ACTA PÆDIATRICA
NURTURING THE CHILD

Acta Pædiatrica ISSN 0803-5253

REGULAR ARTICLE

Lack of sleep could increase obesity in children and too much television could be partly to blame

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Keywords
Mediation, Obesity, Sleep, Television viewing

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Received
31 July 2013; revised 8 September 2013; accepted 30 September 2013.

DOI:10.1111/apa.12447

ABSTRACT

Aim: To examine the bidirectional relationship between short sleep duration and body mass index (BMI). A secondary aim was to investigate whether reduced physical activity and increased screen time (television and computer use) mediated these associations.

Methods: This study utilised data from the Longitudinal Study of Australian Children, which is an observational cohort study of Australian children. The sample included 2984 (52.4% boys) children followed from 4 to 5 years of age until 8 to 9 years of age. Sleep duration, screen time and covariates were reported by parents, with BMI measured objectively. Cross-lagged modelling investigated the bidirectional association between sleep duration and BMI; lagged panel mediation modelling examined physical activity and screen time as potential mediators.

Results: Short sleep duration at 4 to 5 years of age was significantly associated with higher BMI at 8 to 9 years of age ($\beta = -.07$, p = .044). The relationship between short sleep duration at 4 to 5 years of age and higher BMI at 8 to 9 years of age was partially mediated by increased television viewing at 6 to 7 years of age ($\beta = -.01$, 95% confidence interval [−.02, −.002]).

Conclusion: Short sleep duration could be a risk factor for obesity in children. Increased television viewing may be one mechanism underlying this longitudinal relationship.

INTRODUCTION

There is growing interest surrounding the relationship between sleep duration and obesity in children. Although most research has been cross-sectional (1), several prospective studies in children have reported that short sleep predicts higher body mass index (BMI) and/or overweight in later life (2–6). Thus, short sleep could be a risk factor for obesity and have a range of treatment and prevention implications. However, more longitudinal research is needed to clarify the longitudinal relationship between short sleep duration and obesity, as it may be multidirectional. For instance, short sleep may contribute to obesity by influencing the hormonal regulation of energy balance, eating patterns, and physical activity (discussed in more detail below). In addition, obesity could shorten sleep via poor health and sleep disorders such as sleep apnoea and insomnia. Few studies have formally investigated whether a bidirectional association between sleep duration and obesity exists in children.

A second limitation is that the pathways linking sleep duration with obesity over time remain unclear. A number of potential pathways have been hypothesised previously (7–12). For example, experimental studies indicate that short-term sleep restriction alters hormones such as leptin, ghrelin and insulin (13), disturbs glucose regulation (14), and alters thermoregulation (8), in a manner that could promote obesity. It has also been hypothesised that individuals who get less sleep are more likely to gain weight, and be obese, as they have more opportunities to eat (8–10), which has received some empirical support in children (15).

Short sleep duration may also contribute to obesity via lower levels of physical activity and increased sedentary behaviour (8–10,12,16). This is because short sleep is associated with reduced physical activity and increased screen time (e.g. more television viewing and computer use) (16–19), possibly because the resulting fatigue and sleepiness reduces motivation to be active (3,10,16). Although not yet tested in children, this could contribute to weight gain and obesity over time and may be important in linking sleep duration with obesity.

Key notes

- Short sleep duration was a significant predictor of higher BMI in children.
- BMI was a significant predictor of short sleep duration in children from disadvantaged backgrounds and children with sleep problems.
- Increased television viewing partially mediated the longitudinal relationship between sleep duration and BMI in children.

This study therefore had two main aims. The first was to investigate whether there is a bidirectional association between sleep duration and BMI in children. This involved examining whether these associations varied by child gender, child sleep quality, and indicators socioeconomic status, all of which are linked with sleep duration and/or obesity. It was hypothesised that bidirectional relationships would exist between sleep duration and BMI, with these more pronounced in children with poorer sleep quality and from lower socioeconomic backgrounds. The second aim was to investigate whether screen time behaviours and physical activity linked short sleep duration with BMI. It was hypothesised that the longitudinal relationship between short sleep and BMI would be mediated by lower levels of physical activity and increased screen time.

METHODS

Participants and recruitment

The Longitudinal Study of Australian Children (LSAC) commenced in 2004 and tracks the health and development of two cohorts: a sample of infants followed from birth and a sample of children followed from 4 to 5 years of age. This study focused on this second cohort. LSAC randomly selected families to participate in this study from the Australian Medicare database, and collects follow-up data every 2 years. At each time point, children and their parent (s) participate in a structured interview, with the parent(s) also completing self-report questionnaires and time-use diaries (TUD); the child's height and weight is also measured. In this study, we utilised data collected from Waves one to three, covering a developmental period from 4 to 5 years of age until 8 to 9 years of age. For clarity, we refer to the ages of children as 4, 6 and 8 years of age for the three waves, respectively. Ethics approval to use these data for the purposes of the current study was obtained from the University of Wollongong's human research ethics committee.

Wave one included 4483 children, with TUDs (used to assess behaviours such as sleep, physical activity and screen time) completed for 3011 children. A very small proportion of these children (n = 27, 0.9%) had extreme values for sleep duration (e.g. <4 h or >14 h/night) at 4 years of age. When we excluded children with missing TUD data or extreme sleep duration values at baseline, the final sample size was 2984. For all other variables in this study, missing data were addressed using full information maximum likelihood (20).

Anthropometric measures

At each wave, child height was measured by an Invicta stadiometer (Modern Teaching Aids, Brookevale, NSW, Australia); two measurements were taken, and a third was taken if there was more than 0.5 cm difference between the first two measurements. Height was determined by the average of the two closest values. Body weight was measured using digital BMI bathroom scales (HoMedics, Dandenong South, VIC, Australia). All height and weight data were collected by a trained researcher. Height and weight data were used to calculate BMI values for each child. The analyses used raw BMI values rather than standardised values (e.g. z scores) because the latter are less sensitive to changes in adiposity in underweight and overweight/obese children relative to healthy weight children. Raw BMI values are therefore recommended for longitudinal studies in children (21).

Time-use diaries

Information on sleep duration (sleeping/napping), physical activity (time spent engaged in organised sport/physical activity or active play), television viewing (watching television, video, DVD, movie) and computer usage (using a computer/computer games), was derived from TUDs. At each wave, the parent deemed most knowledgeable about the child (normally the child's mother) completed two TUDs; one encompassed a 24-h period on a weekday, the other a 24-h period on a weekend day. The TUDs were split into 15-min intervals, with each the parent instructed to indicate what each child was doing in each period by selecting from a list of 26 different activities.

Sleep duration, television viewing, computer usage and physical activity were calculated by summing each 15-min period the child was engaged in the relevant activity over each 24-h period. Weekday and weekend values were combined to provide an average weekly value using the following formula: weekly average = [(weekday hours $\times$ 5) + (weekend hours $\times$ 2)] $\div$ 7.

Covariates

This study included child gender, child sleep problems, household income, maternal education, and maternal weight status as covariates. A binary indicator of child sleep problems was derived from several questions asking parents to indicate whether the child had any problems sleeping (e.g. difficulty falling asleep, waking during the night). Parents were also asked to indicate their weekly household income, which was standardised according to the number of people residing in the household and split into quartiles. Maternal education was based on questions relating to the highest level of education completed. Responses were categorised as 'some high school', 'completed year 12 (final year of high school)' and 'tertiary qualification' (e.g. university degree and trade certificate). Mothers also self-reported their height and weight; this information was used to create four categories of body weight status: underweight (BMI < 18.5 kg/m^2), healthy (BMI 18.5–24.9 kg/m^2), overweight (BMI 25–29.9 kg/m^2) and obese (BMI $\geq$ 30 kg/m^2).

Statistical analysis

Cross-lagged panel modelling was first used to examine the bidirectional relationship between sleep duration and BMI, controlling for child gender, child sleep problems, maternal weight status, maternal education and household income. The analyses were performed using M*plus,* version 6.11 (22), with the multiple group function used to test whether the relationships varied by the covariates. This involved constraining all paths to be equal between the categories of the covariate (e.g. constrained to be equal for boys and girls). The model was then retested with one path unconstrained, and a chi-square difference statistic was computed to compare whether the two models differed significantly. A significant difference indicated that the paths varied significantly between boys and girls (for example). This approach was repeated for all covariates.

Lagged panel mediation modelling was then used to examine the longitudinal relationship between sleep duration, physical activity/screen time and BMI (23,24). This involved modelling sleep duration at 4 years of age as the independent variable, physical activity/screen time at 6 years of age as potential mediators, with BMI at 8 years of age as the dependent variable (see Fig. 1). This model controlled for all covariates listed above, with the significance of each indirect effect determined using bootstrapping with 5000 resamples.

RESULTS

The final sample consisted of 2984 children aged 4 years at baseline; 52.4% were male, and the majority were Australian born (n = 2859; 95.8%). The characteristics of the sample are shown in Table 1, which includes a comparison between the final sample and those excluded due to missing TUD data. Excluded participants were significantly more likely to be female and have a sleep problem, be mothers with a lower education level, and have lower household income.

Cross-lagged relationship between sleep duration and BMI

The cross-lagged model results indicated a significant inverse association between sleep duration at 4 years of age and BMI at 8 years of age ($\beta = -.07$, p = .044). This association varied significantly by household income (χ^2 for difference = 5.25, p = .022) and maternal obesity (χ^2 for difference = 5.36, p = .020), but not by gender, sleep problems or maternal education. Inspection of these effects indicated that the association between sleep duration at 4 years of age and BMI at 8 years of age was significant in the second highest income category ($\beta = -.17$, p = .009) and where mothers were underweight ($\beta = -.25$, p = .010).

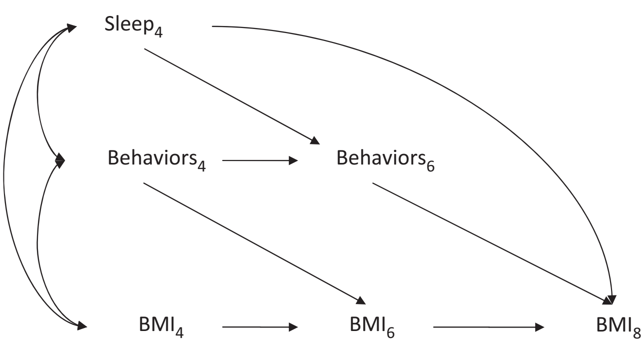

Figure 1 Lagged panel mediation model linking sleep duration at age 4–5 years to body mass index at age 8–9 years. Separate indirect effects were tested for physical activity, television viewing, and computer use. The following variables were included as covariates: child gender, child sleep problems, household income, maternal education, and maternal weight status.

Table 1 Demographic characteristics of the current sample at baseline (age 4–5 years) compared with those excluded due to missing data

	Included in final sample (n = 2984)	Excluded due to missing data (n = 1999)	p value*
Gender, n (%)			
Male	1563 (52.4)	974 (48.7)	.011
Female	1421 (47.6)	1025 (51.3)	
Child sleep problems, n (%)			
Yes	1483 (49.7)	1099 (55.0)	<.001
No	1500 (50.3)	898 (45.0)	
Child BMI, M (SD)	16.31 (1.66)	16.38 (1.82)	.139
Sleep Duration, M (SD)	11.03 (1.11)	–	–
Television viewing, M (SD)	2.01 (1.36)	–	–
Computer usage, M (SD)	0.25 (0.47)	–	–
Physical activity, M (SD)	1.27 (1.21)	–	–
Household income, n (%)			
Quartile 1	773 (25.9)	800 (40.0)	<.001
Quartile 2	703 (23.6)	445 (22.3)	
Quartile 3	745 (25.0)	384 (19.2)	
Quartile 4	763 (25.6)	370 (18.5)	
Maternal Weight Status, n (%)			
Underweight	290 (10.6)	114 (10.2)	.458
Healthy weight	1306 (47.8)	512 (45.6)	
Overweight	690 (25.3)	296 (26.4)	
Obese	445 (16.3)	201 (17.9)	
Maternal Education, n (%)			
<high school	545 (18.3)	546 (27.3)	<.001
Completed high school	1887 (63.2)	1015 (50.8)	
Tertiary qualification	552 (18.5)	438 (21.9)	

*p values are derived from χ^2 (for categorical variables) and *t*-tests (for continuous variables).
–, differences not computed due to missing data.

In the total sample, BMI at 4 years of age was not significantly associated with sleep duration at 8 years of age; this was consistent across gender and maternal weight status. However, there was evidence of a significant association in those with sleep problems (χ^2 for difference = 5.41, p = .020; $\beta = -.05$, p = .032), in the second lowest income category (χ^2 for difference = 9.60, p = .002; $\beta = -.08$, p = .042) and the lowest maternal education group (χ^2 for difference = 6.26, p = .012; $\beta = -.10$, p = .012).

Lagged mediation model

Table 2 shows the results of the mediation model. This indicated that sleep duration at 4 years of age was inversely associated with television viewing ($\beta = -.07$, p = .003) and

Table 2 Results of the lagged panel mediation model linking sleep duration to BMI. Results are presented as unstandardised β coefficients with 95% confidence intervals (subscript numerals indicate child age)

	Unstandardised β	95% confidence interval
a paths		
$Sleep_4 \rightarrow television_6$	−.07*	−.12, −.02
$Sleep_4 \rightarrow computer_6$	−.04*	−.06, −.02
$Sleep_4 \rightarrow$ physical $activity_6$	−.02	−.09, .03
b paths		
$Television_6 \rightarrow BMI_8$	.13*	.05, .22
$Computer_6 \rightarrow BMI_8$	.06	−.11, .24
Physical $activity_6 \rightarrow BMI_8$	−.05	−.11, .02
Indirect effects		
$Sleep_4 \rightarrow Television_6 \rightarrow BMI_8$	−.009*	−.020, −.002
$Sleep_4 \rightarrow Computer_6 \rightarrow BMI_8$	−.002	−.010, .004
$Sleep_4 \rightarrow$ Physical $activity_6 \rightarrow BMI_8$	.001	−.001, .007

*p < .05.

computer use ($\beta = -.04$, p = .001) at 6 years of age, but not physical activity. Television viewing at 6 years of age was significantly associated with BMI at 8 years of age ($\beta = .13$, p = .003). The significant association between sleep duration at 4 years of age and BMI at 8 years of age ($\beta = -.07$, p = .044) attenuated slightly and was not significant in the presence of the mediators ($\beta = -.06$, p = .076). Inspection of the indirect paths indicated that increased television viewing at 6 years of age significantly mediated the longitudinal relationship between shorter sleep durations and increased BMI ($\beta = -.01$, 95% CI [−.02, −.002]). Neither of the other two indirect paths was significant.

DISCUSSION

Sleep duration was inversely associated with BMI at follow-up, which is consistent with several recent prospective studies (2–6). This relationship did not differ significantly by gender, maternal education or sleep problems, although there were some differences by maternal body weight and household income. Interestingly, BMI did not predict subsequent sleep duration in the total sample. However, BMI did predict shorter sleep duration in children with sleep problems. Because higher BMI is associated with health conditions and sleep disorders (e.g. obstructive sleep apnoea, insomnia and asthma) it could contribute to shorter sleep duration in some children (25), which may explain the present results. A significant inverse association between BMI and subsequent sleep duration was also observed where household income and maternal education was lower. This suggests that BMI may influence sleep duration in children from lower socioeconomic backgrounds.

The second aim of this study was to investigate potential behavioural pathways underlying the longitudinal relationship between sleep duration and BMI in children. Although numerous mechanisms (8–12) may underlie this link (e.g. altered hormonal regulation of energy balance, altered thermoregulation and less healthy eating habits), this study focused specifically on physical activity and screen time. Higher television viewing partially mediated the relationship between short sleep duration and higher BMI in children. This can be understood in the context of daytime sleepiness and fatigue, which are consequences of reduced night-time sleep (26). Sleepiness may reduce vigour and motivation to engage in active play and increase the likelihood of sedentary behaviours such as television viewing (10,16–18). This could promote obesity via reduced energy expenditure and potentially less healthy eating habits (12,27). This novel finding adds to previous research examining other potential physiological and behaviour pathways underlying this relationship.

Physical activity and computer usage did not mediate the relationship between sleep duration and BMI. This may reflect methodological issues, because the measures of physical activity and computer usage may have lacked sensitivity. For instance, physical activity levels were assessed according to parental reports of the amount of time spent engaged in active play, riding a bike or walking. This may not have adequately captured other forms of incidental physical activity (e.g. school playground activity), which is important given that children tend to engage in short periods of physical activity (28). Furthermore, we were unable to distinguish between different forms of computer use (e.g. using the internet, social media), which is important because the ways in which children are engaging with these forms of technology are changing rapidly (29). For instance, the increasing use of tablet devices, electronic gaming and social media could influence sleep duration and obesity (19), and need to be addressed further in this context.

Key strengths of this study include the rigorous analytic approach, the relatively large sample of children across three time points, and objective measurements of BMI. The results therefore provide a good indication of the temporal associations between the variables assessed in this study. However, as with many studies investigating the associations between sleep and obesity (12), there are several methodological issues that need to be addressed. One key issue is that although BMI was measured objectively, sleep duration, television viewing, computer usage, and physical activity were assessed using TUDs completed by parents. TUDs are widely used in large cohort studies and generally provide a good indication of the amount of time spent in these behaviours (29,30). However, they are less accurate compared with objective measures such as actigraphs. For example, TUDs can lead to overestimates of child sleep duration, because although parents are generally accurate in estimating bedtimes and waketimes, they may not be aware whether their child wakes up during the night (30). This could be an important methodological issue and bias the results if the nature of the overestimation varies systematically by factors such as socioeconomic status. Therefore, future research using more objective measures of sleep and child behaviour (e.g. actigraphs) is needed to further delineate the mechanisms linking sleep duration to measures of body composition.

A final consideration is that the ways in which short sleep is associated with obesity are likely to be complex, multi-directional and involve numerous behavioural and physiological processes (7–12). This study focused on three potential pathways involving physical activity, television viewing and computer usage and provided a novel insight into this association. However, further longitudinal research is required to better elucidate and explore other mechanisms underlying the relationship between sleep duration and obesity.

In conclusion, this study provides an important and novel extension of the literature by (i) examining whether there is a bidirectional association between sleep and obesity in children; and (ii) clarifying potential pathways linking sleep with obesity. This study adds support to existing research by finding that short sleep could be a contributing factor to obesity in children (but not vice versa), with increased television viewing identified as a potential mechanism linking short sleep with obesity.

ACKNOWLEDGEMENTS

This paper used unit record data from Growing Up in Australia, the Longitudinal Study of Australian Children (LSAC). The LSAC is conducted in partnership between the Department of Families, Housing, Community Services and Indigenous Affairs (FaHCSIA), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the author and should not be attributed to FaHCSIA, AIFS or the ABS.

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