


Sleep and body mass index in infancy and early childhood (6-36 mo): a longitudinal study

Lu Wang¹  | Wilma Jansen^{1,2} | Magda M. Boere-Boonekamp³ | Eline Vlasblom⁴ | Monique P. L'Hoir⁵ | Maaïke Beltman⁴ | Amy van Grieken¹ | Hein Raat¹

¹Department of Public Health, Erasmus University Medical Center, Rotterdam, The Netherlands

²Department of youth and education, City of Rotterdam, Rotterdam, The Netherlands

³Department Health Technology and Services Research, Technical Medical Centre, University of Twente, Enschede, the Netherlands

⁴TNO Child Health, Leiden, The Netherlands

⁵Department of Agrotechnology and Food Sciences, Subdivision Human Nutrition, Wageningen University and Research, Wageningen, The Netherlands

Correspondence

Hein Raat, Erasmus University Medical Center, Department of Public Health, PO Box 2040, 3000 CA, Rotterdam, The Netherlands.
E-mail: h.raat@erasmusmc.nl

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Summary

Background: Relatively, few longitudinal studies have evaluated the association between sleep and body mass index (BMI) among younger children. In addition, few studies have evaluated the bidirectional longitudinal association between sleep duration and child BMI.

Objective: The objective of the study is to determine in children aged 6 to 36 months (1) the cross-sectional association of sleep duration and sleep problems with child BMI z score, (2) whether sleep duration predicts changes in child BMI z score, and (3) and whether BMI z score can predict changes in child sleep duration.

Methods: This study used longitudinal data from the BeeBOFT study (N = 2308). Child sleep duration and sleep problems (indicated by night awakenings and sleep-onset latency) were parent reported, and child BMI was measured using a standardized protocol by trained healthcare professionals at approximately 6, 14, and 36 months of age. Linear mixed models and linear regression models were applied to assess the cross-sectional and bidirectional longitudinal associations between sleep and BMI z scores.

Results: Cross sectionally, shorter sleep duration was associated with higher BMI z scores at 14 ($\beta = -0.034$, $P < 0.05$) and 36 months ($\beta = -0.045$, $P < 0.05$). Sleep duration at 6 or 14 months did not predict BMI z score at either 14 or 36 months. Higher BMI z scores at 6 months predicted shorter sleep duration (hours) at 14 months ($\beta = -0.129$, $P < 0.001$). No association was found between sleep problems and child BMI z scores.

Conclusions: Cross-sectional associations between shorter sleep duration and higher BMI z score emerged in early childhood (age 14 and 36 mo). Higher BMI z scores may precede shorter sleep duration but not vice versa.

KEYWORDS

bidirectional association, child BMI, longitudinal study, sleep duration

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1 | BACKGROUND

There is an increasing evidence that shorter sleep duration is associated with increased risk of overweight among children.¹⁻⁵ However, the available evidence is largely from school-aged children and adolescents. Only a few studies have investigated the relationship between sleep duration and body mass index (BMI) standardized for age and sex (BMI z score) during infancy and early childhood (0-4 y); the findings are mixed.⁶⁻¹¹ For instance, in a longitudinal study of 915 children from the United States, Taveras et al found that a sleep duration of less than 12 hours during infancy (6-24 mo) was associated with higher BMI z score at 3 years.⁶ In contrast, in prospective cohort study of 3857 children from Australia, Hiscock et al reported no associations between sleep duration at 0 to 1 year and BMI z score measured at 2 to 3 years.⁷ In a cohort of 311 children from Denmark, Klingenberg et al found no longitudinal association between sleep duration at 9 and 18 months (parent reported as well as objectively measured) and BMI z score at 3 years.⁸ Furthermore, recent studies have found indications that beyond sleep duration, sleep problems (eg, excessive night awakenings and sleep-onset difficulties) might contribute to increased risk of overweight in children.¹²⁻¹⁴ Few studies have evaluated the association between both sleep duration and sleep problems with BMI z score in infancy and early childhood. Given that infancy and early childhood are a critical period for the development of overweight,¹⁵ further research is warranted to confirm whether sleep duration and sleep problems constitute modifiable risk factors for weight gain in infancy and early childhood.

In addition, a few recent studies have pointed out a potential bidirectional association between shorter sleep duration and higher BMI z score in young children.^{10,11} Therefore, overweight might precede shorter sleep duration and vice versa. Inadequate sleep is associated with poorer cognitive, physical, and socioemotional development.¹⁶ As there has been an increasing trend of insufficient sleep duration and sleep problems among children¹⁷ and short sleep duration and sleep problems in infancy and early childhood may persist to later ages,¹⁸ research is needed to investigate whether overweight contributes to shorter sleep duration and sleep problems in infancy and early childhood.

The present study, with the availability of repeated measured data on sleep duration, sleep problems, and BMI z score across age 6 to 36 months in a large population-based sample of children from The Netherlands, will add further evidence to elucidate the relationship between sleep and BMI z score in younger children. We examined the cross-sectional associations of sleep duration and sleep problems (ie, frequent night awakenings and longer sleep-onset latency) with BMI z score during infancy and early childhood. In addition, we examined whether bidirectional longitudinal association existed between sleep duration and BMI z score, ie, whether shorter sleep duration predicts higher BMI z score at a later age or higher BMI z score predicts shorter sleep duration at a later age. We hypothesized that both sleep duration and sleep problems are cross sectionally associated with BMI z score and that bidirectional longitudinal association exists between sleep duration and BMI z score during infancy and early childhood (age 6-36 mo).

2 | METHODS

2.1 | Study design and population

This study is a secondary data analysis using data from the "BeeBOFT" study, which is a population-based-cluster randomized controlled trial for the primary prevention of overweight among infants and toddlers (0-3 y) conducted in The Netherlands.^{19,20} The study participants were randomly allocated to one of the two intervention conditions, ie, the "BBOFT+" intervention and the "E-health4Uth" intervention or the control condition. Both interventions were targeted on parents and aimed at promoting health behaviours of children (ie, breastfeeding, daily exercise/outdoor playing, daily breakfast, fewer sweet drinks, and less TV viewing). The "BBOFT+" intervention also aimed to improve children's sleep behaviours in addition to the above health behaviours. In the "BBOFT+" intervention group, parents received advice on child rearing skills to promote children's health behaviours at each Youth Health Care routine visit (scheduled at child age 0.5, 1, 2, 3, 4, 6, 9, 11, 14, 18, 24, and 36 mo). In the "E-health4Uth" intervention group, parents received tailored advice on children's health behaviours after they finished an online survey at child age 18 and 24 months, respectively. In the control condition, children received preventive youth healthcare as usual. The Medical Ethics Committee of the Erasmus Medical Centre has reviewed the research proposal of the BeeBOFT study and concluded that the Dutch Medical Research Involving Human Subjects Act (in Dutch: Wet medisch-wetenschappelijk onderzoek met mensen) did not apply to this research proposal. The Medical Ethics Committee therefore had no objection to the execution of this study (proposal number MEC-2008-250).

From January 2009 through September 2010, parents were informed about the BeeBOFT intervention study when the Youth Health Care nurse visited them in the second week after childbirth. Parents were also invited to fill in a written informed consent form to participate in the 3-year study and a baseline questionnaire regarding social demographic characteristics and perinatal factors. In total, parents of 3003 children returned the written informed consent to participation and the baseline questionnaire. At child age 6, 14, and 36 months, the parents were invited to complete the questionnaires on children's health behaviours and determinants of these behaviours. Children' weight and height were measured at each Youth Health Care routine visit scheduled at child age 0.5, 1, 2, 3, 4, 6, 9, 11, 14, 18, 24, and 36 months repeatedly. Children with missing information on BMI or sleep duration at all three time points (ie, age 6, 14, and 36 mo) were excluded (n = 695). Finally, 2308 subjects were included in the study.

3 | MEASUREMENTS

3.1 | Sleep-related variables

Children's sleep characteristics were assessed by parental questionnaire at child age circa 6, 14, and 36 months. The exact ages of the children at the three measurement waves were 6.34 (standard deviation [SD] = 0.61), 14.25 (SD = 1.06), and 37.44 (SD = 1.54), respectively. At all three time points, the respondents were asked to report

children's average sleep duration, number of night awakenings, and sleep-onset latency during the past 4 weeks. For sleep duration, parents were asked to report the average number of hours their child slept between 6:00 PM and 8:00 AM and between 8:00 AM and 6:00 PM. These data were added to get total average sleep duration in a 24-hour period. For number of night awakenings, parents were asked to report how often their child woke up during the night on average (answering categories are zero, one, two, three, four, and five times or more times per night). For sleep-onset latency, parents reported on how long it took the child to fall asleep on average (answering categories are <10 min, 10-30 min, 30 min-1 h, 1-2 h, and more than 2 h). Sleep-onset latency in the questionnaire refers to both night-time and daytime sleep. We defined sleep problems as the presence of night awakenings more than or equal to three times per night or sleep-onset latency more than 30 minutes in our main analysis.²¹⁻²³

3.2 | Child anthropometrics

Data on weight and height of the participating children were acquired from the Youth Health Care registration files. Children's height and weight were measured in accordance with standardized protocols at each Youth Health Care routine visit (set at child age 0.5, 1, 2, 3, 4, 6, 9, 11, 14, 18, 24, and 36 mo) by trained Youth Health Care professionals.²⁴ Children's height and weight were measured without clothes (at 36 mo, only with underwear), using the calibrated weight scales and length meters; height was measured to the nearest 0.1 cm, and weight was measured to the nearest 0.01 (infants) and 0.1 kg (toddlers). Children's BMI was calculated by the weight in kilograms divided by squared body length in meters. Age- and gender-adjusted BMI z scores were calculated using the World Health Organization Growth Standard (2006).²⁵ For analysis of the present study, we only used children's BMI z scores measured at age circa 6, 14, and 36 months. As children's BMI z scores were not always measured at the exact time points, we interpolated children's BMI z scores at 6, 14, and 36 months by the nearest BMI z score measured within the age range of, respectively, 4 to 8, 12 to 16, and 33 to 45 months. The average exact ages of the children at BMI measurement were 6.13 (SD = 0.48), 14.23 (SD = 0.50), and 36.44 (SD = 0.83) months, respectively, for the three measurement waves.

3.3 | Covariates

Potential confounding factors were chosen based on the biological plausibility and previous evidence linking them with BMI^{26,27} and sleep duration^{28,29} in early childhood, including maternal age, maternal educational level, maternal prepregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time, and intervention groups. The following characteristics were assessed by the baseline questionnaire: maternal age, maternal educational level, and maternal prepregnancy BMI, and parity and child gender, child ethnic background, and child gestational age. The highest attained educational level of mother was categorized as high (higher vocational training, university degree, or higher), middle (>4-y general secondary school or intermediate

vocational training), and low (no education, primary school, or 4 y or less general secondary school).³⁰ Mothers reported their prepregnancy body weight and height in the baseline questionnaire, which was used to calculate maternal prepregnancy BMI. The child's ethnic background was defined as Dutch if both of his/her parents were classified as Dutch; a parent was classified as Dutch if both of his/her own parents were born in The Netherlands.²⁴ Child's birthweight (in grams) and date of birth were acquired from Youth Health Care registration files. The expected due date was reported in the baseline questionnaire, using which we calculated the date of conception (based on 280 d of pregnancy). Gestational age in days was then calculated using the calculated date of conception and date of birth of the child. The duration of breastfeeding was assessed in the questionnaire at 6 months (detailed information is shown in Table S1). In addition, the "intervention group" was considered as a potential confounding factor, as both the two intervention groups received interventions on children's lifestyle behaviours and the "BeeBOFT" group received additional interventions on children's sleep.¹⁹ Finally, at all three time points, parents reported the average number of hours their child spent on watching TV/video/DVD (and computer use at 36 mo) per day (detailed information is shown in Table S1).

4 | STATISTICAL ANALYSES

4.1 | Cross-sectional analyses

We applied linear regression models to assess the cross-sectional associations of sleep duration and sleep problems with BMI z score at 6, 14, and 36 months, respectively. The models were adjusted for the exact age at sleep measurement and the exact age at BMI measurement, maternal age, maternal educational level, maternal prepregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time, and intervention groups.

Linear mixed models were fitted to assess the overall cross-sectional association of sleep duration and sleep problems with BMI z score across the age of 6, 14, and 36 months, using the repeated measured sleep variables and BMI z score at all three measurement waves. Using a linear mixed model, we were able to take into account the interdependency between observations of the same child. The models were adjusted for age at measurement (6, 14, or 36 mo), maternal age, maternal educational level, maternal prepregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time, and intervention groups. The interaction terms of age at measurement with sleep variables (duration, problems) were then added to the models to determine whether the association between sleep duration/sleep problems and BMI z score differed by age. In addition, to determine whether the associations of sleep duration and sleep problems with BMI z score differed by child gender,¹² ethnic background,¹¹ intervention groups, and maternal educational level, the interaction terms of these variables with sleep duration or sleep problems were added to the linear mixed models. The interaction term was considered as significant³¹ at $P < 0.10$. The results (additional files, Table S2) suggested that only

the interaction term of sleep duration with ethnic background was significant ($P < 0.001$). Stratified analysis was further performed for the association between sleep duration and BMI according to ethnic background (results for stratified analyses are shown in additional file, Table S3).

4.2 | Longitudinal analyses

Linear regression models were applied to determine whether a bidirectional longitudinal association exists between sleep duration and BMI z score. We used sleep duration at earlier age points to predict BMI z score at later age points (ie, 6-min sleep \rightarrow 14-mo BMI z score, 6-min sleep \rightarrow 36-mo BMI z score, and 14-min sleep \rightarrow 36-mo BMI z score) and then BMI z score at earlier age points to predict sleep duration at later age points (ie, 6-mo BMI z score \rightarrow 14-min sleep, 6-mo BMI z score \rightarrow 36-min sleep, and 14-mo BMI z score \rightarrow 36-min sleep). The models were progressively adjusted for the potential confounding factors including the exact ages at sleep measurement and at BMI measurement, maternal age, maternal educational level, maternal prepregnancy BMI, and parity, and child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time at baseline, intervention groups (model 1), and BMI z score or sleep duration at baseline (model 2). Finally, the interaction terms of child ethnic background and sleep duration/BMI z score were added to the above models to determine whether the potential differences in the longitudinal associations between sleep and BMI differ by child ethnic background.

4.3 | Sensitivity analysis

For sleep problems, we repeated our cross-sectional analyses using different cut-offs of night awakenings (≥ 2 night awakenings vs < 2 awakenings) and sleep-onset latency (> 1 vs < 1 h) in the linear regression models. The results are presented in Table S4.

5 | RESULTS

5.1 | Study population

Table 1 provides a summary of the characteristics of the study population. As age increased, children's sleep duration ($P < 0.001$) and number of night awakenings per night ($P < 0.001$) decreased, while the percentages of children with sleep-onset latency more than 30 minutes increased ($P < 0.001$).

5.2 | Cross-sectional association

The results of the linear regression models for the cross-sectional association of sleep duration and sleep problems with BMI z score at child age circa 6, 14, and 36 months, respectively, (Table 2) showed that sleep duration was inversely associated with BMI z score at 14 ($\beta = -0.034$, $P = 0.03$) and 36 months ($\beta = -0.045$, $P = 0.03$), after adjusting for potential confounding factors. No significant association was found between sleep problems and BMI z score at any ages.

The results of the linear mixed models (Table 3) showed that sleep duration was negatively associated with BMI z score across 6 to

TABLE 1 Characteristics of the study sample (N = 2308)

	N	N (%) or Mean \pm SD
Child gender, boys, n (%)	2308	1185 (51.3)
Child ethnic background, Dutch, n (%)	2308	1933 (83.8)
Child birth weight, kg	2308	3.47 \pm 0.53
Child gestational age, wk	2283	39.66 \pm 1.36
Maternal age, y	2284	31.04 \pm 4.22
Maternal prepregnancy BMI, kg/m ²	2295	24.19 \pm 4.10
Maternal education level, n (%)	2290	
Low		274 (12.0)
Middle		802 (35.0)
High		1214 (53.0)
Parity, primipara, n (%)	2308	1065 (46.1)
Duration of breastfeeding, n (%)	2308	
No breastfeeding		617 (26.7)
Breastfeeding < 2 mo		400 (17.3)
Breastfeeding 2-4 mo		290 (12.6)
Breastfeeding > 4 mo		867 (37.8)
Missing		134 (5.8)
Sleep duration, h/d		
At age 6 mo	1870	14.89 \pm 1.59
At age 14 mo	1781	14.15 \pm 1.36
At age 36 mo	1270	11.97 \pm 1.24
Number of night awakenings, times/d		
At age 6 mo	1870	1.04 \pm 0.99
At age 14 mo	1781	0.85 \pm 0.91
At age 36 mo	1270	0.69 \pm 0.81
Sleep onset latency > 30 min, n (%)		
At age 6 mo	1870	50 (2.6)
At age 14 mo	1781	64 (3.6)
At age 36 mo	1270	117 (9.9)

Abbreviation: BMI, body mass index.

36 months (overall effect, $\beta = -0.023$, $P = 0.01$), after adjusting for potential confounding factors. The interaction term of sleep duration and age (6, 14, or 36 mo) suggested that the cross-sectional association of sleep duration with BMI z score differed by age, with the strength of association between sleep duration and BMI z score at age 6 months lower compared with age 36 months ($P < 0.10$).

Interaction analyses (shown in additional file, Table S2) suggested that the association between sleep duration and BMI z score differs by child ethnic background ($P < 0.001$). Stratified analysis (shown in additional file, Table S3) showed that the cross-sectional association between sleep duration and BMI z score was stronger among children with a Dutch ethnic background (overall effect, $\beta = -0.033$, $P = 0.001$). There was no significant association between sleep duration and BMI z score in children with non-Dutch ethnic background (overall effect, $\beta = 0.021$, $P = 0.34$).

5.3 | Longitudinal association

Table 4 shows the results of the linear regression models examining the bidirectional longitudinal association between sleep duration and

TABLE 2 Results from linear regression models for the cross-sectional association between sleep (independent variable) and child BMI z score (dependent variable) at age 6, 14, and 36 months, respectively

Predictors	6 mo (n = 1816)		14 mo (n = 1741)		36 mo (n = 1240)	
	β (SE)	P Value	β (SE)	P Value	β (SE)	P Value
Total sleep duration (continuous)						
Model 1	-0.004 (0.014)	0.79	-0.035 (0.015)	0.02	-0.047 (0.021)	0.03
Model 2	-0.003 (0.014)	0.83	-0.034 (0.015)	0.03	-0.045 (0.021)	0.03
Sleep problems (yes vs no) ^a						
Model 1	0.104 (0.064)	0.11	-0.025 (0.050)	0.62	0.006 (0.065)	0.93
Model 2	0.099 (0.064)	0.12	-0.030 (0.050)	0.55	0.008 (0.065)	0.90
Separate items of sleep problems						
Night awakenings (≥ 3 vs < 3 times)						
Model 1	0.079 (0.068)	0.25	-0.042 (0.078)	0.59	-0.022 (0.133)	0.87
Model 2	0.075 (0.068)	0.27	-0.048 (0.079)	0.54	0.001 (0.134)	0.99
Sleep-onset latency (> 30 vs < 30 min)						
Model 1	0.271 (0.138)	0.05	-0.072 (0.112)	0.52	0.062 (0.092)	0.50
Model 2	0.268 (0.138)	0.06	-0.085 (0.112)	0.45	0.058 (0.093)	0.53

Abbreviation: BMI, body mass index. Numbers in bold are significant at $P < 0.05$. All the models were adjusted for exact age of the child at sleep measurement, exact age of the child at BMI measurement, maternal age, maternal educational level, maternal prepregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, and duration of breastfeeding, and intervention groups; Model 2 further adjusted for child screen time.

^aSleep problem is defined as the presence of night waking more than or equal to 3 per night or sleep latency more than 30 minutes.

BMI z score. The results revealed that sleep duration at 6 or 14 months did not significantly predict changes in BMI z score at 14 or 36 months. Higher BMI z score at 6 months was significantly associated with shorter sleep duration at 14 months ($\beta = -0.132$, $P < 0.001$), after adjusting for potential confounding factors, and baseline sleep duration. Interaction analyses showed no significant ethnic differences in all these above longitudinal associations (all, $P > 0.20$).

5.4 | Sensitivity analysis

Sensitivity analysis (shown in additional file, Table S4) suggested that sleep problems were not cross sectionally associated with BMI z score when applying different cut-off values for frequency of night awakenings and sleep latency for defining sleep problems.

6 | DISCUSSION

Overall, our study findings demonstrate that a negative cross-sectional association between sleep duration and BMI z score already occurred during early childhood (ie, age 14 and 36 mo). Prospectively, shorter sleep duration at the age of 6 or 14 months did not predict BMI z score at later ages (ie, at 14 and 36 mo). A higher BMI z score at the age of 6 months did predict shorter sleep duration at the age of 14 months after adjusting for baseline sleep. We did not find significant cross-sectional or longitudinal associations between sleep problems and child BMI z score.

Our results suggest that there were modest cross-sectional associations between shorter sleep duration and higher BMI z-score at child age 14 and 36 months but not at 6 months. The magnitude of the associations was modest (eg, the BMI z score was 0.045 higher per 1-h longer sleep duration at the age of 36 mo) and is comparable with a few previous studies.^{10,32} Although the effect size we found might not be

clinically significant, any potential influences on adiposity levels in early life may be important given that adiposity levels may persist into later life. It has been proposed that the association between short sleep duration and increased BMI could be mediated or confounded by increased energy intake,^{33,34} increased television viewing,³⁵ and decreased physical activities in children.³⁵ However, in the present study, the cross-sectional association between sleep duration and BMI z score was not attenuated after adjusting for TV viewing hours. A previous study, which assessed the cross-sectional association between sleep duration and BMI z score, also suggests that the association was not attenuated after adjusting for TV viewing and dietary factors.¹¹

Our interaction analysis and stratified analysis suggested that the cross-sectional association between sleep duration and BMI z score only existed among children with a Dutch ethnic background. This result is in contrast with a previous study conducted in the United Kingdom in which a significant association was found in a South Asian population and not in Caucasian children.¹¹ It is possible that the lack of association in the non-Dutch group is because of the mixed ethnic background of this group. Sleep duration may cluster differently with obesogenic factors among children with different ethnic backgrounds.

We did not find a longitudinal association between sleep at 6 or 14 months and BMI z score at the age of 14 or 36 months. Therefore, our results do not support a causal relationship between shorter sleep duration and weight gain in infancy and early childhood. The observed cross-sectional association between sleep duration and child BMI in the present study could be a result of residual confounding factors. For example, lack of parental vigilance or sensitivity, which were not measured in our study, might be associated with both inadequate sleep and increased BMI of children.³⁶⁻³⁸ Two other previous studies also did not find longitudinal associations between sleep duration and BMI among children aged 3 years and younger: Klingenberg et al found no association between sleep duration at 9 and 18 months and BMI at 3 years among 313 Danish children⁸; Hiscock et al found no association

TABLE 3 Results from linear mixed models for the overall cross-sectional associations between sleep (independent variable) and child BMI z score (dependent variable) across the age of 6 to 36 months (n = 2257)

Predictor	β	SE	P Value
Sleep duration (h/d)			
Model 1			
Overall effect 6 to 36 months	-0.023	0.009	0.01
Model 2			
Effect on 36 months	-0.046	0.021	0.02
Interaction term with age			
6 vs 36 months	0.043	0.024	0.08
14 vs 36 months	0.010	0.026	0.71
Sleep problems (yes vs no) ^a			
Model 1			
Overall effect 6 to 36 months	0.015	0.033	0.66
Model 2			
Effect on 36 m	-0.018	0.061	0.77
Interaction term with age			
6 vs 36 months	0.114	0.086	0.19
14 vs 36 months	0.009	0.079	0.91
Separate items of sleep problems			
Night awakenings (≥ 3 vs < 3 times)			
Model 1			
Overall effect 6 to 36 months	0.019	0.047	0.69
Model 2			
Effect 36 months	-0.093	0.122	0.44
Interaction term with age			
6 vs 36 months	0.173	0.139	0.21
14 vs 36 months	0.090	0.146	0.63
Sleep-onset latency (> 30 vs < 30 min)			
Model 1			
Overall effect 6 to 36 months	0.073	0.061	0.24
Model 2			
Effect 36 months	0.060	0.087	0.49
Interaction term with age			
6 vs 36 months	0.227	0.157	0.15
14 vs 36 months	-0.101	0.142	0.48

Abbreviation: BMI, body mass index. Numbers printed in bold represent significance at $P < 0.05$. Model 1 adjusted for age at measurement (6/14/36 mo), maternal age, maternal educational level, maternal prepregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time, and intervention groups. Model 2 further included the interaction term of age (36 mo as reference) and sleep indicators on the basis of model 1.

^aSleep problems is defined as the presence of night awakenings more than or equal to 3 per night or sleep onset latency more than 30 minutes.

between sleep duration at 0 to 1 year and BMI at 2 to 3 years among 3857 Australian children.⁷ However, in contrast, Taveras et al found that sleep duration of less than 12 h/d in the first 2 years of life was associated with higher adiposity level at age 3 years among 915 US children.⁶ Compared with the study of Taveras et al,⁶ children in our study population and in the study of Klingenberg et al and Hiscock et al have a relatively long average sleep durations per day (ie, 14.9 [SD = 1.6] hours/day at age 6 months in the present study, 13.8 [SD = 1.0] hours/day at age 9 months in the study of Klingenberg et al, and 13.4 [SD = 1.9] hours/day between 0 and 1 year in the study of Hiscock et al, compared with 12.3 [SD = 1.9] hours/day at age 6 months in the study of Taveras et al). Therefore, the lack of a longitudinal association between sleep duration and child BMI could be because of a longer

total sleep duration of children in our population. Sleep duration might have minimal effect on child's weight development when the child gets longer sleep. Another possible explanation for the lack of a longitudinal association is a low intraindividual stability of sleep duration in early childhood,³⁹ which may have reduced the predictive value of sleep duration. Variability in sleep duration might be induced by, for instance, developmental spurts, illnesses or seasonal effects, and changes in parental rearing attitudes.³⁹

We found some evidence that higher BMI z score may precede shorter sleep duration: that higher BMI z score at age 6 months significantly predicted shorter sleep duration at age 14 months, after adjusting for baseline sleep duration and BMI z score at 14 months. Our finding is in line with the study of Ivonne et al,¹⁰ in which a higher

TABLE 4 Results from linear regression models for the bidirectional longitudinal association between sleep duration and BMI z scores

Predictor	Outcome: BMI z Score, 14 mo			Outcome: BMI z Score, 36 mo		
	β	SE	P Value	β	SE	P Value
Sleep duration 6 mo, h/d	N = 1704			N = 1197		
Model 1	-0.007	0.013	0.59	0.001	0.017	0.96
Model 2	-0.005	0.010	0.63	0.000	0.015	1.00
Sleep duration, 14 mo	N = 1169			N = 1169		
Model 1	-0.019	0.020	0.34	-0.019	0.020	0.34
Model 2	-0.002	0.015	0.92	-0.002	0.015	0.92
Predictor	Outcome: Sleep Duration, 14 mo (h/d)			Outcome: Sleep Duration 36 mo (h/d)		
	β	SE	P Value	β	SE	P Value
BMI z score, 6 mo	N = 1549			N = 1405		
Model 1	-0.129	0.037	0.001	-0.016	0.035	0.65
Model 2	-0.132	0.034	<0.001	-0.007	0.034	0.85
Model 3	-0.149	0.048	0.003			
BMI z-score, 14 mo	N = 1385			N = 1385		
Model 1	-0.045	0.038	0.24	-0.045	0.038	0.24
Model 2	-0.026	0.036	0.48	-0.026	0.036	0.48

Abbreviation: BMI, body mass index. Numbers printed in bold represent significance at $P < 0.05$. Model 1 adjusted for exact age of the child at sleep measurement and exact age of the child at BMI measurement, maternal age, maternal educational level, maternal pre-pregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time at baseline, and intervention groups. Model 2 further adjusted for baseline BMI z scores/sleep duration. Model 3 further adjusted for current sleep duration/BMI when model 2 was significant.

BMI z score at the ages of 2 and 24 months predicted shorter sleep duration at the ages of 6 and 36 months, respectively. In the present study, there was no significant association between BMI z score at 6 or 14 months with sleep duration at 36 months. It is possible that BMI z score only has a short-term effect on sleep duration. The mechanism for the observed longitudinal association between higher BMI z score and shorter sleep duration is not clear. It is possible that children with higher BMI z score were less active⁴⁰ and therefore need less sleep.⁴¹ It has also been proposed that the association between higher BMI and curtailed sleep may be mediated by poorer general health and physiological disorders such as sleep apnoea.^{11,42,43} However, the observed longitudinal association could be a result of social or lifestyle factors that were not included as potential confounders. The models were adjusted for TV viewing time, but the residual confounding may be present with regard to other factors reflecting unhealthy lifestyles and behaviours (eg, unhealthy dietary intake or lack of healthy sleeping habits or early bedtime). Because of the limited number of studies, further research is warranted to confirm and to understand the mechanism for the longitudinal association between BMI and sleep duration.

Sleep problems, which were assessed by night awakenings and sleep-onset latency, have no significant association with child BMI z score. Arsham et al¹⁴ suggested that infant sleep problems have differential effect on childhood overweight at around 11 years per different definitions of sleep problems. However, because of different aspects of sleep behaviour assessed in the present study, comparison with the previous study¹⁴ is difficult. In the present study, we did not collect information on duration of the waking episodes. It is possible that night awakening contributes to overweight only when the waking episode is too long. Another possible reason for the null association between sleep problems and child BMI z score is the younger age group of our population. Two previous studies, which investigated

the association between frequent night awakenings with BMI z score in infants, also found no association.^{12,23}

Strengths of this study included the relatively large sample size, repeated assessments of sleep indicators and anthropometrics at 6, 14, and 36 months, and the careful assessment of potential confounding factors. Our data allowed us to assess the longitudinal association between sleep duration as well as sleep problems with child BMI z score. In addition, the reverse causality between BMI z score and sleep was assessed by using the BMI z score to predict later sleep duration.

A first limitation of our study is that children's sleep indicators, including sleep duration, number of night awakenings, and sleep-onset latency, were assessed by parent-reported questionnaire. It has been suggested that parents tend to overestimate children's sleep duration,^{44,45} while underestimate children's night awakenings and sleep-onset latency.⁴⁴ However, despite the potential bias, previous research also suggested that parent-reported sleep data are well correlated with objectively measured sleep data for preschool aged children, suggesting that parent-reported data are still useful.⁴⁴ In addition, parents may even provide a better representation of habitual sleep behaviour than a brief period of objective recording.⁴⁶ Secondly, due to the limitation of observational studies, a causal relationship cannot be inferred. Although we have assessed the potential confounding factors extensively, unobserved confounding factors may exist, such as nonresponsive parenting, which may contribute to both higher BMI z score and shorter sleep duration.³⁶⁻³⁸ Thirdly, we used data from a cluster randomized controlled trial with two interventions aimed at promoting healthy lifestyle behaviours of young children. However, we have adjusted intervention group as a covariate in all the analyses. In addition, the interaction analysis suggested that the association between sleep duration and BMI z score did not differ by intervention group (additional file, Table S2). Finally, our population is relatively highly educated, containing predominantly Caucasian

population. Therefore, generalization of our findings should be made carefully.

In conclusion, shorter sleep duration is associated with higher BMI z score at the age of 14 and 36 months. We found no evidence that shorter sleep duration predicts changes in BMI z score and some evidence that a higher BMI z score may predict a shorter sleep duration.

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H.R., M.M.B., and M.L.H. had the original idea for the study and its design and were responsible for acquiring the study grant. A.v.G. and E.V. were responsible for data collection and project coordination. L. W. did the data analysis, reported the results, and drafted the manuscript. W.J., A.v.G. and H.R. supervised the study. All authors (L.W., W.J., M.M.B., E.V., M.L.H., M.B., A.v.G., H.R.) were involved in writing the paper and had final approval of the submitted manuscript.

CONFLICTS OF INTEREST

No conflict of interest was declared.

ORCID

Lu Wang  <https://orcid.org/0000-0003-0245-7226>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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