.21$, 95% CI: 0.05, 0.36), and Chengdu ($\beta = 0.20$, 95% CI: 0.04, 0.36) reported longer sleep duration than children living in Beijing, especially boys. Compared to children whose primary caregivers were their mothers, those primarily taken care of by other caregivers reported longer sleep duration among all children ($\beta = 0.49$, 95% CI: 0.11, 0.87) and boys ($\beta = 0.51$, 95% CI: 0.03, 0.99). Regarding parental education, in the analyses of all children, those with fathers ($\beta = 0.17$, 95% CI: 0.04, 0.31) or mothers ($\beta = 0.16$, 95% CI: 0.04, 0.29) with ≥college

Table 1. Sample characteristics of Chinese children at baseline based on [mean (SD) or %] pooled data during 2015–2017 from Childhood Obesity Study in China Mega-cities ($n = 3298$).

Characteristics	All ($n = 3298$)	Boys ($n = 1675$)	Girls ($n = 1623$)	p value for sex differences[a]
Age (years)	11.5 ± 2.0	11.5 ± 2.0	11.5 ± 2.0	0.70
School type				0.39
Primary school	55.2	55.9	54.4	
Secondary school	44.9	44.1	45.6	
Health outcomes				
Body mass index (kg/m^2)	19.1 ± 3.8	19.7 ± 3.9	18.6 ± 3.6	**<0.001**
Waist circumference (cm)	65.7 ± 10.3	68.0 ± 11.2	63.3 ± 8.8	**<0.001**
Central obesity[b]	2.3	3.1	1.4	**0.001**
Overweight or obesity[c]	31.4	39.2	23.4	**<0.001**
Eating behaviors (frequency/week)				
Sugar-sweetened beverages	1.6 ± 3.8	2.0 ± 4.4	1.3 ± 3.1	**<0.001**
Healthy snacks	4.8 ± 4.4	5.0 ± 4.4	4.6 ± 3.1	**0.04**
Breakfast	6.5 ± 1.3	6.5 ± 1.2	6.4 ± 1.3	0.30
Screen time				
Total screen time (h/week)	6.3 ± 10.7	7.1 ± 11.8	5.5 ± 9.4	**<0.001**
Surfing the internet/using the computer (h/day)	0.5 ± 0.8	0.6 ± 0.9	0.4 ± 0.7	**<0.001**
Watching TV (h/day)	0.5 ± 0.7	0.6 ± 0.8	0.4 ± 0.5	**<0.001**
Sleep duration (h and min/day)	8.5 ± 1.4	8.6 ± 1.4	8.5 ± 1.4	0.14
Sleep duration (%, categorical)[d]				0.24
Recommended duration	43.1	44.4	41.7	
Shorter duration	49.0	48.1	49.9	
Shortest duration	7.9	7.5	8.4	

$p < 0.05$; $p < 0.01$; $p < 0.001$. Numbers in bold indicated statistical significance.
[a] p value was based on Chi-square test for categorical variables and t tests for continuous variables across gender.
[b] Central obesity was defined as having a waist-for-height ratio ≥0.48.[18]
[c] Overweight and obesity were defined according to the "WS/T 586-2018 Screening for overweight and obesity among school-aged children and adolescents."[17]
[d] Sleep duration was defined using age-specific cutoff points: for children aged <10 years: recommended duration ≥10 h/day, shorter duration: 8–10 h/day, shortest sleep: <8 h/day; for children aged ≥10 years: recommended duration ≥9 h/day, shorter duration: 7–9 h/day, shortest sleep: <7 h/day.[19]

Table 2. Cross-sectional data analysis: correlates of Chinese children's sleep duration based on pooled data during 2015–2017 from Childhood Obesity Study in China Mega-cities ($n = 3298$).

	Sleep duration as a continuous variable (h and min/day) (beta, 95% CI)			Sleep duration as a dichotomous variable (reference: shorter and shortest durations)[a] (OR, 95% CI)		
	All (Model 1)	Boys (Model 2)	Girls (Model 3)	All (Model 1)	Boys (Model 2)	Girls (Model 3)
Age (years) ($n = 3298$)	**−0.29*** (−0.32, −0.27)**	**−0.25*** (−0.28, −0.22)**	**−0.34*** (−0.37, −0.31)**	**0.85*** (0.82, 0.88)**	**0.90*** (0.86, 0.95)**	**0.80*** (0.76, 0.84)**
Boys (vs girls)	0.07 (−0.03, 0.17)	—	—	1.12 (0.97, 1.28)	—	—
School type						
Primary (reference) ($n = 1819$)						
Secondary ($n = 1479$)	**−1.22*** (−1.31, −1.13)**	**−1.05*** (−1.18, −0.92)**	**−1.39*** (−1.51, −1.26)**	**0.37*** (0.32, 0.42)**	**0.44*** (0.36, 0.54)**	**0.30*** (0.24, 0.37)**
City of residence ($n = 3292$)						
Beijing (reference) ($n = 761$)						
Shanghai ($n = 818$)	**0.29*** (0.15, 0.44)**	**0.44*** (0.24, 0.64)**	0.14 (−0.07, 0.34)	**1.52*** (1.24, 1.85)**	**1.89*** (1.42, 2.50)**	1.20 (0.90, 1.60)
Nanjing ($n = 555$)	**0.20* (0.04, 0.36)**	0.14 (−0.08, 0.37)	**0.26* (0.03, 0.48)**	1.12 (0.89, 1.40)	1.12 (0.81, 1.54)	1.12 (0.81, 1.53)
Xi'an ($n = 608$)	**0.21* (0.05, 0.36)**	**0.40*** (0.17, 0.62)**	0.02 (−0.20, 0.25)	**1.48*** (1.19, 1.84)**	**1.99*** (1.46, 2.70)**	1.10 (0.81, 1.49)
Chengdu ($n = 550$)	**0.20* (0.04, 0.36)**	**0.32** (0.09, 0.54)**	0.09 (−0.13, 0.31)	**1.36** (1.09, 1.70)**	**1.65** (1.20, 2.28)**	1.12 (0.82, 1.53)
Child's primary caregiver ($n = 3198$)						
Mother (reference) ($n = 2247$)						
Father ($n = 490$)	0.01 (−0.13, 0.16)	0.11 (−0.08, 0.30)	−0.14 (−0.36, 0.08)	1.08 (0.89, 1.32)	1.29 (1.00, 1.67)	0.81 (0.59, 1.11)
Grandparent ($n = 370$)	0.11 (−0.05, 0.27)	0.17 (−0.06, 0.41)	0.05 (−0.18, 0.27)	1.03 (0.82, 1.28)	1.09 (0.79, 1.49)	0.97 (0.71, 1.33)
Babysitter ($n = 18$)	−0.65 (−1.33, 0.03)	−1.21 (−2.82, 0.40)	−0.51 (−1.27, 0.24)	0.86 (0.33, 2.22)	0.66 (0.06, 7.35)	0.91 (0.32, 2.58)
Other ($n = 60$)	**0.49* (0.11, 0.87)**	**0.51* (0.03, 0.99)**	0.44 (−0.20, 1.07)	1.65 (0.98, 2.76)	1.48 (0.77, 2.82)	1.97 (0.84, 4.65)
Paternal highest education ($n = 3163$)						
≤Middle school ($n = 619$) (reference)						
High or vocational schools ($n = 951$)	−0.01 (−0.16, 0.14)	0.03 (−0.17, 0.24)	−0.04 (−0.26, 0.17)	0.87 (0.71, 1.06)	0.86 (0.65, 1.14)	0.89 (0.66, 1.20)
≥College ($n = 1593$)	**0.17* (0.04, 0.31)**	**0.19* (0.001, 0.37)**	0.17 (−0.03, 0.37)	0.86 (0.72, 1.04)	0.82 (0.64, 1.06)	0.93 (0.70, 1.22)
Maternal highest education ($n = 3165$)						
≤Middle school ($n = 804$) (reference)						
High or vocational schools ($n = 862$)	0.02 (−0.12, 0.16)	0.13 (−0.07, 0.32)	−0.06 (−0.26, 0.14)	0.87 (0.71, 1.05)	0.99 (0.75, 1.29)	0.79 (0.59, 1.05)
≥College ($n = 1499$)	**0.16* (0.04, 0.29)**	0.11 (−0.07, 0.28)	**0.23* (0.04, 0.41)**	0.92 (0.77, 1.09)	0.83 (0.66, 1.06)	1.02 (0.79, 1.32)

Beta/SE and OR/95% CI were calculated based on linear/logistic mixed-effects model examining associations of child and parental characteristics with sleep duration using cross-sectional data.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Numbers in bold indicated statistical significance.
[a]Sleep duration was defined using age-specific cutoff points: for children aged <10 years: recommended duration: ≥10 h/day, shorter duration: 8–10 h/day, shortest sleep: <8 h/day; for children aged ≥10 years: recommended duration: ≥9 h/day, shorter duration: 7–9 h/day, shortest sleep: <7 h/day[19]; sleep duration was dichotomized and shorter and shortest duration were defined as "0" and recommended duration was defined as "1" in the mixed-effects model.

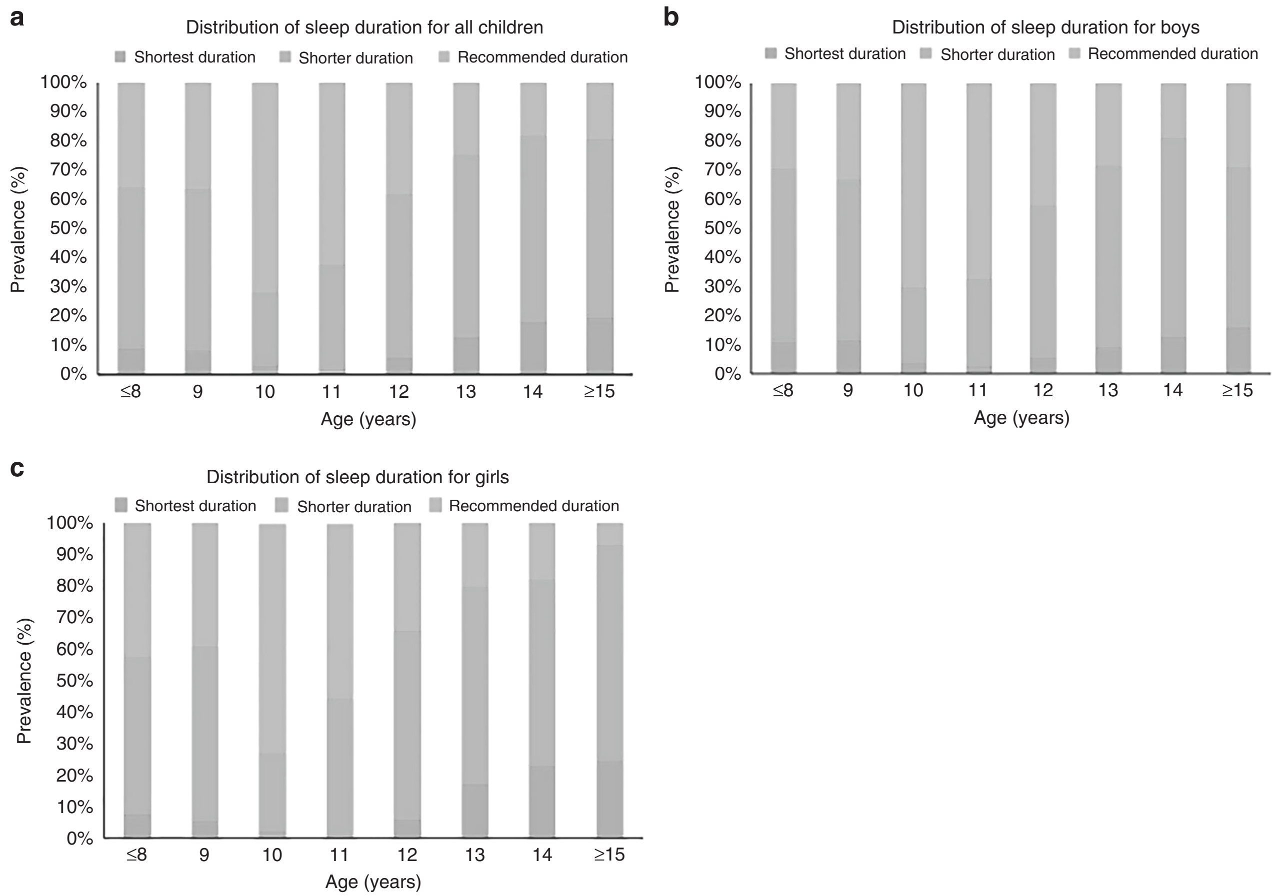

Fig. 1 Cross-sectional data analyses: Distribution of sleep duration for all children (a), boys (b), and girls (c) based on pooled data collected in five mega-cities in China from 2015 to 2017, the Childhood Obesity Study in China Mega-cities ($n = 3298$). Sleep duration was defined using age-specific cutoff points: For children aged 5-10 years: Recommended duration ≥ 10 hours/day, shorter duration: 8-10 hours/day, shortest sleep: <8 hours/day. For children aged ≥ 10 years: Recommended duration ≥ 9 hours/day, shorter duration: 7-9 hours/day, shortest duration: <7 hours/day.

education, longer sleep duration was reported compared to children of fathers or mothers, respectively, with lower education. By sex, longer sleep duration was observed in boys ($\beta = 0.19$, 95% CI: 0.001, 0.37) whose fathers attained ≥college education and in girls ($\beta = 0.23$, 95% CI: 0.04, 0.41) whose mothers attained ≥college education vs respective parents with lower educational attainment (Table 2).

Trend analyses of sleep duration with age found the prevalence of insufficient sleep to increase in children between ages 6 and 17 years, especially after age 10 years. By sex, the prevalence of insufficient sleep increased more rapidly in girls (Fig. 1).

Longitudinal data analysis: associations of sleep duration with children's eating and drinking behaviors

First, we treated sleep duration as a continuous variable in linear mixed-effects models. Among all children, longer sleep duration was associated with more frequent consumption of healthy snacks ($\beta = 0.13$, 95% CI: 0.02, 0.25) and less frequent consumption of SSBs ($\beta = -0.12$, 95% CI: −0.20, −0.03) after adjusting for covariates, such as age and sex. Sex-stratified analysis found longer sleep duration to be associated with less SSB consumption ($\beta = -0.15$, 95% CI: −0.28, −0.02) in boys and more frequent consumption of healthy snacks ($\beta = 0.17$, 95% CI: 0.001, 0.34) and breakfast ($\beta = 0.14$, 95% CI: 0.09, 0.18) in girls (Table 3).

Second, we treated sleep duration as a categorical variable [recommended, shorter, and shortest (reference group)] in mixed-effects models. Compared to the reference group, children in the shorter and recommended sleep duration groups reported more frequent consumption of healthy snacks [$\beta = 0.48$ (95% CI: −0.03, 1.00) and $\beta = 0.78$ (95% CI: 0.24, 1.32), respectively] and breakfast [$\beta = 0.38$ (95% CI: 0.23, 0.52) and $\beta = 0.38$ (95% CI: 0.23, 0.53), respectively]. More significant associations between categories of sleep duration and healthy snacks and breakfast consumption were found for girls than for boys (Table 3).

Longitudinal data analysis: associations between sleep duration and children's screen time

First, we treated sleep duration as a continuous variable. Longer sleep duration was associated with less total screen time ($\beta = -0.22$, 95% CI: −0.43, −0.02) and less surfing the internet/using the computer ($\beta = -0.06$, 95% CI: −0.09, −0.04) for all children. In sex- stratified analysis, an increase of 1 h/day in sleep duration was associated with a 0.54 h/week ($\beta = -0.54$, 95% CI: −0.80, −0.28) decrease in total screen time, a 0.08 h/day ($\beta = -0.08$, 95% CI: −0.11, −0.05) decrease in surfing the internet/using the computer, and a 0.04 h/day decrease in watching TV ($\beta = -0.04$, 95% CI: −0.07, −0.01) for girls. Significant associations were not observed in boys (Table 4).

Second, we treated sleep duration as a categorical variable. A dose–response pattern was observed between sleep duration and child screen time. For all children, compared with the reference group of shortest sleep duration, those with shorter sleep duration reported less total screen time ($\beta = -1.42$, 95% CI: −2.33, −0.50), less time surfing the internet/using the computer ($\beta = -0.24$, 95% CI: −0.35, −0.14), and less time watching TV ($\beta = -0.22$, 95% CI: −0.35, −0.08). Furthermore, compared to those with shortest

Table 3. Longitudinal data analysis using mixed-effects models: association of sleep duration with eating and drinking behaviors (freq./week) of children in five mega-cities in China, stratified by sex ($n = 1691$).

	Sugar-sweetened beverages (β, 95% CI)[a]	Healthy snacks (β, 95% CI)[a]	Breakfast (β, 95% CI)[a]
(1) Sleep duration (h/day) used as a continuous independent variable			
All	**−0.12** (−0.20, −0.03)**	**0.13* (0.02, 0.25)**	**0.07*** (0.04, 0.11)**
Boys	**−0.15* (−0.28, −0.02)**	0.08 (−0.07, 0.24)	0.02 (−0.03, 0.06)
Girls	−0.10 (−0.21, 0.02)	**0.17* (0.00, 0.34)**	**0.14*** (0.09, 0.18)**
(2) Sleep duration used as a categorical independent variable			
All			
Sleep duration			
Shortest (reference)			
Shorter	−0.22 (−0.65, 0.21)	0.48 (−0.03, 1.00)	**0.38*** (0.23, 0.52)**
Recommended	−0.32 (−0.77, 0.13)	**0.78** (0.24, 1.32)**	**0.38*** (0.23, 0.53)**
Boys			
Sleep duration			
Shortest (reference)			
Shorter	−0.16 (−0.90, 0.58)	0.59 (−0.16, 1.35)	**0.28* (0.06, 0.50)**
Recommended	−0.27 (−1.03, 0.49)	0.73 (−0.05, 1.51)	0.19 (−0.04, 0.42)
Girls			
Sleep duration			
Shortest (reference)			
Shorter	−0.29 (−0.77, 0.19)	0.35 (−0.36, 1.06)	**0.47*** (0.28, 0.65)**
Recommended	−0.40 (−0.91, 0.11)	**0.76* (0.01, 1.51)**	**0.57*** (0.37, 0.77)**

Variable definitions: Sleep duration was defined using age-specific cutoff points: for children aged <10 years: recommended duration: ≥10 h/day, shorter duration: 8–10 h/day, shortest sleep: <8 h/day; and for children aged ≥10 years: recommended duration ≥9 h/day, shorter duration: 7–9 h/day, shortest sleep: <7 h/day[19], "shortest duration" = 0, "shorter duration" = 1, and "recommended duration" = 2[19]. Central obesity was defined as waist-to-height ratio ≥0.48.[18]
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Numbers in bold indicated statistical significance.
[a]Age, sex, city of residence, baseline eating and drinking behaviors, school level, and paternal and maternal education levels were adjusted for as covariates in the mixed-effects models. In the sex-stratified analyses, models were adjusted for the same variables except sex.

sleep duration, those with recommended sleep duration reported less total screen time ($\beta = -1.70$, 95% CI: −2.66, −0.74), less time surfing the internet/using the computer ($\beta = -0.32$, 95% CI: −0.43, −0.20), and less time watching TV ($\beta = -0.15$, 95% CI: −0.29, −0.01). Similar findings were observed for girls but not for boys. Compared to girls in the reference group (shortest sleep duration), girls with shorter sleep duration reported less total screen time ($\beta = -2.21$, 95% CI: −3.30, −1.11), less time surfing the internet/using the computer ($\beta = -0.22$, 95% CI: −0.34, −0.10), and less time watching TV ($\beta = -0.13$, 95% CI: −0.24, −0.02). Girls with recommended sleep duration reported less total screen time ($\beta = -2.80$, 95% CI: −3.96, −1.64), less time surfing the internet/using the computer ($\beta = -0.30$, 95% CI: −0.44, −0.17), and less time watching TV ($\beta = -0.12$, 95% CI: −0.24, −0.01) (Table 4).

Longitudinal data analysis: associations between sleep duration and children's weight status

First, sleep duration was treated as a continuous variable. Sleep duration was only significantly associated with the risk of central obesity for girls (OR = 0.46, 95% CI: 0.25, 0.85). It was not significantly associated with BMI or having overweight/obesity in the analyses of all children or by sex (Table 5).

Second, sleep duration was treated as a categorical variable. Compared to girls with the shortest sleep duration (reference group), girls those with shorter sleep duration had lower BMI ($\beta = -0.28$, 95% CI: −0.51, −0.05). Also, compared to counterparts in the reference group, children with recommended sleep duration had significantly reduced risk of general overweight or obesity in all children (OR = 0.70, 95% CI: 0.53, 0.93) and girls (OR = 0.64, 95% CI: 0.43, 0.96). Compared to girls in the shortest sleep duration group, those with shorter sleep duration (OR = 0.19, 95% CI: 0.04, 0.90) had significantly reduced risk of central obesity. This was not observed for all children or boys (Table 5).

The interaction effects between age and sleep duration on eating and drinking behaviors, screen time, and weight status are shown in Supplemental Tables 1 and 2. We found that age significantly moderated the longitudinal associations of sleep duration with having breakfast ($\beta = 0.02$, 95% CI: 0.00, 0.03) and time spent surfing the internet/using the computer ($\beta = -0.02$, 95% CI: −0.03, −0.01). Further age-stratified analyses showed that sleep duration was only significantly associated with having breakfast ($\beta = 0.09$, 95% CI: 0.04, 0.14) and time spent surfing the internet/using the computer ($\beta = -0.09$, 95% CI: −0.14, −0.05) among children aged ≥10 years.

DISCUSSION

Given the rapid rise in the prevalence of insufficient sleep, overweight and obesity, and related unhealthy lifestyle behaviors in China, especially in its mega-cities, it is of great interest to examine the characteristics/correlates of sleep and how it may contribute to the epidemic of childhood obesity. Based on large-scale data from a study of five Chinese mega-cities, we examined sex-specific characteristics and correlates of sleep duration using pooled cross-sectional data and the longitudinal associations of sleep duration with eating and drinking behaviors, screen time, and weight status in children. Our results demonstrated several important findings.

First, we found that children on average slept 8.5 h/day, and the prevalence of insufficient sleep (the shorter and shortest sleep duration group, combined) was 56.9%. Sex differences in sleep duration or in the prevalence of insufficient sleep were not

Table 4. Longitudinal data analysis using mixed-effects models: associations between sleep duration and screen time behaviors of children in five mega-cities in China, stratified by sex ($n = 1691$).

	Total screen time (β, 95% CI; h/week)	Surfing the internet/using the computer (β, 95% CI; h/day)	Watching TV (β, 95% CI; h/day)
(1) Sleep duration (h/day) used as a continuous independent variable			
All[a]	**−0.22* (−0.43, −0.02)**	**−0.06*** (−0.09, −0.04)**	0.00 (−0.03, 0.03)
Boys	0.10 (−0.21, 0.42)	−0.05 (−0.08, 0.01)	0.04 (−0.01, 0.09)
Girls	**−0.54*** (−0.80, −0.28)**	**−0.08*** (−0.11, −0.05)**	**−0.04** (−0.07, −0.01)**
(2) Sleep duration used as a categorical independent variable			
All[a]			
Sleep duration			
Shortest (reference)			
Shorter	**−1.42** (−2.33, −0.50)**	**−0.24*** (−0.35, −0.14)**	**−0.22** (−0.35, −0.08)**
Recommended	**−1.70** (−2.66, −0.74)**	**−0.32*** (−0.43, −0.20)**	**−0.15* (−0.29, −0.01)**
Boys			
Sleep duration			
Shortest (reference)			
Shorter	−0.61 (−2.10, 0.89)	**−0.26** (−0.44, −0.07)**	**−0.33* (−0.60, −0.06)**
Recommended	−0.53 (−2.09, 1.02)	**−0.32** (−0.51, −0.13)**	−0.21 (−0.49, 0.07)
Girls			
Sleep duration			
Shortest (reference)			
Shorter	**−2.21*** (−3.30, −1.11)**	**−0.22*** (−0.34, −0.10)**	**−0.13* (−0.24, −0.02)**
Recommended	**−2.80*** (−3.96, −1.64)**	**−0.30*** (−0.44, −0.17)**	**−0.12* (−0.24, −0.01)**

Variable definitions: Sleep duration was defined using age-specific cutoff points: for children aged <10 years: recommended duration: ≥10 h/day, shorter duration: 8–10 h/day, shortest sleep: <8 h/day; and for children aged ≥10 years: recommended duration ≥9 h/day, shorter duration 7–9 h/day, shortest duration: <7 h/day[19], "shortest duration" = 0, "shorter duration" = 1, and "recommended duration" = 2.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Numbers in bold indicated statistical significance.
[a]Age, sex, city of residence, baseline screen time behaviors, school level, and paternal and maternal education levels were adjusted in the mixed-effects models. In sex-stratified analyses, models were adjusted for the same variables except sex.

observed. Compared with findings reported in Chinese children in 2005 where the mean sleep duration was 9 h and 20 min,[4] children from large cities slept approximately 50 min less in 2015 (our study), and the prevalence of insufficient sleep increased from 28.3 to 56.9% (2015, our study). The prevalence of insufficient sleep found here is similar to rates reported in developed countries. In a 2015 U.S. study, 57.8% of middle school students reported short sleep duration (<9 h/day for children aged 6–12 years and <8 h/day for teens aged 13–18 years).[6] The large percentages of insufficient sleep among school-aged children demonstrate a global need for promoting sleep health in these still developing populations.

Regarding the correlates of sleep duration, older children and secondary school students reported shorter sleep duration and higher prevalence of insufficient sleep compared to their counterparts. These correlates were consistent with previous findings in this area.[4,6,23] Factors that contribute most to insufficient sleep in older and higher-grade school-aged children include increasing academic demands and stress, earlier school start times, and more delayed bedtimes.[2,24] Few studies have examined associations between places of residence and sleep duration in Chinese children. We found that, compared to children living in Beijing, children, especially boys, living in Shanghai, Nanjing, Xi'an, and Chengdu reported longer sleep duration. This pattern highlights how unique regional contexts of economic development and academic stress may serve to differentially impact sleep duration in Chinese children. Previous studies also found the prevalence of insufficient sleep to be lower in children from middle-economic areas compared to children from high-economic areas.[25,26]

Another key finding was the observation that children from ≥college-educated parents reported longer sleep duration. These findings corroborate these associations seen in Western settings.[27] It may be that more highly educated parents are more aware of the importance of sleep in their children's health and development. They may also be more proactive and/or better equipped to deal with child sleep problems. Interestingly, sex-stratified analyses found boys' sleep duration to be significantly affected by highest paternal education level and girls' sleep duration by highest maternal education level. Parents may be important allies for interventions seeking to increase child sleep duration, and future efforts may benefit from considering sexes of both target children and their parents.

Our longitudinal data analyses revealed that shorter sleep duration reduced the frequency of healthy snacks consumption while increasing the frequency of SSB consumption, breakfast skipping, and time spent with screens. This was consistent with our hypotheses as well as previous cross-sectional studies[28–30] of young adults. Several mechanisms have been proposed to explain these phenomena, including the thought that children sleeping less are awake at irregular times. Also, with shorter sleep duration, children have longer awake times and more time to consume food and drinks, more energy may be needed to sustain extended wakefulness, and children may experience sleep-related changes in appetite hormones.[31,32] Less sleep could also promote tiredness and fatigue, which could then reduce the motivation to engage in more active behaviors and lead to more sedentary activities, such as television viewing and computer use.[33,34] Our findings demonstrate the potential impacts of insufficient sleep duration on important health behaviors

Table 5. Longitudinal data analysis using mixed-effects models: associations between sleep duration and weight status of children in five mega-cities in China, stratified by sex ($n = 1691$)[a].

	Body mass index[c] (β, 95% CI; kg/m^2)	Overweight and obesity[a] (OR, 95% CI)	Central obesity[b] (OR, 95% CI)
(1) Sleep duration (h/day) used as a continuous independent variable			
All	−0.00 (−0.05, 0.04)	0.94 (0.89, 1.00)	0.85 (0.61, 1.19)
Boys	−0.00 (−0.06, 0.05)	0.94 (0.87, 1.02)	1.00 (0.71, 1.42)
Girls	−0.01 (−0.07, 0.05)	0.92 (0.84, 1.02)	**0.46* (0.25, 0.85)**
(2) Sleep duration used as a categorical independent variable			
All			
Sleep duration			
Shortest (reference)	1	1	1
Shorter	−0.14 (−0.32, 0.04)	0.80 (0.61, 1.05)	0.73 (0.23, 2.37)
Recommended	−0.11 (−0.30, 0.08)	**0.70* (0.53, 0.93)**	0.63 (0.14, 2.76)
Boys			
Sleep duration			
Shortest (reference)	1	1	1
Shorter	0.03 (−0.23, 0.29)	0.82 (0.57, 1.20)	2.49 (0.37, 16.90)
Recommended	0.05 (−0.23, 0.32)	0.78 (0.53, 1.14)	2.15 (0.29, 16.12)
Girls			
Sleep duration			
Shortest (reference)	1	1	1
Shorter	**−0.28* (−0.51, −0.05)**	0.79 (0.53, 1.14)	**0.19* (0.04, 0.90)**
Recommended	−0.25 (−0.49, −0.00)	**0.64* (0.43, 0.96)**	0.13 (0.02, 1.03)

Variable definitions: Sleep duration was defined using age-specific cutoff points: for children aged <10 years: recommended duration: ≥10 h/day, shorter duration: 8–10 h/day, shortest sleep: <8 h/day; and for children aged ≥10 years: recommended duration ≥9 h/day, shorter duration: 7–9 h/day, shortest duration: <7 h/day[19], "shortest duration" = 0, "shorter duration" = 1, and "recommended duration" = 2.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Numbers in bold indicated statistical significance.

[a]Overweight and obesity were defined according to the "WS/T 586-2018 Screening for overweight and obesity among school-aged children and adolescents."[17]

[b]Central obesity was defined as waist-for-height ratio ≥0.48.[18]

[c]Age, sex, city of residence, baseline screen time behaviors, school level, paternal and maternal education levels, and baseline BMI were adjusted for in the mixed-effects models. In sex-stratified analyses, models were adjusted for the same variables except sex.

Regarding weight status, however, our longitudinal results only indicated that insufficient sleep duration increased the risk of central obesity for girls but not general overweight and obesity. This contradicts our hypotheses and the findings of the majority of the extant literature.[35] Differences in findings on associations between sleep duration and obesity could reflect differences in geographical location and cutoff points for sufficient or adequate sleep duration. For example, a study of sleep duration and obesity in Australian children also found no significant relationships,[36] though the non-significant associations may have been attributable to the low prevalence (7.9%) of the shortest sleep duration in that study. The risk of overweight and obesity may also vary across sleep duration, as the most pronounced associations have been observed in those reporting ≤4 h sleep per night.[37] Additionally, central obesity is a more sensitive indicator of "early health risk" than general obesity.[38] Therefore, in children and adolescents, sleep duration may have more observable impacts on central obesity risk than general overweight and obesity risks.

By assessing a comprehensive number of obesity and weight-related behaviors using large-scale 3-year longitudinal data, this study provides critical and novel insights on key causal relationships between sleep duration and central obesity, eating behaviors, and screen behaviors in children from mega-cities in China. However, this study has a few limitations. First, sleep duration, eating behaviors, and screen time were child reported. While these data generally correspond well with more objective measures,[39,40] the potential for inaccuracies and biases do remain. Future studies could record bedtimes and wake times to improve sleep duration measurement. Second, we did not assess potential associations of sleep duration with mobile device time and behaviors (e.g., mobile phone and tablet devices), which are increasingly common. Third, selection bias may have been introduced as this study utilized an open cohort design—some participants graduated or were otherwise lost to follow-up as new participants were added at each follow-up. Fourth, residual confounding by unmeasured variables is always possible in observational studies.

In conclusion, insufficient sleep was prevalent among children in urban areas in China. Age, school level, city of residence, primary caregiver type, and parental education appear to affect children's sleep duration. Short sleep duration may increase the risk of central obesity and unhealthy weight-related behaviors in children, especially girls. Intervention programs and policies should consider these correlates to increase sleep duration, and such efforts may also help prevent unhealthy weight-related behaviors and childhood obesity.

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AUTHOR CONTRIBUTIONS

The authors' responsibilities were as follows—Y. Wang designed the research and provided essential materials; Y.D. performed statistical analyses; L.M. drafted the manuscript; L.M., D.T.C., and Y. Wang revised the manuscript; Y. Wang and L.M. had primary responsibility for the final content and are the guarantors; Z.W. and X.W. helped the data collection; all authors critically helped in the interpretation of results, revised the manuscript, provided relevant intellectual input, and read and approved the final manuscript.

ADDITIONAL INFORMATION

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