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Poor sleep quality and its associated neurocognitive function in children with obesity with or without obstructive sleep apnea

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Abstract

Objective To evaluate the associations of OSA severity, snoring symptoms, subjective sleep quality, and daytime sleepiness with executive functioning and behaviors in children with obesity.

Methods This was a cross-sectional study of children aged 8–18 years with obesity and symptoms suggestive of OSA. All participants underwent an overnight polysomnography and completed a set of questionnaires to assess their sleep-related breathing disordered (SRBD) symptoms [Pediatric Sleep Questionnaire (SRBD-PSQ)], sleep quality [Pittsburgh Sleep Quality Index (PSQI)], executive function [Behavior Rating Inventory of Executive Function (BRIEF)], and inattention and hyperactivity symptoms (Conners-3 Parent Short Form).

Results A total of 85 children (62% male, mean age: 13.9 ± 3.0 years) were included in this analysis, of whom 36, 16, and 33 were categorized into the non-OSA (obstructive apnea hypopnea index, OAHI < 1.5/h), mild OSA (OAHI 1.5–5/h), and moderate-severe OSA (OAHI ≥ 5/h) groups, respectively. Of 85 participants, 27 (32%) were classified with poor sleep quality (PSQI composite score ≥ 8). From multiple linear regression analyses, poor sleep quality and sleepiness were both independently associated with higher BRIEF behavioral regulation T-score, metacognition T-score, and global executive composite T-score in the fully adjusted model. In addition, poor sleep quality was also independently associated with higher Conners-3 inattention and executive functioning T-scores, while greater sleepiness was also associated with a higher learning problem T-score. The presence of OSA and snoring were not associated with any cognitive outcomes.

Conclusions Subjective sleep quality and daytime sleepiness, but not OSA severity and snoring symptoms, were independently associated with executive functioning and behavioral problems in children with obesity.

Keywords Obesity · Obstructive sleep apnea · Sleep quality · Daytime sleepiness · Executive function · Behavioral problems

Introduction

Sleep is essential for normal cognitive functioning across the lifespan [1, 2]. A systematic review which summarized 16 adolescent studies concluded that sleep deprivation, i.e. at least 1 whole night without sleep, is followed by poor performance in vigilance tasks [3], while sleep extension by as little as 13 min in those with chronic sleep reduction [4] and sleep improvement in insomniacs contributes to improvement in working memory [5]. A meta-analysis showed that poor sleep quality and excessive daytime sleepiness were even stronger contributors to poor school performance than sleep duration [6].

Conflicting findings have been reported regarding the association between sleep disordered breathing (SDB), specifically obstructive sleep apnea (OSA), and cognitive function in children. While there is evidence suggesting that children with OSA have lower intellectual abilities, there is no strong evidence of reduced academic performance, nor impairment in language, memory, attention, or executive functioning [7]. An important confounder exists when examining the association between sleep apnea and academic performance in individuals with obesity-related OSA, as obesity has been found to be associated with cognitive deficits across the lifespan. Particularly, reduced executive function has been reported in children and adolescents with obesity [8].

Currently, there is a paucity of data describing the association between OSA, sleep quality, and neurocognition in

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children with obesity. Given the increasing prevalence of obesity in youth [9], and the close linkage of obesity with both OSA [10] and impaired sleep quality [11], a better understanding of the inter-relationship between sleep-related parameters and cognitive performance in children with obesity could potentially provide strategies for targeted intervention to mitigate long-term adverse neurocognition.

This study aimed to evaluate the associations between OSA severity, snoring symptoms, subjective sleep quality, and daytime sleepiness on parent-reported executive functioning and neurocognition in children with obesity. We hypothesized that OSA severity and symptoms, poor sleep quality, and daytime sleepiness were independently associated with lower neurocognitive function in children with obesity.

Methods

Study population

This was a cross-sectional study of children with obesity, aged 8–18 years, who were enrolled into an ongoing multicentre, prospective cohort study conducted at the Hospital for Sick Children (Toronto, Ontario) and the Children's Hospital of Eastern Ontario (Ottawa, Canada) to identify predictors and outcomes of OSA in children with obesity. Overweight and obese children with symptoms suggestive of OSA, who were referred and reviewed at these sleep centres and scheduled to undergo an overnight polysomnogram (PSG), were recruited between June 2015 and August 2022. All participants underwent a diagnostic PSG following enrolment. Overweight and obesity were defined respectively as a BMI of 85^{th} – 95^{th} percentile and > 95^{th} percentile for age and sex [12]. Children were ineligible for participation if they were referred for an adenotonsillectomy, had craniofacial anomalies, central nervous system lesions, syndromes (neuromuscular, neurological, or genetic), coronary heart disease or ventricular dysfunction, chronic lung disease other than asthma, diabetes or used medication for glucose management or hypertension. We also excluded children already using positive airway pressure therapy as this was an outcome of interest in our larger study. Patients' demographics and anthropometrics at the time of the diagnostic PSG (age, sex, height, weight, body mass index (BMI)), symptoms including snoring, nasal congestion and presence of tonsillar and/or adenoid hypertrophy, and PSG data were recorded systematically. Waist and hip circumferences were measured according to the National Institutes of Health, and World Health Organization guidelines, respectively [13]. Neck circumference was measured according to a previously published protocol specific for pediatric populations [14]. This study was approved by the local Research Ethics Boards at The Hospital for Sick Children, Toronto, Canada and the Children's Hospital of Eastern Ontario, Ottawa, Canada. All participants and parents provided written informed consent and/or assent, as appropriate, prior to conducting any study procedures.

Overnight polysomnography (PSG)

Overnight PSG was performed using XLTEK data acquisition and analysis systems (Natus Medical, San Carlos, CA). PSG measurements included electroencephalograms, bilateral electrooculograms, and submental and bilateral anterior tibialis electromyograms. Chest wall and abdominal movements were monitored using respiratory inductance plethysmography belts. Arterial oxyhemoglobin saturation (SaO_2) was measured by a finger probe oximeter. Transcutaneous carbon dioxide ($TcCO_2$) and end tidal carbon dioxide ($EtCO_2$) were monitored. Respiratory airflow pressure signal was obtained via a nasal catheter placed at the anterior nares and connected to a pressure transducer. An oronasal thermal sensor was used to detect absent airflow. Snoring was measured by a microphone placed near the throat. Body position was monitored via a body position sensor. Sleep architecture was assessed using standard techniques [15]. Respiratory events were scored according to the American Academy of Sleep Medicine (AASM) guidelines [15] by a registered, certified PSG technician and were reviewed and interpreted by one of five experienced pediatric sleep physicians. As per AASM, all PSG data for children aged 13 years and younger were scored based on pediatric guidelines, whereas all PSG data for children older than 13 years were scored based on adult rules. OSA severity was graded according to the obstructive apnea–hypopnea index (OAHI) – the total number of obstructive apneas, mixed apneas and obstructive hypopneas per hour during sleep. Participants were divided into non-OSA (OAHI < 1.5 events/hour), mild OSA (OAHI ≥ 1.5 – < 5 events/hour) and moderate-severe OSA (OAHI ≥ 5 events/hour) for comparisons.

Sleep questionnaires

All questionnaires were completed either prior to or in the morning after the diagnostic PSG. The Sleep-Related Breathing Disorder scale of the Pediatric Sleep Questionnaire (SRBD-PSQ) [16] was completed by a parent or caregiver. It contains 22 symptom items which assess the overall symptoms of sleep-disordered breathing with three symptom subscales: snoring, daytime sleepiness, and behavioral problems. Responses are "yes" = 1, "no" = 0, and "don't know" = missing. The mean response on non-missing items is the score, which can vary from 0 to 1. The present study specifically analyzed the sleepiness (4 items) and snoring (4 items) subscales of the PSQ. A subscale

score of 0.33 or higher, equivalent to having at least 2 out of 4 symptoms, was defined as elevated concerns of sleepiness and snoring [17–19].

The Pittsburgh Sleep Quality Index (PSQI) is a self-rated questionnaire which assesses sleep quality and disturbances over the recent one month. Nineteen individual items generate seven "component" scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of scores for these seven components yields one composite score [20]. A composite score of ≥ 8 indicates poor self-perceived sleep quality in a clinical population [21–24].

Executive function

The Behavior Rating Inventory of Executive Function (BRIEF), which is a caregiver-completed questionnaire, was used to assess executive function in this study. The BRIEF provides three age- and gender-adjusted summary scores: Behavioral Regulation Index (BRI), Metacognition Index (MI), and the Global Executive Composite scale (GEC) [25]. The BRI measures the caregiver's perception of the child's ability of emotional and behavioral regulation with appropriate inhibitory control. The MI measures the child's ability of initiating, planning, and organizing self-managed tasks, and the GEC is a summary score of the child's overall executive function. A higher score indicates worse functioning.

Behavioral outcomes

Behavioral problems were assessed by the Conners 3 – Parent Short Form (Conners-3 SF), which measures the symptoms of attention-deficit/hyperactivity disorder in children aged between 6 and 18 years of age [26]. The Conners-3 SF yields six subscales: Inattention, Hyperactivity/Impulsivity, Executive Functioning, Learning Problems, Defiance/Aggression, and Peer/Family Relations. Responses are rated on a 4-point Likert scale from 0 = not true at all (never, seldom), 1 = Just a little true (occasionally), 2 = Pretty much true (often, quite a bit), 3 = very much true (very often, very frequently). A higher score indicates worse functioning.

Statistical analysis

Normally distributed, skewed, and categorical data were shown as mean ± SD, median (IQR), and percentages, respectively. Comparisons between moderate-severe OSA, mild OSA, and non-OSA groups were tested by one-way ANOVA, Kruskal–Wallis tests, and chi-square tests for normally distributed, skewed, and categorical data, respectively. Comparisons between good and poor sleep quality groups were tested by independent t tests, Mann–Whitney U tests, and chi-square tests (or Fisher's exact tests) for normally distributed, skewed, and categorical data, respectively. Bivariate correlation was assessed by Pearson correlation analysis. General linear model was used to test the associations of sleep-related parameters (presence of OSA (OAHI ≥ 1.5/h), poor sleep quality (PSQI ≥ 8), elevated concerns of snoring and sleepiness) with neurocognitive outcomes (BRIEF and Conners-3 scores), using neurocognitive outcomes as dependent variables, while adjusting for age, sex, and BMI z score. Two-way interactions between the presence of OSA, poor sleep quality, elevated concerns of sleepiness and snoring, and sex were also tested, and subgroup analyses were performed if any significant interactions were detected. Skewed data such as OAHI were log-transformed before analysis. A p-value < 0.05 determined significance. All the analyses were conducted with SPSS version 26.0 (IBM Corp, Armonk, NY).

Results

Subject characteristics

A total of 85 children (62% male, mean age: 13.9 ± 3.0 years, mean body mass index (BMI): 38.2 kgm^{-2} ± 8.7) were included in this analysis, of whom 36, 16, and 33 were categorized into the non-OSA, mild OSA, and moderate-severe OSA groups, respectively. Using a cut-off of ≥ 8 of the PSQI composite score, 27 participants were classified with poor sleep quality. BMI z score significantly correlated with log-transformed OAHI, and log-transformed ODI as well as SRBD-PSQ snoring subscale (Fig. 1).

Characteristics of different OSA severity groups

The moderate-severe OSA group had greater proportion of males, and greater BMI z score, waist-to-hip ratio, and neck-to-height ratio. No significant differences in age and body height were observed between groups (Table 1). For the PSG findings, apart from the expected differences in OAHI between groups, the moderate-severe group also had significantly higher ODI and a lower SpO2 nadir, as well as a higher arousal index (Table 1).

The sleep questionnaire data showed that the moderate-severe group had a significantly higher SRBD-PSQ snoring subscale score than the non-OSA group (Table 1).

Characteristics of Subjects with PSQI < 8 versus ≥ 8

Participants with poor sleep quality had a smaller proportion of males than those with good sleep quality. No significant differences in age and body size were observed between the two groups. (Table 2) The poor

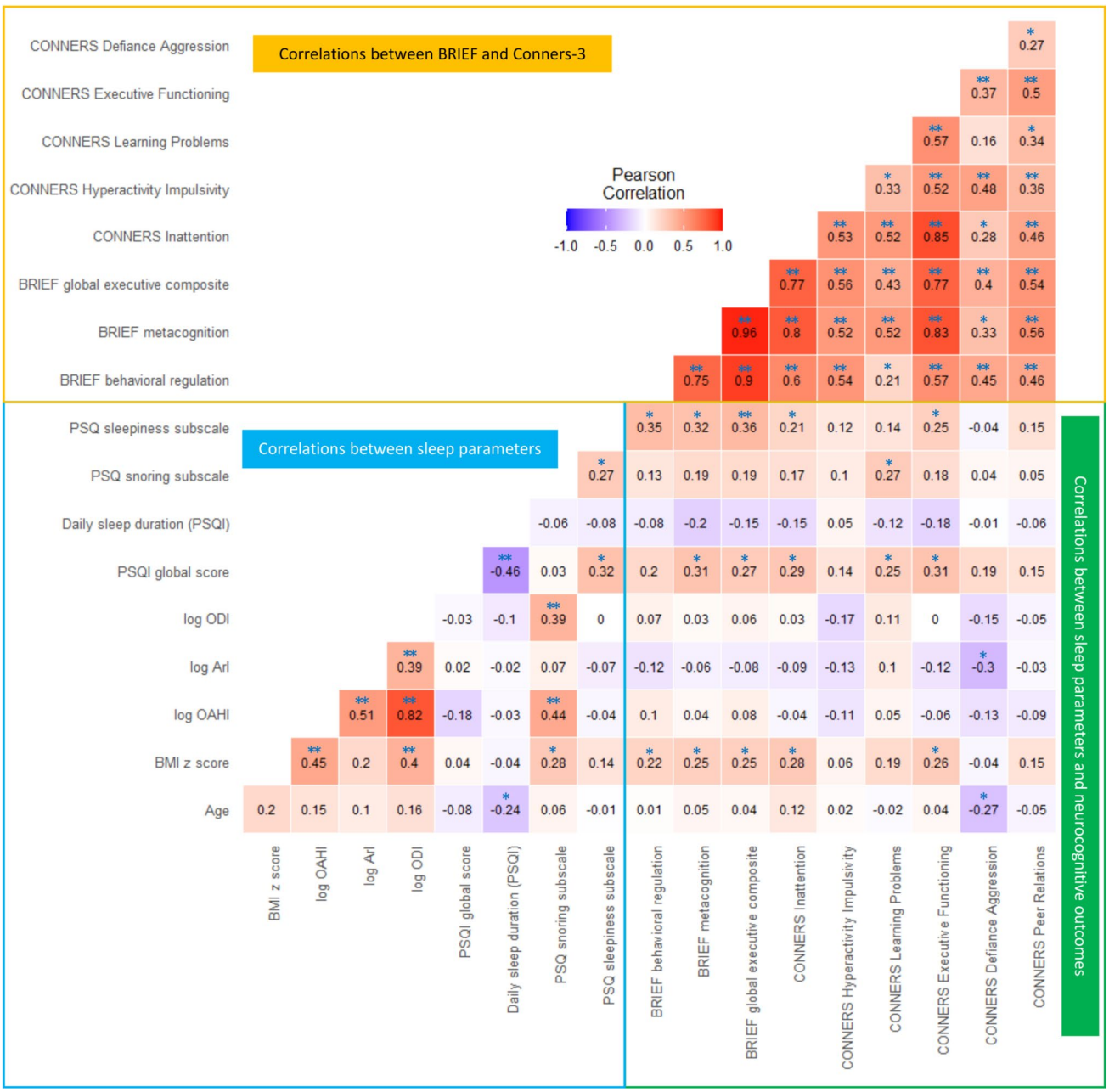

Fig. 1 A heatmap showing the Pearson correlation coefficients between variables, with red and blue indicating positive and negative correlations, respectively, while white indicates zero correlation. The "*" and "**" indicate significant correlation with $p < 0.05$ and $p < 0.001$, respectively. The orange panel displays the correlations between BRIEF and Conners-3 subscales. The light blue panel displays the correlations between age, BMI z score, and various sleep parameters. The green panel displays the correlation between sleep parameters and neurocognitive outcomes. Abbreviations: BMI, body mass index; BRIEF, Behavioral Rating Inventory of Executive Function; log ArI, log-transformed arousal index; log OAHI, log-transformed obstructive apnea hypopnea index; log ODI, log-transformed oxygen desaturation index; PSQ, Pediatric Sleep Questionnaire; PSQI, Pittsburgh Sleep Quality Index; SRBD, sleep related breathing disorder

sleep quality group had a lower OAHI. However, there were no significant differences in ODI, SpO_2 nadir, and arousal index between the two groups. (Table 2) From the sleep questionnaire data, the poor sleep quality group was reported to have less daily sleep duration, and a higher SRBD-PSQ sleepiness subscale score when compared to the good sleep quality group (Table 2).

Table 1 Characteristics of different OSA severity groups

	OAHI < 1.5 *N* = 36	OAHI 1.5– < 5 *N* = 16	OAHI ≥ 5 *N* = 33	*p*
Demographics and anthropometrics				
Age, y	14.0 ± 2.6	12.8 ± 2.6	14.4 ± 3.4	0.20
Male sex, *n* (%)	16 (44%)	9 (56%)	28 (85%)	0.002*
Weight, kg	91.9 ± 28.1	91.7 ± 27.6	118.4 ± 27.6	< 0.001*‡
Height, cm	162 ± 11	159 ± 12	167 ± 12	0.066
Body mass index, kgm^{-2}	35.6 ± 7.5	35.6 ± 8.4	42.2 ± 8.6	0.002*‡
Body mass index z score	2.32 ± 0.36	2.44 ± 0.33	2.69 ± 0.29	< 0.001*‡
Waist circumference, cm	105 ± 16	107 ± 18	120 ± 16	0.001*‡
Hip circumference, cm	117 ± 16	112 ± 22	127 ± 17	0.012‡
Waist-to-hip ratio	0.65 ± 0.09	0.67 ± 0.10	0.72 ± 0.10	0.011*
Neck circumference, cm	37.8 ± 3.5	38.7 ± 4.5	42.4 ± 3.9	< 0.001*‡
Neck-to-height ratio	0.23 ± 0.02	0.24 ± 0.02	0.25 ± 0.02	< 0.001*
Polysomnographic data				
AHI, events/h	1.1 (0.5 to 1.7)	4.3 (3.3 to 5.5)	11.7 (8.4 to 21.5)	< 0.001*†‡
OAHI, events/h	0.5 (0.3 to 0.7)	3.1 (2.4 to 4.0)	10.2 (7.9 to 20.9)	< 0.001*†‡
CAHI, events/h	0.5 (0 to 1.1)	0.9 (0.3 to 1.3)	0.2 (0 to 1.2)	0.25
ODI, events/h	1.4 (0.9 to 2.3)	3.6 (2.3 to 4.5)	11.3 (6.6 to 17.4)	< 0.001*†‡
SpO_2 nadir, %	91 ± 3	89 ± 3	86 ± 8	< 0.001*
Arousal index, events/h	9.7 (7.7 to 14.3)	9.3 (8.1 to 13.3)	13.6 (9.8 to 23.8)	0.003*‡
Sleep questionnaire data				
PSQI composite score	6.6 ± 3.4	6.4 ± 3.2	5.6 ± 3.0	0.41
Poor sleep quality (PSQI ≥ 8)	15 (42%)	6 (38%)	6 (18%)	0.096
Daily time in bed, min	537 ± 98	545 ± 59	503 ± 97	0.21
Daily sleep duration, min	482 ± 104	464 ± 73	456 ± 82	0.52
SRBD-PSQ	0.37 (0.23 to 0.50)	0.43 (0.28 to 0.54)	0.41 (0.27 to 0.66)	0.37
SRBD-PSQ – snoring subscale	0.25 (0 to 0.50)	0.50 (0.25 to 1)	0.67 (0.50 to 1)	< 0.001*
SRBD-PSQ – sleepiness subscale	0.50 (0.25 to 0.75)	0.25 (0 to 0.69)	0.33 (0 to 0.75)	0.50
SRBD-PSQ – behavior subscale	0.33 (0 to 0.67)	0.25 (0.04 to 0.50)	0.17 (0 to 0.67)	0.77

AHI apnea hypopnea index; *CAHI* central apnea hypopnea index; *OAHI* obstructive apnea hypopnea index; *ODI* oxygen desaturation index; *PSQI* Pittsburgh Sleep Quality Index; *SpO_2* oxygen saturation; *SRBD-PSQ* Sleep-Related Breathing Disorder scale of the Pediatric Sleep Questionnaire

Normally distributed and skewed continuous data are shown as mean ± SD and median (IQR), respectively. Categorical data are shown as number (percentage)

P values were obtained from one-way ANOVA, Kruskal–Wallis tests, and chi-square tests for normally distributed, skewed, and categorical data respectively

* Significant difference between OAHI < 1/h and OAHI ≥ 5/h, $p < 0.017$ in post-hoc pairwise test

† Significant difference between OAHI < 1/h and OAHI 1– < 5/h, $p < 0.017$ in post-hoc pairwise test

‡ Significant difference between OAHI 1– < 5/h and OAHI ≥ 5/h, $p < 0.017$ in post-hoc pairwise test

Neurocognitive outcomes

There were no significant differences in any scales or subscales in BRIEF and Conners-3 between the three OSA severity groups. (Table 3) The poor sleep quality group had significantly higher BRIEF metacognition T score and global executive composite T score than the good sleep quality group. They also had significantly higher T scores of several Conners-3 subscales: inattention, learning problems, and executive functioning (Table 3).

The associations were further supported by the correlations between higher PSQI composite score and worse relevant neurocognitive outcomes. (Fig. 1) Similarly, higher SRBD-PSQ sleepiness subscale correlated with higher BRIEF subscale T scores and Conners-3 executive functioning T score. However, higher SRBD-PSQ snoring subscale was associated with a higher T score of only one subscale (learning problem) of Conners-3. Log-transformed OAHI and ODI were not correlated with any cognitive outcomes,

Table 2 Characteristics of participants with good (PSQI < 8) and poor sleep quality (PSQI ≥ 8)

	PSQI < 8 *N* = 58	PSQI ≥ 8 *N* = 27	p
Demographics and anthropometrics			
Age, y	14.0 ± 2.8	13.6 ± 3.4	0.56
Male sex, n (%)	44 (76%)	9 (33%)	< 0.001
Weight, kg	100.8 ± 32.4	105.1 ± 26.1	0.55
Height, cm	165 ± 13	162 ± 9	0.32
Body mass index, kgm^{-2}	37.5 ± 9.1	39.8 ± 7.6	0.26
Body mass index z score	2.49 ± 0.36	2.48 ± 0.40	0.95
Waist circumference, cm	111 ± 19	113 ± 16	0.60
Hip circumference, cm	118 ± 19	124 ± 17	0.14
Waist-to-hip ratio	0.67 ± 0.10	0.70 ± 0.08	0.28
Neck circumference, cm	40.1 ± 4.7	39.1 ± 3.6	0.36
Neck-to-height ratio	0.24 ± 0.02	0.24 ± 0.02	0.73
Polysomnographic data			
AHI, events/h	5.7 (1.5 to 11.7)	3.5 (0.7 to 7.0)	0.044
OAHI, events/h	4.8 (0.6 to 11.0)	0.8 (0.4 to 3.7)	0.011
CAHI, events/h	0.4 (0 to 0.9)	0.9 (0.2 to 1.6)	0.052
ODI, events/h	3.6 (1.4 to 11.3)	3.7 (1.5 to 7.0)	0.63
SpO_2 nadir, %	88 ± 7	90 ± 3	0.19
Arousal index, events/h	11.8 (8.7 to 16.3)	10.9 (8.0 to 14.4)	0.26
OSA severity			0.096
Non-OSA, n (%)	21 (36%)	15 (56%)	
Mild OSA, n (%)	10 (17%)	6 (22%)	
Moderate-severe OSA, n (%)	27 (47%)	6 (22%)	
Sleep questionnaire data			
PSQI composite score	4.4 ± 1.9	10.0 ± 1.6	< 0.001
Daily time in bed, min	527 ± 92	520 ± 95	0.76
Daily sleep duration, min	495 ± 71	412 ± 99	< 0.001
SRBD-PSQ	0.37 (0.23 to 0.56)	0.41 (0.32 to 0.52)	0.19
SRBD-PSQ – snoring subscale	0.50 (0.25 to 1)	0.50 (0.25 to 0.67)	0.66
SRBD-PSQ – sleepiness subscale	0.29 (0 to 0.67)	0.50 (0.25 to 0.75)	0.024
SRBD-PSQ – behavior subscale	0.17 (0 to 0.67)	0.50 (0 to 0.67)	0.22

AHI apnea hypopnea index; *CAHI* central apnea hypopnea index; *OAHI* obstructive apnea hypopnea index; *ODI* oxygen desaturation index; *OSA* obstructive sleep apnea; *PSQI* Pittsburgh Sleep Quality Index; *SpO_2* oxygen saturation; *SRBD-PSQ* Sleep-Related Breathing Disorder scale of the Pediatric Sleep Questionnaire

Normally distributed and skewed continuous data are shown as mean ± SD and median (IQR), respectively. Categorical data are shown as number (percentage)

P values were obtained from independent t tests, Mann–Whitney U tests, and chi-square tests for normally distributed, skewed, and categorical data respectively

while higher log-transformed arousal index was correlated with lower Conners-3 Defiance/Aggression T score (Fig. 1).

Multiple linear regression analyses revealed that poor sleep quality and elevated concerns of sleepiness were both independently associated with higher BRIEF behavioral regulation T score, metacognition T score, and global executive composite T score in the fully adjusted model which included age, sex, BMI z score, the presence of OSA, and snoring. (Table 4) In addition, poor sleep quality was also independently associated with higher Conners-3 inattention T score and executive functioning T score, while elevated concerns of sleepiness was also associated with a higher learning problem T score in the fully adjusted model (Table 4). The presence of OSA and elevated concern of snoring were not associated with any cognitive outcomes (Table 4). Female sex was independently associated with a lower BRIEF behavioral regulation T score (β = –10.3 (SE 3.6), p = 0.005) and global executive composite T score (β = –8.8 (SE 3.4), p = 0.011). However, sex did not significantly moderate the association of OSA, sleep quality and sleepiness with cognitive outcomes.

Table 3 Neurocognitive outcomes according to OSA severity groups and sleep quality categories

	OAHI < 1.5/h	OAHI 1.5- < 5/h	OAHI ≥ 5/h		PSQI < 8	PSQI ≥ 8	
	N = 36	*N* = 16	*N* = 33	p*	*N* = 58	*N* = 27	p†
BRIEF							
Behavioral Regulation	53 ± 14	56 ± 11	56 ± 16	0.60	53 ± 14	58 ± 15	0.17
Metacognition	57 ± 13	60 ± 13	58 ± 14	0.74	56 ± 13	63 ± 12	0.020
Global Executive Composite	56 ± 13	59 ± 12	58 ± 15	0.64	55 ± 14	61 ± 12	0.057
Conners-3 parent short form							
Inattention	60 ± 13	59 ± 15	59 ± 13	0.95	57 ± 12	64 ± 14	0.024
Hyperactivity/Impulsivity	58 ± 15	59 ± 12	53 ± 11	0.21	54 ± 12	60 ± 15	0.091
Learning Problems	56 ± 12	57 ± 12	56 ± 12	0.99	54 ± 12	60 ± 12	0.046
Executive Functioning	58 ± 14	61 ± 17	56 ± 14	0.51	55 ± 13	63 ± 15	0.016
Defiance/Aggression	54 ± 12	57 ± 17	51 ± 10	0.31	52 ± 11	57 ± 16	0.19
Peer Relations	66 ± 18	66 ± 16	63 ± 19	0.80	63 ± 18	69 ± 17	0.18

OAHI obstructive apnea hypopnea index; *PSQI* Pittsburgh Sleep Quality Index

Data are shown as mean ± SD

* *P* values were obtained from one-way ANOVA comparing the three OSA severity groups

† *P* values were obtained from independent t tests comparing the good and poor sleep quality groups

Discussion

In this prospective cohort of overweight/obese children and adolescents with or without OSA, after adjusting for age, sex, and BMI z score, poor sleep quality and increased daytime sleepiness were both independently associated with lower behavioral regulation, metacognition, and executive function. Furthermore, poor sleep quality was also independently associated with inattention, while sleepiness was also associated with learning problems. Interestingly, the presence of OSA or snoring was not significantly associated with any cognitive outcomes measured in the study.

Obesity is a well-known confounder between OSA and adverse physical and mental health outcomes. Adjusting for the confounding effect of obesity is the major challenge in the investigation of OSA-related complications. One of the strengths of the current study was that we exclusively recruited overweight/obese children only, such that the body sizes of the participants in different OSA severity groups were more comparable although the moderate-severe OSA group still had a higher BMI than the mild and no OSA groups. BMI z score correlated with log-transformed OAHI, log-transformed ODI, and SRBD-PSQ snoring subscale, suggesting that its associations with OSA symptoms and severity were still significant even in this overweight/obese cohort. Moreover, BMI z score also correlated with the BRIEF scores as well as Conners-3 inattention and executive functioning T scores, supporting that adjustment for BMI z score had to be made when examining the association between OSA and these neurocognitive outcomes.

The association between OSA and neurocognitive impairment has been well documented in the literature [27]. However, current evidence of the association specifically in children with obesity is conflicting. A large-scale cross-sectional study investigating the association of SDB severity in 1010 children aged 5–7 years found that cognitive performance was significantly lower in children with more severe SDB. The association remained similar when analyzing the normal weight and obese subgroups separately, suggesting that obesity did not moderate the association [28]. Another study showed that normal weight children with OSA had lower total intelligent quotient (IQ) when compared to normal weight controls. However, another group with both OSA and obesity had an even lower total IQ, suggesting that obesity exerted an additive worsening effect on top of SDB [29]. However, the study did not include a group of obese children without SDB such that the independent effect of SDB within the obese subgroup could not be evaluated. Xanthopoulos et al. compared 3 different groups: i) obese children with OSA, ii) obese controls, and iii) lean controls and they revealed a significantly worse BRIEF scores in obese children with OSA when compared to obese controls, while no significant differences could be observed between obese controls and lean controls, suggesting that OSA plays a more important role in the impairment of executive function when compared to body mass. Furthermore, their mediation analysis demonstrated that the direct effect of BMI z score on BRIEF scores was not significant after controlling for AHI, but its indirect effect through AHI was significant, implying that OSA severity significantly mediated the effect of obesity on executive functioning and behaviors [30]. In contrast to these findings, Biggs et al. compared the neurocognitive function between normal

Table 4 Regression coefficients of sleep-related parameters on neurocognitive outcomes

	OSA (OAHI ≥ 1.5)				Elevated concerns of snoring (PSQ snoring subscale > 0.33)			
	Age, sex, and BMI z score adjusted		Fully adjusted		Age, sex, and BMI z score adjusted		Fully adjusted	
	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
BRIEF								
Behavioral Regulation	–1.35 (3.44)	0.70	0.28 (3.65)	0.94	2.56 (3.25)	0.43	1.05 (3.43)	0.76
Metacognition	–1.31 (3.28)	0.69	–0.24 (3.42)	0.94	3.59 (3.07)	0.25	2.45 (3.22)	0.45
Global Executive Composite	–1.47 (3.35)	0.66	–0.23 (3.47)	0.95	3.65 (3.14)	0.25	2.31 (3.27)	0.48
Conners-3								
Hyperactivity/Impulsivity	–4.52 (3.39)	0.19	–5.25 (3.74)	0.16	1.54 (3.21)	0.63	3.28 (3.5)	0.35
Learning Problems	–1.76 (3.05)	0.57	–1.17 (3.24)	0.72	3.32 (2.81)	0.24	2.63 (3.02)	0.39
Executive Functioning	–4.38 (3.2)	0.18	–3.4 (3.43)	0.32	3.05 (3.33)	0.36	3.39 (3.55)	0.34
Defiance/Aggression	–3.3 (3.45)	0.34	–4.18 (3.87)	0.28	1.59 (2.94)	0.59	3.46 (3.24)	0.29
Peer Relations	–7.02 (4.47)	0.12	–4.04 (4.94)	0.42	–3 (4.24)	0.48	–2.64 (4.69)	0.57
Inattention	–5.17 (3.32)	0.12	–4.11 (3.55)	0.25	1.31 (3.11)	0.67	1.89 (3.28)	0.57
	Poor subjective sleep quality (PSQI ≥ 8)				Elevated concerns of sleepiness (PSQ sleepiness subscale > 0.33)			
	Age, sex, and BMI z score adjusted		Fully adjusted		Age, sex, and BMI z score adjusted		Fully adjusted	
	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
BRIEF								
Behavioral Regulation	9.39 (3.4)	0.007	7.73 (3.48)	0.029	8.05 (2.91)	0.007	6.87 (3.09)	0.029
Metacognition	10.07 (3.2)	0.002	8.45 (3.26)	0.011	7.45 (2.78)	0.009	5.89 (2.9)	0.046
Global Executive Composite	10.3 (3.26)	0.002	8.54 (3.31)	0.012	8.41 (2.82)	0.004	6.84 (2.94)	0.023
Conners-3								
Hyperactivity/Impulsivity	7.15 (3.47)	0.043	6.51 (3.61)	0.075	3.52 (2.98)	0.24	1.25 (3.15)	0.69
Learning Problems	6.52 (3.08)	0.037	4.8 (3.11)	0.13	6.82 (2.55)	0.009	5.78 (2.71)	0.036
Executive Functioning	9.3 (3.56)	0.011	8.46 (3.66)	0.024	6.66 (3.03)	0.031	4.34 (3.19)	0.18
Defiance/Aggression	6.28 (3.2)	0.053	6.25 (3.35)	0.066	–0.88 (2.76)	0.75	–2.72 (2.92)	0.35
Peer Relations	8.37 (4.64)	0.075	6.58 (4.83)	0.18	5.18 (3.95)	0.19	4.54 (4.21)	0.28
Inattention	9.75 (3.29)	0.004	8.35 (3.38)	0.016	6.25 (2.83)	0.03	4.34 (2.95)	0.15

Multiple linear regression analyses were used to test the associations between sleep parameters and neurocognitive outcomes, with neurocognitive outcomes as the dependent variables. The presence of obstructive sleep apnea (OSA, OAHI ≥ 1.5 events/h), poor subjective sleep quality [Pittsburgh Sleep Quality Index (PSQI) ≥ 8], elevated concerns of snoring [Pediatric Sleep Questionnaire (PSQ) snoring subscale > 0.33, i.e. at least 2 relevant symptoms positive], and elevated concerns of sleepiness [Pediatric Sleep Questionnaire (PSQ) sleepiness subscale > 0.33, i.e. at least 2 relevant symptoms positive] were tested in (1) the age-, sex- and BMI z score-adjusted model and (2) the fully adjusted model that included all the variables in model 1 and all the other sleep parameters listed in the table

weight children without OSA, normal weight children with OSA, and overweight children with OSA and they demonstrated that the overweight-OSA group had significantly worse BRIEF subscale and global composite scores while no significant differences could be observed between the normal weight-control and the normal weight-OSA groups, suggesting that a higher BMI but not OSA contributes to the cognitive impairment [31]. A recent study specifically in obese children showed that SDB severity was not associated with academic performance measured by standardized tests. They were also unable to observe any significant associations between SDB severity and brain volumes measured by MRI [32]. Moreover, data from the Penn State Child Cohort suggested that SDB itself was not associated with neurocognitive impairments or behavioral problems [33]. Apart from these cross-sectional data, a prospective follow-up study conducted 4 years after adenotonsillectomy in children aged 3–12 years at baseline found only little improvement in neurocognitive performance as measured by NEPSY in both non-obese and

obese children despite substantial improvement in SDB. Instead, obesity appeared to be the major contributor to the cognitive impairment [34]. All these findings suggest that SDB may not be a strong contributor to the cognitive impairment in children with obesity.

Our findings concur with some of the previous studies by showing that OSA or snoring was not associated with executive functioning and behavioral problems in obese children. However, poor sleep quality and daytime sleepiness were associated with worse cognitive function, independent of OSA and snoring severity. The association of poor sleep quality and daytime sleepiness with cognition has been well documented in pediatric population. A meta-analysis involving more than 13,000 children confirmed that poor sleep quality (measured by PSG, actigraphy, or questionnaires) and daytime sleepiness (measured by questionnaires) were modestly associated with worse school performance [6]. However, relevant evidence specifically within the obese subgroup is scarce. Hannon et al. conducted a small-scaled cross-sectional study to compare severely obese adolescents with or without OSA and found that OSA was not associated with most of the neurocognitive outcomes except for a lower math score. Instead, sleep fragmentation and poor sleep quality were associated with reduced psychomotor efficiency, poorer memory recall, and lower scores on standardized academic tests [35]. Some recent studies supported these findings by showing that parent-reported sleep disturbance mediated the association of obesity with various aspects of cognitive function including behavioral regulation, metacognition, episodic memory, executive function, attention, working memory, and processing speed [36, 37].

Interestingly, the poor sleep quality group had a lower OAHI than the good sleep quality group in this study. It might be partly because the former group had a higher percentage of females, as females are associated with a lower prevalence of OSA [38], but at the same time more vulnerable to poor sleep quality [39]. However, other factors which were not measured in the study may also contribute to the observed findings. Children and adolescents with lower OAHI had lower BMI, which may be an advantage for social and peer relationship development [40]. Establishment and maintenance of peer relations may increase the risk of social media addiction [41], which in turn lead to poorer sleep quality, especially when the social media use is close to bedtime [42], as it would postpone bedtime and shorten sleep duration by interfering with melatonin production via screen exposure at bed [43]. The anxiety of not being connected to the social media may also make it difficult to relax at bedtime as highlighted by the finding that social media incoming alerts significantly contributed to sleep disruptions in teens [42].

Cautions should be taken when interpreting the results of this study as the study had several limitations. Given the cross-sectional study design, whether cognitive impairment was the cause or the consequence of sleep disturbance could not be discerned. As both cognitive function and sleep disturbance can be affected by multiple factors, there are potential confounding factors that were not measured in the study, such as genetic background, family environment, and the educational levels of the parents. The small sample size also made it impossible to investigate the inter-relationship between various sleep parameters and the cognitive outcomes using more sophisticated methods such as structural equation modeling. Furthermore, this study did not have objective neurocognitive data—all cognitive outcomes were subjectively reported by parents, which may be subject to reporting bias.

Conclusions

This study provided evidence that subjective sleep quality and daytime sleepiness, but not objectively measured OSA severity, were independently associated with executive functioning and behavioral problems in children and adolescents with obesity. Children with obesity require a broader evaluation of their sleep, not only SDB severity determination, but also sleep quality and daytime sleepiness assessments. Future studies are needed to evaluate if improving the sleep quality and sleepiness in children with obesity provides any beneficial effect to their cognitive functioning longitudinally.

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Author contribution Dr Au carried out the analyses, drafted the initial manuscript, and reviewed and revised the manuscript.
Mr Voutsas and Ms Chan collected data, and reviewed and revised the manuscript.
Drs Katz and Narang conceptualized and designed the study, supervised data collection, 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.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Lo JC, Groeger JA, Cheng GH et al (2016) Self-reported sleep duration and cognitive performance in older adults: a systematic review and meta-analysis. Sleep Med 17:87–98. https://doi.org/10.1016/j.sleep.2015.08.021
2. Richards A, Inslicht SS, Metzler TJ et al (2017) Sleep and cognitive performance from teens to old age: More is not better. Sleep 40:zsw029. https://doi.org/10.1093/sleep/zsw029
3. de Bruin EJ, van Run C, Staaks J, Meijer AM (2017) Effects of sleep manipulation on cognitive functioning of adolescents: A systematic review. Sleep Med Rev 32:45–57. https://doi.org/10.1016/j.smrv.2016.02.006
4. Dewald-Kaufmann JF, Oort FJ, Meijer AM (2013) The effects of sleep extension on sleep and cognitive performance in adolescents with chronic sleep reduction: An experimental study. Sleep Med 14:510–517. https://doi.org/10.1016/j.sleep.2013.01.012
5. de Bruin EJ, Dewald-Kaufmann JF, Oort FJ et al (2015) Differential effects of online insomnia treatment on executive functions in adolescents. Sleep Med 16:510–520. https://doi.org/10.1016/j.sleep.2014.12.009
6. Dewald JF, Meijer AM, Oort FJ et al (2010) The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. Sleep Med Rev 14:179–189. https://doi.org/10.1016/j.smrv.2009.10.004
7. da Silva Gusmão Cardoso T, Pompéia S, Miranda MC (2018) Cognitive and behavioral effects of obstructive sleep apnea syndrome in children: a systematic literature review. Sleep Med 46:46–55. https://doi.org/10.1016/j.sleep.2017.12.020
8. Smith E, Hay P, Campbell L, Trollor JN (2011) A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. Obes Rev 12:740–755. https://doi.org/10.1111/j.1467-789X.2011.00920.x
9. Jebeile H, Kelly AS, O'Malley G, Baur LA (2022) Obesity in children and adolescents: epidemiology, causes, assessment, and management. Lancet Diabetes Endocrinol 10:351–365. https://doi.org/10.1016/S2213-8587(22)00047-X
10. Frye SS, Fernandez-Mendoza J, Calhoun SL et al (2019) Childhood obesity, weight loss and developmental trajectories predict the persistence and remission of childhood sleep-disordered breathing. Pediatr Obes 14:e12461. https://doi.org/10.1111/ijpo.12461
11. Duraccio KM, Krietsch KN, Chardon ML et al (2019) Poor sleep and adolescent obesity risk: a narrative review of potential mechanisms. Adolesc Health Med Ther 10:117–130. https://doi.org/10.2147/AHMT.S219594
12. Kuczmarski RJ, Ogden CL, Guo SS et al (2002) 2000 CDC Growth Charts for the United States: methods and development. Vital Health Stat 11(246):1–190
13. World Health Organization (2011) Waist circumference and waist-hip ratio: report of a WHO expert consultation, Geneva, 8–11 December 2008
14. LaBerge RC, Vaccani JP, Gow RM et al (2009) Inter- and intra-rater reliability of neck circumference measurements in children. Pediatr Pulmonol 44:64–69. https://doi.org/10.1002/ppul.20944
15. Berry RB, Brooks R, Gamaldo CE et al (2012) The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Techinical Specifications. Version 2.0. American Academy of Sleep Medicine, Darien
16. Chervin RD, Hedger K, Dillon JE, Pituch KJ (2000) Pediatric sleep questionnaire (PSQ): validity and reliability of scales for sleep-disordered breathing, snoring, sleepiness, and behavioral problems. Sleep Med 1:21–32. https://doi.org/10.1016/S1389-9457(99)00009-X
17. Chervin RD, Weatherly RA, Ruzicka DL et al (2006) Subjective sleepiness and polysomnographic correlates in children scheduled for adenotonsillectomy vs. other surgical care. Sleep 29:495–503
18. Paruthi S, Buchanan P, Weng J et al (2016) Effect of adenotonsillectomy on parent-reported sleepiness in children with obstructive sleep apnea. Sleep 39:2005–2012. https://doi.org/10.5665/sleep.6232
19. Oswald KA, Richard A, Hodges E, Heinrich KP (2021) Sleep and neurobehavioral functioning in survivors of pediatric cancer. Sleep Med 78:153–159. https://doi.org/10.1016/j.sleep.2020.12.026
20. Buysse DJ, Reynolds CF, Monk TH et al (1989) The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. Psychiatry Res 28:193–213. https://doi.org/10.1016/0165-1781(89)90047-4
21. Carpenter JS, Andrykowski MA (1998) Psychometric evaluation of the pittsburgh sleep quality index. J Psychosom Res 45:5–13. https://doi.org/10.1016/S0022-3999(97)00298-5
22. Fichtenberg NL, Putnam SH, Mann NR et al (2001) Insomnia screening in postacute traumatic brain injury: utility and validity of the Pittsburgh sleep quality index. Am J Phys Med Rehab 80:339–345
23. Fichtenberg NL, Zafonte RD, Putnam S et al (2002) Insomnia in a post-acute brain injury sample. Brain Inj 16:197–206. https://doi.org/10.1080/02699050110103940
24. Beck SL, Schwartz AL, Towsley G et al (2004) Psychometric evaluation of the Pittsburgh sleep quality index in cancer patients. J Pain Symptom Manage 27:140–148. https://doi.org/10.1016/j.jpainsymman.2003.12.002
25. Gioia G, Peter K, Guy S, Kenworthy L (2000) Behavior rating inventory of executive function professional manual. Psychological Assessment Resources, Inc, Lutz
26. Conners CK (2008) Conners manual, 3rd edn. Multi-Health Systems Inc., North Tonawanda
27. Menzies B, Teng A, Burns M, Lah S (2022) Neurocognitive outcomes of children with sleep disordered breathing: A systematic review with meta-analysis. Sleep Med Rev 63:101629. https://doi.org/10.1016/j.smrv.2022.101629
28. Hunter SJ, Gozal D, Smith DL et al (2016) Effect of sleep-disordered breathing severity on cognitive performance measures in a large community cohort of young school-aged children. Am J Respir Crit Care Med 194:739–747. https://doi.org/10.1164/rccm.201510-2099OC
29. Vitelli O, Tabarrini A, Miano S et al (2015) Impact of obesity on cognitive outcome in children with sleep-disordered breathing. Sleep Med 16:625–630. https://doi.org/10.1016/j.sleep.2014.12.015
30. Xanthopoulos MS, Gallagher PR, Berkowitz RI et al (2015) Neurobehavioral functioning in adolescents with and without obesity and obstructive sleep apnea. Sleep 38:401–410. https://doi.org/10.5665/sleep.4498
31. Biggs SN, Tamanyan K, Walter LM et al (2017) Overweight and obesity add to behavioral problems in children with sleep-disordered breathing. Sleep Med 39:62–69. https://doi.org/10.1016/j.sleep.2017.09.001
32. Torres-Lopez LV, Cadenas-Sanchez C, Migueles JH et al (2022) Does sleep-disordered breathing add to impairments in academic performance and brain structure usually observed in children with overweight/obesity? Eur J Pediatr 181:2055–2065. https://doi.org/10.1007/s00431-022-04403-0
33. Frye SS, Fernandez-Mendoza J, Calhoun SL et al (2018) Neurocognitive and behavioral functioning in adolescents with sleep

disordered breathing: a population-based, dual-energy X-ray absorptiometry study. Int J Obes (Lond) 42:95–101. https://doi.org/10.1038/ijo.2017.229
34. Kohler M, Kennedy D, Martin J et al (2018) The influence of body mass on long-term cognitive performance of children treated for sleep-disordered breathing. Sleep Med 51:1–6. https://doi.org/10.1016/j.sleep.2018.05.021
35. Hannon TS, Rofey DL, Ryan CM et al (2012) Relationships among obstructive sleep apnea, anthropometric measures, and neurocognitive functioning in adolescents with severe obesity. J Pediatr 160:732–735. https://doi.org/10.1016/j.jpeds.2011.10.029
36. Pearce AL, Mackey E, Nadler EP, Vaidya CJ (2018) Sleep health and psychopathology mediate executive deficits in pediatric obesity. Child Obes 14:189–196. https://doi.org/10.1089/chi.2017.0281
37 Mattey-Mora PP, Nelson EJ (2021) Sleep disturbances, obesity, and cognitive function in childhood: a mediation analysis. Curr Dev Nutr 5:nzab119. https://doi.org/10.1093/cdn/nzab119
38. Li AM, So HK, Au CT et al (2010) Epidemiology of obstructive sleep apnoea syndrome in Chinese children: a two-phase community study. Thorax 65:991–997. https://doi.org/10.1136/thx.2010.134858
39. Fatima Y, Doi SAR, Najman JM, Mamun AA (2016) Exploring gender difference in sleep quality of young adults: findings from a large population study. Clin Med Res 14:138–144. https://doi.org/10.3121/cmr.2016.1338
40. Pearce MJ, Boergers J, Prinstein MJ (2002) Adolescent obesity, overt and relational peer victimization, and romantic relationships. Obes Res 10:386–393. https://doi.org/10.1038/oby.2002.53
41. Fabris MA, Marengo D, Longobardi C, Settanni M (2020) Investigating the links between fear of missing out, social media addiction, and emotional symptoms in adolescence: The role of stress associated with neglect and negative reactions on social media. Addict Behav 106:106364. https://doi.org/10.1016/j.addbeh.2020.106364
42. Woods HC, Scott H (2016) #Sleepyteens: Social media use in adolescence is associated with poor sleep quality, anxiety, depression and low self-esteem. J Adolesc 51:41–49. https://doi.org/10.1016/j.adolescence.2016.05.008
43. van der Lely S, Frey S, Garbazza C et al (2015) Blue blocker glasses as a countermeasure for alerting effects of evening light-emitting diode screen exposure in male teenagers. J Adolesc Health 56:113–119. https://doi.org/10.1016/j.jadohealth.2014.08.002

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