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ORIGINAL RESEARCH

The Sleep-Obesity Nexus: Assessment of Multiple Sleep Dimensions and Weight Status Among Victorian Primary School Children

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Purpose: To examine the association between sleep and weight status across multiple dimensions of sleep (duration, efficiency, quality and timing) and assess the cumulative influence of these dimensions on the overall sleep-obesity association.

Participants and Methods: Cross-sectional data from 2253 students aged 8.8 to 13.5 years participating in two monitoring studies across regional Victoria was analyzed. Students were invited to have measures of height and weight taken and to complete a self-report electronic questionnaire on demographic characteristics and health behaviors. Logistic regression models were used to assess association between sleep dimensions and BMI z-scores.

Results: Beyond sleep duration, poor perceived sleep quality, delayed sleep initiation, later bed times and sleep-wake timing, all significantly increased the odds of overweight/obesity (OR 1.47, 95% CI: 1.07–2.01; OR 1.25, 95% CI: 1.02–1.55; and OR 1.70. 95% CI: 1.28–2.28, respectively). Additionally, a cumulative effect of having multiple poorly scored sleep dimensions was found, where four or more poorly scored sleep dimensions more than doubled the odds of overweight/obesity among children (OR 2.25, 95% CI: 1.41–3.58).

Conclusion: This study highlights the importance of measuring and considering multiple dimensions of sleep, along with the individual and additive influence of the sleep dimension on the sleep-obesity nexus.

Keywords: sleep quality, bedtime, sleep duration, childhood obesity

Introduction

It is well established that sleep influences the health, wellbeing, growth and development of children.[1] In addition to the widely acknowledged association between health behaviors such as poor diet quality and physical inactivity on childhood obesity,[2,3] it has been proposed that adequate sleep is also required to maintain a healthy energy balance and weight status.[4,5] It has been suggested that insufficient sleep creates an energy deficit, leading to a reduction of energy for physical activity; as well as altering the regulation of hormones such as leptin and ghrelin, which influence satiety and fat metabolism.[4,5] With national data reporting one in four children (24.9%) aged 5–17 years are affected by either overweight (17%) or obesity (8%),[6] furthering current understanding on the influence of sleep on childhood obesity may offer promise to assist in reducing the epidemic.

Consensus exists for an overall sleep–obesity relationship in childhood.[7,8] However, a limitation around the measurement and classification of sleep insufficiency has been highlighted, with a large body of this research focused on sleep duration to define adequate sleep.[7–11] For example, an Australian study found children aged 9–13 years were twice as likely to present with a poorer weight status (overweight/obesity) if they slept <10hrs/night compared to those who met sleep duration recommendations (>10hrs/night).[12] Despite these strong associations, it has been argued that duration alone might not be sufficient to explain the sleep–obesity relationship among children.[13,14] Several additional dimensions of sleep have been highlighted as important to consider, including: sleep timing, sleep quality, and sleep continuity/efficiency on childhood

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obesity risk. Sleep timing is outlined as a measure of bed/wake patterns and placement of sleep across a 24-hour day; sleep quality can include subjectively reported satisfaction/perceived problems with sleep, or objectively measured architecture of sleep (adequacy of time spent in the different sleep wave cycles);[13,14] while sleep continuity/efficiency, can be determined by the proportion of time spent sleeping between bed and wake times, or around one's ability to initiate (sleep latency/onset) and maintain sleep (experience of wake episodes) in an efficient manner.[13,15]

Emergent literature is now exploring the contribution of these dimensions of sleep on the sleep-obesity nexus. Golley et al[16] reported that adolescents with later sleep onset and later wake times had higher BMI (Body Mass Index) z-scores than those with earlier sleep onset and earlier wake times (0.46 ± 1.10 vs 0.68 ± 1.24, $P = 0.008$), despite similar total sleep durations. Jarrin et al[14] demonstrated that independent from adolescents' sleep duration, participants were at greater risk of overweight and obesity if they presented with poor sleep quality, poor sleep continuity/efficiency, or delayed sleep timing. It has therefore been argued that dimensions of sleep beyond duration may drive the negative association between sleep and obesity among children.[14,17,18]

The increasing literature of these dimensions of sleep add to our understanding on the sleep-obesity association, although to date there is limited research comparing these dimensions in one study. A recent systematic review on the association between sleep dimensions and childhood obesity found 74 out of 113 articles looked at sleep duration alone, while 22 assessed duration alongside any one other dimension and seven assessed at least another two dimensions.[19] Highlighting that, in order to better understand their individual and cumulative impact of these dimensions, it would be beneficial to compare and analyze the contribution of each of them. That is, students who have both sleep insufficiency and poor sleep quality may be at greater risk of overweight and obesity than those who suffer just sleep insufficiency or poor sleep quality in isolation.

To the authors' knowledge, the current paper will be the first paper to date to concurrently examine all four dimensions of sleep and measured weight status among children, in a representative population sample of children aged 8–13 years old from Victoria, Australia. The paper aims to firstly examine the association between each individual sleep dimension (duration, efficiency, quality, timing) and weight status, and secondly to assess the cumulative influence of the sleep dimensions on the overall sleep-obesity association.

Participants and Methods

Study Sample

The sample comprised cross-sectional data of Grade Four (aged approx. 9–10 years) and Grade Six (aged approx. 11–12 years) students participating in the Great South Coast Childhood Obesity Monitoring Study (GSC)[20] and the Goulburn Valley Health Behaviours Monitoring Study (GV).[21] GV data was collected between July and September 2016 and GSC between April and June 2017. Detailed information on the study design, sampling strategy, school and student recruitment process and measure have previously been published for the GSC study[20] which has been replicated in the GVHS.[21]

Briefly, all government, independent and catholic primary schools (with enrolled students generally aged between 5–12 years) within the nine local government areas of the Great South Coast region of Victoria, Australia (Colac-Otway, Corangamite, Southern Grampians, Glenelg, Moyne, Warrnambool) and Goulburn Valley region of Victoria, Australia (Shepparton, Moira and Strathbogie) were invited to participate. A passive (opt-out) consent approach was used to invite all Grade Four and Six students within each participating school. Children were excluded from participation if their parent or guardian completed an opt-out form, or if the student verbally declined on the day. Children were also free to participate in as little or as much of the data collection process (eg, just have their height measured and not their weight, just complete the self-report behavioral questionnaire, etc).

All data collection took place at the school during school time. Students were invited to have anthropometric measurements taken and to complete a self-report electronic questionnaire which examined demographic characteristics, health behaviors and well-being. In total, data from 2862 Grade Four and Grade Six children (GSC N = 1817; GV N = 1045) from 94 primary schools (GSC N = 56; GV N = 38) across Victoria were collected.

This study received ethical approvals from Deakin University's Human Research Ethics Committee (DUHREC 2014_289 and 2014–279), the Victorian Department of Education and Training (DET 2015_002622) and the Catholic Archdiocese of Sandhurst and Ballarat. This study complied with the Declaration of Helsinki.

Measures and Data Management

Demographic Information

Children self-reported date of birth, gender, information on ancestry and primary language spoken at home. Socio-Economic Indexes for Areas (SEIFA) scores[22] and School Index of Community Socio-Educational Advantage (ICSEA)[23] were used as a proxy for socioeconomic position. Developed by Australian Curriculum, Assessment and Reporting Authority (ACARA),[24] ICSEA scores were retrieved from the MySchool website.[23] ICSEA takes into account both student and school level factors to summarize educational advantage or disadvantage, with 1000 being the average benchmark score.

Sleep

A 16-item questionnaire was developed from previous studies and questionnaires,[5,25–30,46] to assess aspects of children's sleep (duration, quality, efficiency and timing). A detailed description including reliability and validity properties (where possible) of these is available in Supplementary Table S1.

Children self-reported usual bed time and wake time on school nights within 15-minute increments, allowing for the calculation of sleep duration (the difference between the two time points); with short sleep defined as <9 hours and long as 11 or more hours, as per national and international guidelines.[31,32] Median splits of bed and wake times were used to determine categorization early/late bedtimes and wake times, following previously used criteria.[25,33,34] Here, late to bed was determined as 20:30 (8:30pm) or later, and early to rise as 7:00am or earlier, similar to previous literature.[18,25,34] From this, sleep-wake categories were categorized as either: early to bed/late to rise (≤20:15/≥7:15) early to bed/early to rise (≤20:15/≤7:00); Late to bed/late to rise (≥20:30/≥7:15); late to bed/early to rise (≥20:30/≤7:00).

Sleep efficiency was assessed via two questions: one question on sleep initiation/latency ("over the last two weeks, have you found it hard to fall asleep (ie taken longer than 20 mins)"); and one question on maintenance/wake episodes ("Some people wake up during the night, others never do. How often did you wake up"). Sleep initiation was dichotomized from a five-option Likert scale (ranging from "never" to "almost always"), with poor sleep initiation scored from responses of "often" or "almost always". Poor sleep maintenance/wake episodes responses was determined as reporting having three or more wake episodes per night from a four-option Likert scale ranging from "never (I don't wake up during the night)" to "often (3 or more times per night)".

Subjective sleep quality was based on the questionnaire item "overall, how well do you think you sleep" with children required to select a response on a six-option Likert scale ranging from "Very Good" to "Very Bad". These response options were dichotomized as "good" or "bad/very bad" sleep quality.

Weight Status

Height and weight were measured without shoes and wearing only light clothing, by trained staff. Height was measured twice to the nearest 0.1 cm. Where the first and second measures differed by greater than 0.5 cm, a third measure was taken. Weight was measured twice to the nearest 0.1 kg, with a third measure taken if the difference was greater than 0.1 kg. The average of two or three measurements was used to generate each child's height and weight. Height, weight, gender and age measures were used to calculate participants' BMI z-score, from which weight status was classified using the WHO growth standards for children 5–19 years.[35]

Data Management

Of the 2862 consenting students, 2253 were included in the analysis (816 GV; 1437 GSC); with 169 students were excluded due to missing BMI z-scores; 6 due to extreme BMI z-scores being ±3 standard deviations from the mean; and 262 due to missing sleep data. Cut-points for bedtime and wake times were created to exclude irregular/inaccurate, with exclusion criteria set for bedtimes reported before 6pm or after 2:15am; or wake-times before 3am or after 8:45am. A final 172 records were excluded for irregular bed/wake times as defined above.

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Results from each sleep variable were dichotomized as positive or negative (as outlined above), with negative defined as: sleeping less than nine hours per night, going to bed later than 8:30pm; waking earlier than 7:00am; sleep quality perceived as bad/very bad; an initiation/latency problem of 20mins or more to fall asleep; and 3 or more wake episodes per night. Modelled from previous methods,[26,36] a sleep score was created to indicate the number of sleep dimensions scored as negative, out of a maximum of 6 (poor duration, poor bed time, poor wake time, poor quality, poor initiation, poor wake episodes). The sleep score was categorized ranging from 0 "no Sleep Problem" to 4 "Four or more sleep problems".

Statistical Analysis

All statistical analyses were conducted using STATA SE15 (Stata Corporation, Texas, USA). Children outcomes were summarized for each study sample separately, and compared between studies using *t*-test or Chi-squared test. There were no significant differences between the two samples (GV and GSC) in BMI z-scores, weight status categorization, gender, proportion of English-only speakers, proportion per grade four and six, or the proportion categorized as short sleepers (<9 hours per night) (See Supplementary Table S2). As such, the samples were pooled for all further analysis.

Correlational analysis, t-tests and chi-square tests were used to test for significant associations between BMI z-scores/weight status categories and the different dimensions of sleep. Logistic regressions were conducted to further investigate the relationship of each sleep dimension with children's odds of overweight or obesity (combined variable), adjusting for study sample, school clustering and potential demographic confounders (age, gender, ICSEA). A logistic regression analysis was conducted to assess whether odds of overweight and obesity was increased by the number of sleep dimensions recorded as negative (sleep score).

Results

Descriptive statistics conducted for each study sample separately are available in Supplementary Table S2. As there were no statistical differences between the two samples, Table 1 presents the pooled sample participant characteristics and distributions of sleep dimensions, by weight status. Children were on average aged 10.9 (±1.1), ranging from 8.8 to 13.5 years. Half of the sample were males (50.2%) and most spoke English at home (90.7%). Prevalence of combined overweight/obesity was 35.2% (34.3% for boys, and 36.1% for girls), with 21.5% overweight and 13.6% obese. Less than 1% of participants were classified as underweight (0.6%), and were therefore merged into the healthy weight category.

Children on average reported sleeping 624 (±60.3) mins per night (10.4 hours), with 5.6% categorized as short or excessively short sleepers (<9 hrs/night). Despite this, 18.2% of children perceive that they never/almost never receive enough sleep. Children with overweight/obesity were more frequent among short sleepers (42.4%) than among those sleeping 11 hours or more (31.9%, p = 0.03). After controlling for age, gender, and ICSEA and accounting for school clustering (Table 2), those sleeping 11 hours or more were significantly less likely to be in the overweight or obesity weight status category (OR 0.77, 95% CI: 0.63–0.94), compared with those sleeping within the recommended nine to less than eleven hours per night.

Weight status did not differ significantly children's wake times; however, a higher proportion of late sleepers (later than 8:30) were classified as being with overweight or obesity, than those getting to bed before 8:30 (p = 0.001). This remained significantly associated in the adjusted model (OR 1.46, 95% CI: 1.17–1.81). Furthermore, with sleep-wake timing categories involving both bed and wake time classifications, overweight/obesity prevalence was significantly higher among Late to bed/Early to rise sleepers and Late to bed/Late to rise sleepers (41.2% and 36.0%, respectively), compared with Early to bed/Late to rise sleepers (30.8%, p < 0.01). This too remained significant in the adjusted analysis (OR 1.70. 95% CI: 1.28–2.28 and OR 1.36. 95% CI: 1.05–1.72, respectively). Interestingly, of the two mid-range duration sleep-wake categories, while an increased risk of overweight or obesity was evident among Late to bed/Late to rise sleepers, this risk was not significant for Early to bed/Early to rise sleepers.

Interestingly, in the adjusted model, an increased risk of overweight or obesity was not evident among the sleep timing category with the shortest duration (Early to bed/Early to rise), however this risk was significant for Late to bed/Late to rise sleepers (OR 1.36, 95% CI: 1.05–1.72) and Late to bed/Early to rise sleepers (OR 1.70. 95% CI: 1.28–2.28)

Table 1 Participant Characteristics and Distributions by Weight Status[a]

	All Participants (N=2253)[b]	Normal Weight (N=1461)	Overweight/Obese (N=792)	p[c]
Gender (%)				
Male	50.2%	65.8%	34.3%	NS
Girls	49.8%	63.9%	36.1%	
Age Mean (±SD)				
Years	10.9(±1.1)	10.9(±1.1)	10.9(±1.1)	NS
Primary Language (%)				
English Only	90.7%	65.0%	35.0%	NS
Other	9.3%	61.1%	38.9%	
ICSEA Mean (±SD)	995.5(±51.9)	999.1(±51.2)	988.9(±52.6)	<0.01
SEIFA Quintiles (%)				
Quintile 1	29.6%	61.9%	38.1%	NS
Quintile 2	39.2%	66.2%	33.8%	
Quintile 3	14.8%	66.1%	33.9%	
Quintile 4	15.7%	65.7%	34.3%	
Quintile 5	0.8%	70.6%	29.4%	
Weight Status				
BMI Mean (±SD)	19.2(±3.6)	17.2(±1.5)	22.9(±3.3)	p=<0.01
BMIz (WHO)	—	64.9%	35.2%	—
BMIz (IOTF)	—	73.2%	26.8%	—
Sleep Duration				
Minutes Mean (±SD)	624.0(±60.3)	626.4(±59.1)	619.6(±62.3)	p=0.01
<9 hours	5.6%	57.6%	42.4%	p=0.03
≥9 to <11 hours	61.2%	63.7%	36.3%	
11 or more hours	33.2%	68.1%	31.9%	
Perceived sufficient duration (%)				
Usually/always	81.9%	65.8%	34.2%	p=0.04
Never/Almost Never	18.2%	60.3%	39.73%	
Bed Time (%)				
Early	32.1%	69.6%	30.4%	p=<0.01
Late	67.9%	62.6%	37.4%	
Wake Time (%)				
Early	29.6%	63.2%	36.8%	NS
Late	70.4%	65.5%	34.5%	
Sleep-wake Timing (%)				
Early To Bed/Late To Rise	20.7%	69.2%	30.8%	p=<0.01
Early To Bed/Early To Rise	11.4%	70.3%	29.7%	
Late To Bed/Late To Rise	49.7%	64.0%	36.0%	
Late To Bed/Early To Rise	18.2%	58.8%	41.2%	
Perceived Quality (%)				
Good/moderate	91.8%	65.5%	34.5%	p=0.01
Bad/Very Bad	8.2%	56.3%	43.7%	

(*Continued*)

Table 1 (Continued).

	All Participants (N=2253)[b]	Normal Weight (N=1461)	Overweight/Obese (N=792)	p[c]
Sleep Continuity/Efficiency (%)				
Sleep initiation: Good (<20min)	70.9%	66.5%	33.5%	p=0.01
Bad/Problem (>20min)	29.1%	61.1%	38.9%	
Wake episodes: Never/rarely	91.8%	65.5%	34.5%	NS
≥3 wake episodes per night	8.3%	56.3%	43.7%	
Number of dimensions scored as poor (%)				
No recorded problems	13.9%	79.5%	29.5%	p=<0.01
One dimension	46.1%	67.9%	32.1%	
Two dimensions	25.1%	59.5%	40.5%	
Three dimensions	9.9%	62.6%	37.4%	
Four or more dimensions	5.1%	52.2%	47.8%	

Notes: [a]Categorization of weight status according to WHO cut points; [b]Percentages in column represent proportions of total study sample; [c]p values indicate significance in difference across weight categories according to chi-squared test for categorical variables and *t*-test for continuous variables.
Abbreviations: SD, standard deviation; ICSEA, Index of Community Socio-Educational Advantage; SEIFA, Socio-Economic Indexes for Areas according to school (1 Low, 5 High); BMI, body mass index; BMIz (WHO), BMI z-scores (age and sex adjusted) according to World Health Organization cut-points;[35] BMIz (IOTF), BMI z-scores (age and sex adjusted) according to the International Obesity Task Force IOTF cut-points;[45] NS, non-significant differences between weight categories.

Over three quarters (77.6%) of children reported sleep quality as good, 14.2% as average, and 8.2% reporting bad or very bad quality. Significantly more children with poor quality sleep were affected by overweight or obesity (43.7%) compared with those reporting good sleep quality (34.5%, p = 0.038). This remained significant in the adjusted model, with bad/very bad quality sleepers having higher odds of experiencing overweight or obesity (OR 1.47, 95% CI: 1.07–2.01).

In terms of efficiency, 29.1% report having issues falling asleep (taking longer than 20 minutes), and 27.2% waking up during the night either sometimes or often (18.9% and 8.3%, respectively). Sleep initiation issues (>20mins) were associated with significantly higher odds of being affected by overweight or obesity in the adjusted regression model (OR 1.25, 95% CI: 1.02–1.55), while increases in the number of wake episodes were not significantly associated with overweight and obesity risk.

Overall, 15.1% of participants reported having no sleep issues, with 48.3% classified as having one sleep issue, 23.1% having two, 9.5% as any three and 4.1% having four or more. A final logistic regression was conducted to assess whether risk of overweight or obesity increased with an increasing number of problematic sleep dimensions (see Table 3). Compared with having no reported sleep problems, having any one sleep problem was not associated with overweight or obesity (OR 1.17, 95% CI: 0.90–1.54). However, having two (OR 1.68, 95% CI: 1.29–2.18), three (OR 1.45, 95% CI: 1.03–2.01) and four or more (OR 2.25, 95% CI: 1.41–3.58) sleep issues were associated with overweight/obesity, after adjusting for age, sex, gender, study sample and ICSEA and controlling for school clustering.

Discussion

The present study investigated the multiple sleep dimensions among two population samples of school-aged children, along with the individual and combined odds of overweight and obesity. In support of previous literature,[9–11] children with shorter sleep durations were 1.7 times more likely to be categorized as being affected by overweight/obesity than children with sufficient/longer sleep. Looking beyond sleep duration dimensions including poor perceived quality, delayed sleep initiation, along with later bed times and sleep-wake timing all significantly increased the risk of overweight/obesity among the current sample. However, while scoring poorly on any single sleep dimension was not significantly associated with an increase in weight status, the risk of overweight/obesity more than doubled among children who reported having four or more sleep problems. This highlights the importance of examining multiple dimensions of sleep to further our understanding of the sleep–obesity relationship.

Table 2 Logistic Regressions for Odds of Overweight/Obesity by Sleep Dimensions

Sleep Dimensions	Unadjusted			Adjusted for Demographics[a]		
	OR	95% CI	p	OR	95% CI	p
Sleep Duration						
≥9 to <11 hours	ref.	—	—	—	—	—
11+ hours	**0.82**	**0.68–0.99**	**0.04**	**0.77**	**0.63–0.94**	**0.01**
<9hours	1.29	0.84–1.99	0.24	1.21	0.78–1.89	0.39
Bed Time						
Before 8:30pm	ref.	—	—	—	—	—
8:30pm or later	**1.37**	**1.11–1.68**	**<0.01**	**1.46**	**1.17–1.81**	**<0.01**
Wake Time						
Before 7am	ref.	–	–	–	–	–
7am or later	0.90	0.74–1.10	0.31	0.89	0.73–1.08	0.24
Sleep-wake Categories[b]						
EL	ref.	—	—	—	—	—
EE	0.95	0.70–1.29	0.73	0.97	0.71–1.32	0.84
LL	**1.26**	**1.00–1.59**	**0.04**	**1.36**	**1.05–1.72**	**0.02**
LE	**1.57**	**1.18–2.09**	**<0.01**	**1.70**	**1.28–2.28**	**<0.01**
Perceived Quality						
Good	ref.	—	—	—	—	—
Moderate	1.26	0.98–1.62	0.08	1.24	0.96–1.60	0.10
Bad/very bad	**1.53**	**1.12–2.09**	**<0.01**	**1.47**	**1.07–2.01**	**0.02**
Sleep initiation						
Good <20 mins	ref.	—	—	—	—	—
Moderate Sometimes >20mins	1.05	0.83–1.34	0.67	1.07	0.84–1.34	0.611
Bad/very bad	**1.29**	**1.05–1.58**	**0.02**	**1.25**	**1.02–1.55**	**0.034**
Mostly >20 mins						
Wake Episodes						
Never/rarely	ref.	—	—	—	—	—
Once/twice	1.18	0.94–1.48	0.15	1.12	0.90–1.41	0.31
Three or more	1.36	0.98–1.89	0.07	1.26	0.91–1.76	0.17

Notes: Bold text indicates significant association. [a]Adjusted for: school, study sample, gender, age, ICSEA (Index of Community Socio-educational Advantage); [b]bed time/wake time with early to bed/late to rise as reference category.
Abbreviations: EL, early to bed/late to rise; EE, early to bed/late to rise; LL, late to bed/late to rise; LE, late to bed/late to rise; OR, odds ratio.

Table 3 Logistic Regression with Odds Ratio of Overweight/Obese by Number of Sleep Issues

Number of Sleep Issues[a]	Unadjusted Analysis			Adjusted for Demographics[b]		
	OR	95% CI	p	OR	95% CI	p
No sleep issues	Ref.	—	—	Ref.	—	—
One Sleep Issue	1.13	0.87–1.46	0.36	1.17	0.90–1.54	0.25
Two Sleep Issue	**1.63**	**1.25–2.11**	**<0.01**	**1.68**	**1.29–2.18**	**<0.01**
Three Sleep Issue	1.43	1.03–1.99	0.04	1.44	1.03–2.01	0.03
Four or More Sleep issues	**2.19**	**1.39–3.45**	**<0.01**	**2.25**	**1.41–3.58**	**<0.01**

Notes: Bold text indicates significant association. [a]Number of sleep dimensions scored as poor; [b]adjusted for: school, study sample, gender, age, ICSEA (Index of Community Socio-educational Advantage).
Abbreviation: OR, odds ratio.

Similar to previous literature,[27,37] the timing of sleep among the current sample was shown to be of importance. While wake times were found to have no significant association between children's weight status, later bed times and children's sleep-wake patterns were shown to significantly increase risk of overweight and obesity. Compared with children who went to bed early and woke up late (EL), children who were categorized as late to bed and early to rise (LE) were significantly more likely to be affected by overweight or obesity (OR 1.7, CI: 1.28–2.28). With early to bed/late to rise being the longest possible duration of sleep (median 690 mins/night, data not shown) and late to bed/early to rise being the shortest possible duration of sleep (median 570 mins/night, data not shown), it could be argued that this difference might be simply due to the duration of sleep attained in these categories. However, it was novel to find that of the two mid-range duration sleep-wake categories, those in the Late to bed/Late to rise category also had higher risk of overweight or obesity, while those in the early to bed/early to rise category did not. Suggesting that the placement of sleep, particularly of bed times, might be more important than simply sleep duration which is in agreement with previous literature.[25,33]

As those going to bed late, regardless of being an early or late riser, were more likely to be in the unhealthy weight categories, it would be important to consider what drives this impact of the later placement of sleep on the sleep–obesity interaction. It has been proposed that later bedtimes lead to increased risk of overweight/obesity due to the time available for increased screen time along with increased opportunities for poor snacking behaviors.[17,38] Higher engagement and usage with screen usage has been reported to increase troubles with sleep onset, along with sleep quality.[39] Therefore, children going to bed later might have higher risk of obesity not only because of potentially higher caloric intake, but also due to reduced sleep quality cause by excess screen time, which could be effecting hormone regulation and restoration.[4,5] Future research would benefit from assessing the combined impact and risk of these negative behaviors and how they impact both overall sleep as well as the sleep-obesity nexus.

In terms of sleep efficiency, linked with later sleep timing, delayed sleep initiation was associated with overweight/obesity risk among the current sample. However, wake episodes were not found to significantly impact overweight/obesity risk among the current sample. It has been suggested that the number of wake episodes may not be important, with the length of these episodes being more important to consider. Previous data on a sample of 23,511-year-old students in America[40] report that while BMI was not correlated significantly with total night-time activity/wake episodes, the number of long wake episodes was significantly associated with increased BMI. This might suggest that regardless of the number of wake episodes, a short wake episode might not have any detrimental effect to overall sleep and the sleep-obesity association. However, longer wake episodes not only impact overall duration, they affect efficiency, and could also alter sleep-wave cycles and therefore overall quality. Whilst this current study found no association between the number of wake episodes and obesity, the length of the episodes was not assessed. With the advancement of wearable technologies (such as wrist worn accelerometers) enabling objective measurement of sleep duration, timing quality and efficiency, employing such technologies in future studies might enable more accurate assessment of the frequency and duration of wake episodes.

The current study furthered the currently available evidence by examining both the individual and additive influence of duration, efficiency, timing and quality on children's overweight and obesity risk. It was found that having any one sleep dimension problem only did not significantly increase the risk of overweight or obesity. However, having two (OR = 1.68, CI: 1.29–2.18), three (OR = 1.44, CI: 1.03–2.01), or four or more (OR = 2.25, CI: 1.41–3.58) sleep dimension issues led to an increased risk of overweight/obesity among the current sample. This suggests that studies which have only assessed sleep duration or any single one of the other dimensions alone could be missing out on capturing the full impact of poor sleep on overweight/obesity among children. Furthermore, it appears that additional dimensions may have an additive effect of poor sleep on risk of obesity. For example, a child might be sleeping for what is considered a sufficient duration each night, however they might experience a poorer quality sleep, or multiple wake episodes, which could influence the overall sleep-obesity association.

The current study poses some limitations. Firstly, while the current study benefits from the strengths of its large sample size and high school (GSC = 68.7%, GV62.9%) and student (GSC = 90.6%, GV = 79.3%) response rates, providing good representativeness, the results are not necessarily applicable beyond the current sample populations. Secondly, the current study utilized cross-sectional analysis, meaning a causal association cannot be inferred. Furthermore, the self-report nature of the sleep items could be subject to recall or report bias.[41] However, a moderate to high correlation between subjective measured dimensions of sleep with more objective assessments of sleep stages,[13,42] indicating children have a general understanding of their sleep. Furthermore, the current question items were sourced from studies with previous validated question items.[28–30] with these and similar self-report questionnaires validated among young children. While some reliability and validity of the sleep quality questions comes from adult data, the authors conducted face validity of these question items with a registered teacher to ensure appropriateness for the target audience. Future studies would benefit from psychometrically testing this questionnaire among children.

While there is a risk of error associated with potential recall bias from self-report among young children, or reporter bias through proxy report by parents,[43] self/proxy-reported measures are practical and cost-effective, and are deemed more suitable in population-based research.[43,44] However, the authors note that more objective assessment of these dimensions should be used where possible. Finally, additional correlated factors relating to both sleep and obesity among children, such as physical activity, sedentary time and diet, were not accounted for in this study.

Future studies would benefit from the investigation of how factors such as screen time and caloric intake influence not only sleep, but the overall sleep–obesity relationship; along with the use of more objective measures of the different dimensions of sleep (such as accelerometry); and also collecting repeat measures for longitudinal data, to be able to assess the impact of these sleep dimensions simultaneously overtime.

Conclusion

To the authors' knowledge, the current paper is the first to date to concurrently examine all four dimensions of sleep and measured weight status among a representative population sample of children aged 8–13 years old from Victoria, Australia. This study highlights the importance of measuring and considering multiple dimensions of sleep, along with the individual and additive influence of the sleep dimension on the sleep-obesity nexus. Reporting any one issue across dimensions was not shown to significantly influence overweight/obesity risk compared with no issues, however risk did increase significantly from any two to four or more sleep dimension issues. These findings accentuate the need to account for multiple dimensions of sleep when assessing the association between adequate sleep on weight status among children. Greater improvements in health are likely if population efforts focus beyond mere sleep duration, considering the influence of these multiple dimensions on sleep outcomes. Future studies should continue to consider the influence and combined impact of these multiple dimensions on the sleep-obesity nexus. Longitudinal studies would further assist in understanding this relationship, along with unpacking how these dimensions might impact and be influenced by additional obesity-related behaviors such as excess screen time and high caloric intake.

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