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Original Article

The associations among objectively estimated sleep and obesity indicators in elementary schoolchildren

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ABSTRACT

Objective: A negative linear association between sleep duration and obesity in children has been reported, but this has been predominantly based on subjective estimates of sleep duration and only one indicator of obesity. This cross-sectional study aimed to examine the relationships among objectively measured sleep parameters and a range of obesity indicators in schoolchildren.
Patients/methods: Baseline data were obtained from 335 elementary schoolchildren (aged 7–12 years) recruited to the study. Five indicators of obesity were determined and two global cut-off points (WHO and International Obesity Task Force) were used to define overweight/obesity. Participants wore wrist actigraphy devices ($N = 264$) for seven consecutive days/nights to objectively estimate six sleep features.
Results: Average weekday sleep duration was 7.6 ± 0.7 h and 42.1% of the participants were overweight/obese. After adjustment, those achieving <8 h of sleep had an increased body mass index z-score ($\beta = 0.88$, $p < 0.001$), waist circumference ($\beta = 6.49$, $p < 0.001$), body fat percentage ($\beta = 5.17$, $p < 0.001$), and fat mass (kg) ($\beta = 3.23$, $p < 0.001$) compared to those sleeping ≥8 h. Based on two standardized cut-off points for overweight/obesity, sleeping <8 h was associated with an increased risk of obesity (odds ratio (OR) = 3.75, 95% confidence interval (CI): 1.56–9.05; OR = 4.79 95% CI: 2.11–10.90).
Conclusion: Sleep insufficiency, in addition to other lifestyle factors, is likely to play a role in childhood obesity. Lifestyle interventions should include advice regarding sleep improvement with promotion of other healthy lifestyle behaviors to tackle childhood obesity, a serious global public health problem.

1. Introduction

Obesity in childhood is an increasing global problem [1] which predisposes children to serious chronic health disorders in adulthood [2–5]. Sleep is a vital behavior for optimal health and longevity, and has been implicated as a key factor in body weight regulation [6]. Research attention has predominantly focused on sleep loss in children and its contribution to obesity. The evidence demonstrates a negative linear association between sleep duration and indicators of obesity such as body mass index (BMI) [7]. Several meta-analyses have advocated that short sleep duration is associated with overweight/obesity [8–11] with one suggesting up to an almost three-fold increased risk of childhood overweight/obesity [8]. There are, however, several shortcomings to previous studies. First, many studies have estimated children's sleep duration based on parental estimates [12–17]. Second, research has mainly focused on sleep duration [12–16], thus limiting knowledge to one facet of a multicomponent behavior. Third, overweight/obesity has been mainly defined using just one estimate of excess adiposity (mainly BMI) [13–15], and this has not always been determined objectively. Finally, sleep-obesity studies in children may be confounded by one or more established contributors of obesity (diet quality [18,19], physical activity/sedentariness [20], electronic device use [21]), with few studies taking all of these known drivers into consideration.

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The aims of our study were to comprehensively examine the potential associations between these objectively estimated sleep parameters using wrist actigraphy (a validated measure of sleep [22]) and multiple objective indicators of overweight/obesity in the same cohort of children. We hypothesized that objectively estimated sleep duration would be significantly associated with multiple objective indicators of overweight/obesity in our large cohort of schoolchildren.

2. Methods

The Qatar Obesity Reduction Study (QORS) was a prospective cohort evaluation study aimed at reducing childhood obesity through the implementation of a health awareness campaign, “Sahtak Awalan/Your Health First”. The campaign involved a multidimensional approach to promote healthy food selection. The QORS evaluation aimed to understand factors contributing to childhood obesity in Qatar, including sleep. Sleep in children is of particular interest in Qatar given that school start times can be before 07:00 h. We analyzed the cross-sectional associations between six objectively estimated sleep parameters with five indicators of overweight/obesity and two globally accepted cut-off points for pediatric overweight/obesity, from data obtained at baseline.

2.1. Study population

Students were recruited from a large private elementary school in Doha, Qatar. A letter about study participation was distributed to all parents/guardians of registered students in grades 2–5. Students were approached for study participation if they (1) had parental approval; (2) were a registered student at the participating school; (3) were in grades 2–5; (4) did not have a diagnosed sleep disorder; and (4) provided written assent. Parents ($N = 445$) were approached and 81.8% ($N = 364$) provided approval. Assent was not obtained for 29 students and 335 students voluntarily provided baseline data during the second term (academic year 2014/2015). The study was approved by the Weill Cornell Medicine in Qatar Institutional Review Board (14-00144) and by Qatar's Ministry of Education.

2.2. Outcome assessments

2.2.1. Obesity indicators

Each procedure was explained to students prior to conducting measurements. The following anthropometric measurements were obtained by trained researchers using a non-stretchable measuring tape (SECA 201) as follows: (1) Neck circumference (NC) [23] was measured at the middle of the neck, between the mid-cervical spine and the mid anterior neck, whilst standing. (2) Waist circumference (WC), an indicator of central adiposity, was measured between the costal margin and iliac crest in the mid-axillary side. NC and WC were measured in centimeters (cm) and reported to the nearest 0.1 cm (3) Height (cm) was obtained using a portable stadiometer (SECA 213). Participants were instructed to remove shoes and to look straight ahead with shoulders relaxed and head positioned at 90°. Height was reported to the nearest 0.5 cm (4) weight (kg) was measured using a calibrated machine (TANITA BC420) when participants were wearing light indoor clothing, without shoes and socks, and with empty pockets. Half a kilogram was deducted from the total weight to account for the weight of clothes, in accordance with manufacturer recommendations. Reliability of bioimpedance analysis has been previously demonstrated in pediatric populations [24] and the following information was generated: weight (kg); fat %; fat mass (kg); BMI (kg/m^2). All of these outcomes, as well as waist and neck circumference, were used as indicators of overweight/obesity. Furthermore, sex and age-specific BMI cut-off points were derived to determine overweight/obesity, based on z-scores according to the World Health Organization (WHO) [25] and the International Obesity Task Force (IOTF) [26].

2.2.2. Demographic data

A clinical research coordinator conducted a one-to-one interview with participants to ascertain subjective information on sex (male/female), age (7–12 years), and grade (2–5) which were

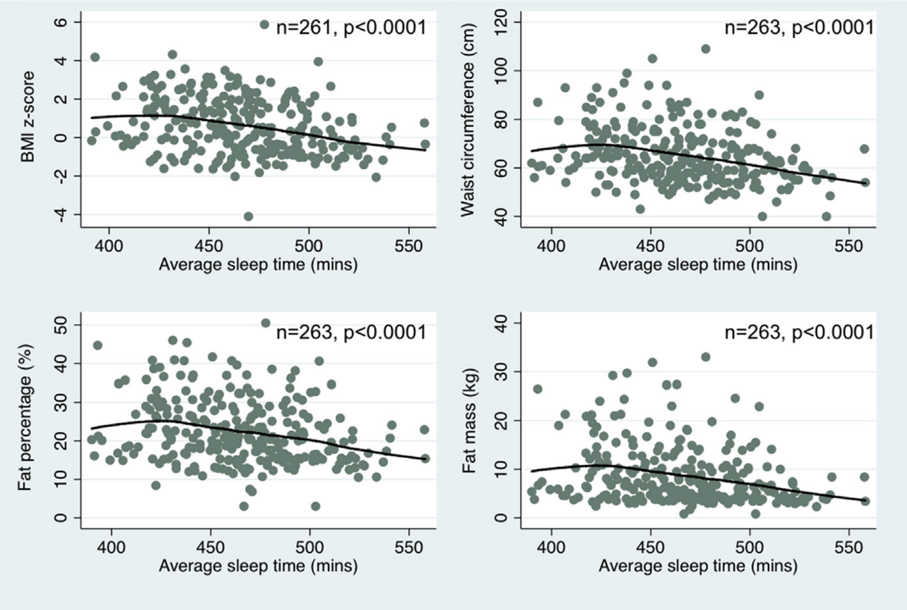

Fig. 1. Lowess curves of overweight/obesity indicators against average sleep time (combined).

verified by the school. Subjective ethnicity (White/Black/Asian/Arab/Other) was also obtained.

2.2.3. *Dietary assessment instruments*

During the interview, participants reported the frequency of consumption of 18 food/drink items, from the Health Behavior in School-Aged Children (HBSC) food frequency questionnaire (FFQ) [27]. Response options ("None/A little/A lot") were reported for each item. Frequency of breakfast consumption during weekdays (0–5) and weekends (0–2) was recorded. Reliability of this questionnaire has previously demonstrated a percentage agreement of up to 87% [28].

2.2.4. *Technology use*

A Technology Use Questionnaire (TUQ) was used to gather information concerning frequency and types of technology used preceding bedtime. The TUQ was previously developed for a large birth cohort study [29] with good reliability (Cronbach's $\alpha = 0.68$) [21]. Information was obtained for five technology types (television viewing, video gaming, computer/internet, social networking, and mobile telephone) used 2 h before bedtime on weekdays and weekends ("Never [0]/Sometimes [1]/Usually [2]/Always [3]).

2.2.5. *Sleep and sedentariness*

Students were issued with wrist actigraphy (GT3X+, Actigraph, Pensacola, FL, USA) on the non-dominant wrist and were instructed to wear it for seven consecutive days/nights. This ensured that weekday and weekend data were captured, which is Sunday–Thursday and Friday–Saturday in Qatar, respectively. Data were downloaded using the manufacturers software (ActiLife, version 6) and non-wear periods (ActiLife software scanned the vector magnitude of three-axis data) were excluded from all analyses. Sleep scoring was performed using ActiLife software based on a well-accepted algorithm for pediatric populations [30]. Each participant file was then visually inspected and compared against sleep logs which students were asked to complete. Actigraphy data (minimum of three days/nights wear time) were used to derive the following sleep outcomes: (1) average total sleep time, calculated as the difference between sleep onset and offset minus minutes of wakefulness between that time period (weekday; Saturday–Wednesday); (2) average total sleep time (weekend; Thursday–Friday); (3) combined average total sleep time across all nights. We also extracted information regarding sleep efficiency (%), calculated using the equation ((total sleep time/time in bed) *100), and average bed/wake times (weekdays and weekends). We also calculated midpoint sleep (midpoint between sleep onset and final awakening times) as an indicator of circadian preference. Additionally, we used the standard deviation of average total sleep time to assess night-to-night sleep variability [31]. The GT3X+ has been previously validated against polysomnography [32].

Actigraphy data was also extracted for the amount of time spent sedentary (min) after removing all non-wear and sleep periods. Sedentariness (%) was calculated as number of minutes spent sedentary/wear time period for each day the device was worn (minimum 10 h per 24-h period) and an average calculated across all days. Activity levels were based on Freedson cut-off points for children [33] and the wrist device has been previously validated in children [34]. We used sedentariness (%) as a potential confounder of the associations examined in our subsequent analyses, based on current evidence [20].

Of the total sample ($N = 335$) only one participant declined to wear the wrist actigraph; 35 actigraphs were not returned; we did not retrieve data from 16 actigraphs due to malfunction, and 20 participants were administered with the actigraph, but did not wear it during the specified time period. The remaining 264 participants had actigraphy data for estimating sleep characteristics and did not differ by age ($p = 0.10$) but there were significantly more boys than girls ($p = 0.001$) and Arabs ($p = 0.019$) without retrievable actigraphy data.

2.3. *Statistical analysis*

All statistical analyses were performed using Stata, version 13.0 (StataCorp LP, College Station, TX, USA). We calculated the mean/median for multiple sleep characteristics (sleep duration, sleep efficiency, bed time, wake time, midpoint sleep, and night-to-night variability) from wrist actigraphy data, according to distribution. Total technology use (weekdays/weekends) was calculated by adding responses for all five technologies assessed and a final score derived (0–15, where 0 = no technology and 15 = maximum use).

We compared a number of sample characteristics according to weight status (underweight/normal weight versus overweight/obesity) in 330 participants with complete data, derived using WHO criteria [25]. We ran chi-squared tests for categorical variables, or chi-squared test for trend for ordinal categorical variables; independent *t*-tests for continuous variables, or the non-parametric alternative for non-normally distributed data.

We performed a series of linear regressions to assess potential associations between sleep parameters to predict five indicators of overweight/obesity (BMI z-score, waist circumference, neck circumference, body fat %, and fat mass) in those with actigraphy data ($N = 264$) using two models: univariate (model 1) and an adjusted model (model 2): age, sex, ethnicity, total technology use, frequency of fast food and takeaway food consumption, and sedentariness. We also dichotomized sleep duration (weekday) based on the median of 8 h to examine potential associations between those with shorter sleep duration (<8 h) compared to those achieving ≥8 h for the aforementioned obesity indicators. We used the median sleep duration cut-off point (8 h) due to an insufficient number of participants ($N = 4$) meeting the minimum recommendation of 9 h. Sleep efficiency was dichotomized (<85% poor sleep quality versus ≥85% good sleep quality). Bed and wake times were calculated based on minutes after midnight and then converted into hours, where an increasing number of hours indicated later bed/wake timings.

Furthermore, we ran binary logistic regression to assess the potential associations between all sleep parameters to predict two definitions of overweight/obesity [25,26] using the same two models described above.

3. Results

The actigraphic estimated sleep characteristics of the sample of schoolchildren are presented in Table 1 and sample characteristics are depicted in Table 2. The average weekday sleep duration in the sample was 7.6 ± 0.7 h. The average bed and wake times on weekdays was 20:57 h and 05:53 h, respectively. Of the total sample, 42.1% were classified as either overweight or obese, according to the WHO definition [25]. Weekday sleep duration was significantly shorter in the overweight/obese group (7.4 h) compared to the under/normal weight group (7.7 h, $p < 0.001$).

Table 3 shows the linear relationships amongst all sleep variables and five obesity indicators assessed. Sleep duration (weekday/weekend/combined) and sleep insufficiency (<8 h), after adjustment for a range of known confounders, were significantly associated with all indicators of obesity, except for neck circumference. In particular, waist circumference (cm) yielded the largest effect where $\beta = -4.99$, $p < 0.001$ (average sleep duration) and $\beta = 6.49$, $p < 0.001$ (<8 h sleep), after

Table 1
A description of sleep characteristics determined using wrist actigraphy for a large cohort of elementary school-aged Qatari children.

Sleep characteristic	
Weekday sleep duration (h)	7.6 ± 0.7
Weekend sleep duration (h)	8.2 ± 0.9
Combined sleep duration (h)	7.8 ± 0.6
Weekday sleep efficiency (%)	84.9 ± 4.6
Weekend sleep efficiency (%)	84.2 ± 5.5
Combined sleep efficiency (%)	84.7 ± 4.4
Bedtime (weekdays)	20:57 (20:14–21:34)
Bedtime (weekends)	22:11 (21:21–23:01)
Bedtime (combined)	21:22 (20:45–21:54)
Wake time (weekdays)	05:53 (05:35–06:10)
Wake time (weekends)	07:58 (07:08–08:58)
Wake time (combined)	06:26 (06:04–06:51)
Midpoint sleep time (weekdays)	00:56 (00:22–01:28)
Midpoint sleep time (weekends)	02:29 (01:30–03:14)
Midpoint sleep time (combined)	01:21 (00:48–01:51)
Night to night sleep duration (min) variability (weekdays)	34.2 (25.5–48.8)
Night to night sleep duration (min) variability (combined)	48.8 (35.6–64.0)

Data are presented as mean ± standard deviation or median (interquartile range).

Table 2
Baseline characteristics of 330 elementary school-aged Qatari children according to weight status.

	Healthy/underweight[a] (*N* = 191; 57.9%)	Overweight/obese[a] (*N* = 139; 42.1%)	*p*
Age (years)	9.0 ± 1.2	9.3 ± 1.3	0.055
Sex, *N* (%)			
Male	103 (53.9)	81 (58.3)	0.432
Female	88 (46.1)	58 (41.7)	
Ethnicity, *N* (%)			
Arab	142 (74.4)	118 (84.9)	0.021
Non-Arab	49 (25.7)	21 (15.1)	
Sedentariness (%)	48.2 ± 6.2	47.6 ± 5.6	0.428
Breakfast (weekday), *N* (%)			
Never	7 (3.7)	20 (14.4)	0.003
1 day	3 (1.6)	4 (2.9)	
2 days	9 (4.7)	5 (3.6)	
3 days	12 (6.3)	15 (10.8)	
4 days	6 (3.2)	7 (5.0)	
5 days	153 (80.5)	88 (63.3)	
Weekday technology	5.5 ± 3.3	6.5 ± 3.5	0.007
Weekend technology	6.5 ± 3.4	6.9 ± 3.5	0.320
Breakfast (weekend), *N* (%)			
Never	11 (5.8)	6 (4.3)	0.272
1 day	17 (9.0)	20 (14.4)	
Both days	162 (85.3)	113 (81.3)	
Fast food, *N* (%)			
None	42 (22.1)	30 (21.6)	0.098
A little	105 (55.3)	90 (64.8)	
A lot	43 (22.6)	19 (13.7)	
Takeaway, *N* (%)			
None	28 (14.7)	18 (13.0)	0.604
A little	119 (62.3)	94 (67.6)	
A lot	44 (23.0)	27 (19.4)	
Average TST weekday (h)	7.7 ± 0.7	7.4 ± 0.5	<0.001
Average TST weekend (h)	8.3 ± 1.0	8.0 ± 0.9	0.057
Average TST combined (h)	7.9 ± 0.6	7.6 ± 0.5	<0.001
<8 h	103 (65.2)	95 (89.6)	<0.001
≥8 h	55 (34.8)	11 (10.4)	

Data are presented as mean ± standard deviation unless otherwise specified. TST, total sleep time. Sleep data derived from wrist actigraphy were available from 264 participants.

[a] Cut-off points for weight status were defined according to the World Health Organization.

adjustment. Circadian preference, indicated by midpoint sleep, and bed/wake times were not significantly associated with any obesity indicator after adjustment. Similarly, sleep duration variation (night-to-night sleep duration variability) was not significantly associated with any outcome. Poor sleep efficiency was positively associated with body fat percentage ($\beta = 2.20$, $p = 0.028$) but no other adipose indicator Fig. 1 shows the Lowess curves of overweight/obesity indicators against average sleep time.

Sleep parameters in relation to overweight/obesity status based on standardized cut-off points are shown in Table 4. Clear associations were observed for both definitions of overweight/obesity for sleep quantity where those sleeping <8 h had an almost four-fold or five-fold increased risk of the condition, based on the IOTF and

Table 3
Linear regression analyses to assess the cross-sectional association between sleep parameters and five indicators of overweight/obesity in elementary school-aged Qatari children.

BMI z-score	Model 1	Model 2
Average TST weekday (h)	−0.58 (0.13)[b]	−0.44 (0.14)
Average TST weekend (h)	−0.27 (0.10)	−0.31 (0.11)
Average TST combined (h)	−0.78 (0.15)[b]	−0.69 (0.17)[b]
<8 h	1.00 (0.20)[b]	0.88 (0.21)
Sleep efficiency weekday (<85%)	0.13 (0.18)	0.34 (0.18)
Average weekday bedtime	0.31 (0.10)	0.20 (0.11)
Average weekday wake time	0.27 (0.16)	0.15 (0.17)
Average weekday midpoint sleep time[a]	0.22 (0.11)	−0.03 (0.12)
Night to night sleep duration (mins) variability	0.00 (0.00)	0.00 (0.00)
Waist circumference (cm)	**Model 1**	**Model 2**
Average TST weekday (h)	−4.94 (1.05)[b]	−3.50 (1.07)
Average TST weekend (h)	−1.96 (0.79)	−2.18 (0.81)
Average TST combined (h)	−6.12 (1.22)[b]	−4.99 (1.27)[b]
<8 h	7.23 (1.62)[b]	6.49 (1.62)[b]
Sleep efficiency weekday (<85%)	−0.30 (1.46)	1.97 (1.39)
Average weekday bedtime	2.85 (0.76)[b]	1.76 (0.80)
Average weekday wake time	2.42 (1.31)	1.22 (1.26)
Average weekday midpoint sleep time[a]	2.18 (0.89)	−0.21 (0.93)
Night to night sleep duration (min) variability	0.06 (0.03)	0.03 (0.03)
Neck circumference (cm)	**Model 1**	**Model 2**
Average TST weekday (h)	−0.63 (0.35)	−0.59 (0.36)
Average TST weekend (h)	−0.33 (0.25)	−0.30 (0.28)
Average TST combined (h)	−0.78 (0.40)	−0.66 (0.44)
<8 h	0.72 (0.53)	0.87 (0.56)
Sleep efficiency (<85%)	0.26 (0.46)	0.74 (0.47)
Average weekday bedtime	0.33 (0.25)	0.26 (0.26)
Average weekday wake time	0.32 (0.42)	0.19 (0.42)
Average weekday midpoint sleep time[a]	0.23 (0.28)	−0.05 (0.31)
Night to night sleep duration (min) variability	0.00 (0.01)	0.00 (0.01)
Body fat %	**Model 1**	**Model 2**
Average TST weekday (h)	−3.28 (0.76)[b]	−2.67 (0.77)[b]
Average TST weekend (h)	−0.68 (0.57)	−1.49 (0.59)
Average TST combined (h)	−3.63 (0.88)[b]	−3.73 (0.92)[b]
<8 h	5.30 (1.15)	5.17 (1.17)
Sleep efficiency weekday (<85%)	0.25 (1.04)	2.20 (1.00)
Average weekday bedtime	1.98 (0.55)[b]	1.34 (0.59)
Average weekday wake time	1.92 (0.94)	1.10 (0.93)
Average weekday midpoint sleep time[a]	1.62 (0.63)	−0.08 (0.69)
Night to night sleep duration (minutes) variability	0.06 (0.02)	0.01 (0.02)
Fat mass (kg)	**Model 1**	**Model 2**
Average TST weekday (h)	−2.40 (0.55) [b]	−1.79 (0.56)
Average TST weekend (h)	−0.75 (0.41)	−1.05 (0.43)
Average TST combined (h)	−2.81 (0.64) [b]	−2.47 (0.67) [b]
<8 h	3.56 (0.84)	3.23 (0.85)
Sleep efficiency weekday (<85%)	−0.20 (0.76)	1.17 (0.73)
Average weekday bedtime	1.43 (0.40) [b]	0.89 (0.42)
Average weekday wake time	1.42 (0.68)	0.76 (0.66)
Average weekday midpoint sleep time[a]	1.19 (0.46)	−0.03 (0.49)
Night to night sleep duration (min) variability	0.03 (0.02)	0.01 (0.02)

Data are presented as unstandardized beta coefficient (standard error). Model 1, unadjusted; Model 2, adjusted for age, sex, ethnicity, technology use, frequency of fast food consumption, frequency of takeaway food consumption, level of sedentariness (%). BMI, body mass index; TST, total sleep time.

[a] Further adjusted for average weekday sleep duration in model 2.

[b] *p*-Value significant after Bonferroni adjustment.

WHO cut-off points (OR = 3.75 (95% CI: 1.56–9.05) and OR = 4.79 (95% CI: 2.11–10.90)), respectively.

4. Discussion

Our study is the first to comprehensively describe, assess, and report on objective sleep estimates in elementary-school-aged children in Qatar. We observed, in our large sample of children, that sleep duration is an important, and potentially modifiable, behavior in relation to all obesity indicators. We also observed that sleep quantity is the most vital sleep feature, particularly pertaining to central adiposity (waist circumference). A high prevalence of overweight/obesity was observed in our sample (42.1%), which is consistent with previous estimates from Qatar [1].

Our findings are consistent with a recent systematic review which investigated the relationship between objectively estimated sleep duration and obesity in pediatric populations [35]. The review identified nine studies which employed wrist-worn actigraphy to estimate sleep duration. The authors concluded that sleep duration influences weight gain, despite the majority of these studies being of cross-sectional design. There are numerous other studies that have relied upon either parental or subjective sleep reports which

Table 4
Logistic regression analyses to assess the cross-sectional association between sleep parameters and two standardized definitions of overweight/obesity in elementary school-aged Qatari children.

Overweight and obese (IOTF)	Model 1	Model 2
Average TST weekday (h)	0.50 (0.33–0.76)[b]	0.58 (0.36–0.95)
Average TST weekend (h)	0.75 (0.56–1.00)	0.72 (0.50–1.02)
Average TST combined (h)	0.41 (0.25–0.67)[b]	0.42 (0.23–0.77)[b]
<8 h	3.65 (1.71–7.80)[b]	3.75 (1.56–9.05)
Sleep efficiency weekday (<85%)	1.16 (0.69–1.96)	1.70 (0.92–3.15)
Average weekday bed time	1.35 (1.01–1.80)	1.15 (0.82–1.59)
Average weekday wake time	1.34 (0.84–2.13)	1.10 (0.67–1.81)
Average weekday midpoint sleep time[a]	1.27 (0.92–1.75)	0.89 (0.60–1.31)
Night to night sleep duration (min) variability	1.01 (0.99–1.02)	1.00 (0.99–1.01)
Overweight and obese (WHO)		
Average TST weekday (h)	0.43 (0.28–0.66)[b]	0.49 (0.31–0.79)[b]
Average TST weekend (h)	0.76 (0.58–1.01)	0.73 (0.53–1.02)
Average TST combined (h)	0.34 (0.21–0.56)[b]	0.35 (0.20–0.63)[b]
<8 h	4.42 (2.18–8.95)[b]	4.79 (2.11–10.90)[b]
Sleep efficiency weekday (<85%)	1.27 (0.77–2.10)	1.77 (0.99–3.16)
Average weekday bed time	1.45 (1.10–1.92)	1.31 (0.96–1.71)
Average weekday wake time	1.30 (0.83–2.05)	1.12 (0.70–1.81)
Average weekday midpoint sleep time[a]	1.32 (0.97–1.79)	0.94 (0.65–1.37)
Night to night sleep duration (min) variability	1.00 (0.99–1.01)	1.00 (0.99–1.01)

Data are presented as odds ratio (95% confidence interval). Model 1, unadjusted; Model 2, adjusted for age, sex, ethnicity, technology use, frequency of fast food consumption, frequency of takeaway food consumption, sedentariness (%). IOTF, International Obesity Task Force; TST, total sleep time; WHO, World Health Organization.

[a] Further adjusted for average weekday sleep duration in model 2.

[b] p-Value significant after Bonferroni adjustment.

have consistently observed similar results to ours. For example, one of the earliest studies conducted in 8274 children, aged 6–7 years, demonstrated that those with a sleep duration of <8 h were almost three times more likely to be obese (based on the adult BMI cut-off point of ≥25) compared to those sleeping >10 h [13]. Another study conducted in 7767 German children (aged 3–10 years) measured obesity according to BMI and body fat percentage, estimated from skinfold thickness. Parents reported average sleep duration to the nearest hour and percentiles of sleep duration were derived. The authors observed a negative association between sleep duration and BMI z-score ($\beta = -0.235$, $p < 0.0001$), as well as body fat percentage ($\beta = -0.182$, $p < 0.0001$) [36]. Reports from a recent meta-analysis are also consistent with our findings which revealed that waist circumference was negatively correlated with sleep duration in adults ($r = -0.10$, $p < 0.0001$) [37]. In particular, insufficient sleep was most strongly associated with waist circumference where children obtaining <8 h of sleep had almost 6.5 cm increased waist circumference compared to those sleeping ≥8 h. Thus, insufficient sleep duration appears to be especially important for the central adiposity in children. Mechanistic explanations for this observation are, however, unclear and require further investigation.

The difference between average bed–wake times on weekdays was just under 9 h and average sleep duration was 7.6 h, suggesting poor sleep quality, confirmed by borderline sleep efficiency (<85%) in our sample. Sleep quality was not, however, significantly associated with any obesity outcome after adjustment, with the exception of body fat percentage. A recent meta-analysis demonstrated a 27% significant increased risk of overweight/obesity in children, adolescents and young adults when insufficient sleep was combined with poor sleep quality [38]. When sleep quality was assessed separately, the pooled odds of overweight/obesity increased to 1.46 (95% CI: 1.24–1.72), suggesting that this sleep parameter is more important than sleep quantity. Disparity in our results could be due to the combined age groups in the meta-analysis. Furthermore, we used wrist actigraphy to determine sleep efficiency, which is commonly reported in actigraphic studies but has not been validated against the gold-standard measure (polysomnography) [39]. Sleep efficiency data obtained from actigraphy is, however, likely to be a better estimate than subjective reports.

The indicators of circadian preference assessed in our study (bedtime, wake time, and midpoint sleep) were not associated with any obesity indicator after adjustment. Extreme circadian preferences are pronounced in adolescents and/or older adults [40,41], and may explain why significant associations were not observed in our pre-adolescent sample. Different findings may, however, emerge with prospective study of our cohort. With regard to sleep duration variability, however, one group found higher variability in sleep was related to altered metabolic function in 4- to 10-year-olds [42]. It should, however, be noted that those children had longer average sleep time compared to our sample, although prevalence of overweight/obesity was comparable. Further investigation is warranted to extricate how this domain-specific sleep feature may or may not influence adiposity.

Our study benefits from a large sample size, comprehensive and objective estimates of sleep and obesity indicators, and is the first to describe children's sleep in Qatar. Furthermore, we were able to obtain and adjust for a range of potential confounders, including an objective estimate of sedentariness, technology use, dietary habits and other known confounders. Whilst the prevalence of overweight/obesity in our sample was high (42.1%), this is representative based on recent statistics [1]. We do, however, acknowledge several study limitations. First, although we excluded children with physician-diagnosed sleep disorder(s), undiagnosed sleep disorder(s) remain a possibility amongst those recruited; thus, the possibility of hidden confound may be present. Second, a relatively large number of actigraphs were either not returned, malfunctioned or were not worn as instructed ($N = 71$), thus these individuals could have been children with different sleep patterns that were not captured. Third, we did not obtain information concerning socioeconomic status, however the school was privately funded. This may infer that participants came from a mid-high social class which could limit generalizability of our study findings to other populations. Fourth, our findings are based on cross-sectional data, thus causality cannot be inferred. Finally, whilst we adjusted for diet, we acknowledge that the instrument relies on self-report. Despite this crude estimate, capturing and adjusting for some dietary information is favorable compared to complete omission.

Qatar and neighboring countries are experiencing a significant rise in the prevalence of obesity, diabetes mellitus, and cardiovascular disease. When these conditions occur at a young age, there are devastating consequences for both the affected individuals and society. A lack of sufficient sleep quantity has important health ramifications for children and efforts should be made to educate children about the importance of this shared behavior. Longitudinal assessment is urgently required, accompanied by objective measures of both sleep and obesity so that robust causal conclusions can be reached. Once these are established, interventions that capture and attempt to improve sleep within carefully developed programmes may help to ease the burden of obesity both on healthcare systems and at an individual and societal level.

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Conflicts of interest

The authors have no conflicts of interest relevant to this article to disclose.

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