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Sleep and physical growth in infants during the first 6 months

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SUMMARY The aim of this study was to explore the relationships between infant sleep patterns and infant physical growth (weight for length ratio) using both objective and subjective sleep measures. Ninety-six first-born, healthy 6-month-old infants and their parents participated in the study. Infant sleep was assessed by actigraphy for four consecutive nights and by the Brief Infant Sleep Questionnaire (BISQ). In addition, parents were asked to complete background and developmental questionnaires. Questions about feeding methods were included in the developmental questionnaire. Infants' weight and length were assessed during a standard checkup at the infant-care clinic when the infants were 6 months old. Significant correlations were found between infant sleep and growth after controlling for potential infant and family confounding factors. Actigraphic sleep percentage and reported sleep duration were correlated negatively with the weight-to-length ratio measures. Sex-related differences in the associations between sleep and physical growth were found. Breast feeding at night was correlated with a more fragmented sleep, but not with physical growth. These findings suggest that sleep is related significantly to physical growth as early as in the first months of life. The study supports increasing evidence from recent studies demonstrating a link between short sleep duration and weight gain and obesity in young children.

KEYWORDS actigraphy, infant, physical growth, sleep, weight

INTRODUCTION

The maturation and consolidation of sleep–wake patterns are highly important developmental tasks in infancy. The most rapid development in sleep organization takes place during the first 6 months of life, followed by more moderate changes (Coons, 1987; Goodlin-Jones *et al*., 2001; Mirmiran *et al*., 2003). While many studies documented possible medical and physiological influences (e.g. prematurity, airways anatomy, colic, allergies, iron deficiency anemia, stunting) on infant sleep (Anders *et al*., 1985; Carrol and Louglin, 1995; Chamlin *et al*., 2005; Kahn *et al*., 1989; Kordas *et al*., 2008; Mindell *et al*., 1999; Sadeh and Anders, 1993), to date, there have been no published studies examining the associations between infant sleep and basic physiological factors such as physical growth and weight gain. This is surprising in light of the increasing evidence from cross-sectional and prospective studies demonstrating that short-sleep duration is linked to weight gain and obesity in adults (Bass and Turek, 2005; Hasler *et al*., 2004; Taheri *et al*., 2004), adolescents and children (Agras *et al*., 2004; Cappuccio *et al*., 2008; Chaput *et al*., 2006; Eisenmann *et al*., 2006; Gupta *et al*., 2002; Knutson, 2005; von Kries *et al*., 2002; Locard *et al*., 1992; Marshall *et al*., 2008; Patel and Hu, 2008; Snell *et al*., 2007; Taheri, 2006). To our knowledge, only one study reported associations of infant sleep duration and child overweight (Taveras *et al*., 2008). This study examined the longitudinal association of short sleep duration between ages 6 months and 2 years with overweight at age 3 years. Sleep duration of fewer than 12 h a day during infancy was associated with overweight at age 3 years.

A number of risk factors have been documented as predictors of both childhood obesity and infant sleep, and should be taken into account as possible confounders of the association between children's sleep and weight gain. These

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factors include: (i) perinatal and infant factors such as gestational age, birth weight, sex and rapid infant weight gain; and (ii) family characteristics and demographics such as parental body mass index (BMI), parental socioeconomic status (SES), parental education, parental age and ethnicity (Chaput *et al*., 2006; Locard *et al*., 1992; Reilly *et al*., 2005; Snell *et al*., 2007; Stettler, 2007; Taveras *et al*., 2008). When considering the link between sleep and weight in infancy, breast feeding should also be taken into account. Breast feeding has been found to be associated with more fragmented sleep (i.e. more frequent night wakings) and with lower percentage of self-soothing (Burnham *et al*., 2002; DeLeon and Karraker, 2007). Concerning the impact of breast feeding on maintenance of an infant's weight within the normal range, the results are less conclusive (Owen *et al*., 2005; Snethen *et al*., 2007; Stettler, 2007).

There are two major limitations in the growing literature on the links between sleep and weight: (i) the disregard of sleep quality as a potential explanatory factor. To our knowledge, only one study in the paediatric field examined the links between sleep quality and obesity (Gupta *et al*., 2002); and (ii) the reliance on subjective reports (Marshall *et al*., 2008); parents have limited knowledge about their children's sleep patterns, and are particularly inaccurate, in reporting sleep quality (Sadeh *et al*., 1994; So *et al*., 2007; Tikotzky and Sadeh, 2001). To our knowledge, only two studies have used objective measures (actigraphy) to assess the links between sleep and obesity in children (Gupta *et al*., 2002; Nixon *et al*., 2008).

AIMS AND HYPOTHESES OF THE STUDY

The aim of the present study was to examine the relationships between infant sleep and infant physical growth during the first 6 months of life using both objective and subjective sleep measures. Because of the overlapping effects of shorter and poorer sleep, we hypothesized that both shorter sleep and lower sleep quality would be associated with physical growth (i.e. higher weight-to-height ratio).

METHODS

Participants

Ninety-six first-born infants (62 boys, 34 girls) and their parents participated in this study. Parents were recruited through prenatal courses or announcements on internet forums for expectant parents, or in the hospital during the first 48 h after birth. Exclusion criteria (based on parental reports) included significant complications during pregnancy or delivery and infants with medical problems, including breathing-related sleep problems. The sample comprised of families from the middle–upper socioeconomic class. Most parents were young couples and well educated. Mean age of mothers was 29.9 ± 3.0 years (range 24–40) and of fathers 32.1 ± 4.1 years (range 24–51). Mean mothers' years of formal education was 16.5 ± 2.0 years (range 12–22) and fathers' 16.1 ± 2.0 years (range 12–22). Mean number of rooms at home was 3.4 ± 0.7 (range 2–5). Mean gestational age was 39.5 ± 1.5 weeks (range 36–43) and mean birth weight was 3.3 ± 0.5 kg (range 2.3–4.3).

Procedure

The study was approved by the Institutional Ethical Committee. All parents signed informed consent. After delivery, parents completed a questionnaire obtaining information on parental and perinatal characteristics. When the infants reached the age of 6 months, their sleep was assessed by actigraphy for four nights. In addition, parents were asked to complete a developmental questionnaire. The questionnaires were completed at home during the sleep assessment period. All infants were assessed in good health. In case of appearance of an acute health problem (e.g. a cold) during the assessment week, the infants were reassessed after recovery.

Infants' weight and length measures were obtained from the infant care records kept by the parents. These records are based upon measurements performed by certified nurses during standard checkups at local child care clinic when the infants were 6 months old. Parents received a graphic report on their infant's sleep patterns and a gift (with a value of approximately $15).

Instruments and measures

Sleep assessment

Actigraphy. Actigraphy has been established as a non-intrusive reliable method for assessing sleep–wake patterns in infants, children and adults (Ancoli-Israel *et al*., 2003; Sadeh *et al*., 1991, 1995a,b). The actigraph is a wristwatch-like device that records body motion data that can be translated to reliable and valid sleep–wake measures. In the present study, we used the miniature actigraph (Ambulatory Monitoring Inc., Ardsley, NY, USA), with amplifier setting 18 and a 1-min epoch interval according to the standard working mode for sleep–wake scoring. The actigraph was attached to the infant's ankle during the nocturnal sleep period.

The Actigraphic Sleep Analysis program was used to score the data based on validated sleep–wake scoring algorithm for infants (Sadeh *et al*., 1995a). The following sleep measures were used: (i) total sleep period, from sleep onset time to morning awakening time; (ii) true sleep time, sleep time excluding all periods of wakefulness at night; (iii) sleep percentage, the percentage of true sleep time from total sleep period; and (iv) number of night-wakings (lasting 5 min or longer). The last two measures are considered as measures of sleep quality because they reflect sleep fragmentation. High sleep percentage and low number of wakings reflect consolidated sleep.

Brief Infant Sleep Questionnaire (BISQ). The BISQ is a sleep questionnaire assessing the infant's typical sleep patterns based on parental reports. The questionnaire has been validated against sleep diary and actigraphic measures (Sadeh, 2004). The derived measures used in the present study are: (i) sleep onset time; (ii) nocturnal sleep duration; (iii) daytime sleep duration; (iv) number of night wakings; and (v) sleep position (supine, side and prone).

Background and developmental questionnaires

These questionnaires were used to collect information about (i) parental characteristics: age, education, job status, number of rooms at home; (ii) perinatal information: difficulties during pregnancy or delivery, type of delivery, gestational age, date of birth, birth weight; and (iii) infant development: weight and length at 6 months, feeding method (exclusive breast feeding, partial breast feeding, formula), health problems (e.g. allergies, breathing problems), daycare setting (with mother at home, with babysitter or nursery).

Feeding. In addition to the general question about feeding included in the developmental questionnaire (full, partial or no breast feeding), parents were asked to rate (on a five-point Likert-type scale from 'not at all' to 'very frequently') their use of breast feeding and bottle feeding as a means of soothing the infant. Separate scales were used for night feeding and day feeding.

Body size measures. On the basis of the infants' weight and length records, the following body size measures were calculated: (i) simple weight-to-length ratio (WLR), which is the most common body size measure for infants (Williams and O'Brien, 1997; Yau and Chang, 1993); and (ii) weight above expected weight for length (WEFL). Although the WLR is used commonly to quantify infants' body size, it does not relate to the distinct growth patterns documented in boys and girls. Therefore, we calculated the WEFL measure in order to examine an alternative measure for BMI in infancy, taking sex differences in physical growth into account. This measure was based on separate regressions models computed for boys and girls calculating the expected weight for a specific length of the infant. Our data are very similar to the Israeli growth chart norms and provided the following regression lines:

- for boys: expected weight (in grams) = length (cm) × 157 - 2 545;
- for girls: expected weight (in grams) = length (cm) × 162 - 3 342; and
- the computed WEFL = actual weight - expected weight.

RESULTS

Descriptive data on the objective and subjective sleep variables and on the body size measures are presented in Table 1.

Table 1 Means and standard deviations of the sleep and physical growth parameters at 6 months

	Mean	*SD*	*Range*
Actigraphic measures			
Sleep percentage	94.26	3.80	77.11–99.98
No. of night-wakings	1.79	1.06	0–5.67
Night sleep duration (min)	589.26	57.02	441–715
True sleep time (min)	554.48	53.67	424–661
Reported measures			
Night-wakings	2.28	1.72	0–11
Night sleep duration (min)	572.4	83.40	360–780
Day sleep duration (min)	186.00	73.80	20–480
Growth measures			
Weight (g)	7 854	831.39	5 800–10 250
Length (cm)	67.00	2.54	60.50–75.00
WLR	11.71	1.04	8.79–14.64
WEFL	46.57	636.71	-1 550 to 1 805

SD: standard deviation; WEFL: weight above weight expected for length; WLR: weight to length ratio.

Sex-related differences in growth and sleep

Because of the existence of sex-specific growth curves for infants (Van't Hof *et al*., 2000; WHO, 2006), prior to addressing the links between sleep and physical growth, we first examined whether there were sex-related differences in weight gain during the first 6 months in our sample. We performed analyses of variance (ANOVA) with sex as the between-group independent variable and time (birth versus 6 months) as the repeated within-subject variable. A significant sex × age interaction was found ($F = 18.12$, $P < 0.0001$). No significant sex differences were found for birth weight (mean for boys = 3 301 ± 481 and for girls: 3165 ± 451), but at the age of 6-month boys weighed significantly more than girls ($F = 27.55$; $P < 0.0001$; mean for boys = 8146 ± 791 and for girls = 7 322 ± 617).

In addition, Pearson correlations were calculated between birth weight and weight at 6 months. The correlation for the girls was 0.29 ($P < 0.05$) and a similar correlation was found for the boys ($r = 0.26$, $P < 0.05$). No significant sex differences were found on any of the infant sleep measures.

Correlations between potential confounding factors and sleep and body size

Before assessing the correlations between sleep and body size, we assessed whether there were significant correlations between these two variables and the following potential confounding factors: gestational age, birth weight, feeding, sleep position, parental education and parental age. Significant correlations were found only for two factors: birth weight and breast feeding.

Infant birth weight was correlated significantly with weight at 6 months ($r = 0.30$, $P < 0.005$), length at 6 months ($r = 0.29$, $P < 0.005$) and WLR at 6 months ($r = 0.25$, $P < 0.05$).

The correlations between breast feeding and infant sleep and body size are described in Table 2. Breast feeding, especially at night, was correlated significantly with more fragmented sleep.

Table 2 Correlations between sleep and body size measures and between feeding at day and night

Sleep measures	*Breast-F general*	*Breast-F night*	*Breast-F day*
Actigraphic			
Sleep percentage	−0.20	−0.23*	−0.19
No. of night-wakings	0.36***	0.41****	0.32***
Night sleep duration	−0.15	−0.18	0.17
True sleep time	−0.09	0.08	0.09
Reported			
Night-wakings	0.11	0.33***	0.14
Night sleep duration	−0.09	−0.17	−0.01
Day sleep duration	−0.18	−0.29**	−0.22*
Growth measures			
Weight	0.13	0.05	0.19
Length	0.09	0.00	0.15
WEFL	0.06	0.06	0.09
WLR	0.12	0.11	0.16

Pearson correlations were calculated for all measures, except for Spearman correlations for Breast-F general which was a three-point scale (full, partial or no breast feeding).
Breast-F: breast feeding; WEFL: weight above weight expected for length; WLR: weight to length ratio.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.005$; ****$P < 0.0001$.

In addition, breast feeding was associated with reported sleep duration measures at day and night.

No significant correlations were found between any of the feeding scales and between the different body size measures.

Correlations between sleep and physical growth

To test our main hypothesis concerning the links between infant sleep and infant body size, Pearson correlations were calculated between the objective and subjective sleep measures and between the infants' body size measures (Table 3 and Fig. 1).

Significant correlations were found between infant sleep and body size after controlling the following factors: gestational age, birth weight, breast feeding, sleep position, parental education, parental age and number of rooms at home (as an indicator of SES). Sleep percentage (an actigraphic sleep quality measures) in the total sample was correlated negatively with WRL and WEFL and positively with length. When analysing the results separately for boys and girls, these associations were statistically significant only for the boys.

In addition, in the total sample, shorter night sleep duration (according to parental reports) was found to be associated with higher weight, WRL and WEFL measures. For the girls only, shorter actigraphic sleep duration and true sleep time measures were also associated with higher body size measures.

Regression analysis

In addition to the Pearson correlations, a stepwise regression analysis was conducted to examine the relative power of different sleep measures in predicting the body size measures.

Table 3 Pearson correlations between sleep measures and body size measures in 6-month-old infants

Actigraphic measures	*Weight*	*Length*	*WEFL*	*WLR*
Sleep percentage				
Total sample	−0.11	0.26*	−0.30***	−0.23*
Boys	−0.09	0.33*	−0.34**	−0.25
Girls	−0.11	0.08	−0.16	−0.15
No. of night-wakings				
Total sample	0.03	−0.14	0.12	0.09
Boys	−0.08	−0.25	0.09	0.02
Girls	0.23	0.14	0.15	0.19
Night sleep duration				
Total sample	−0.04	−0.07	0.00	−0.02
Boys	0.10	−0.02	0.13	0.13
Girls	−0.48**	−0.26	−0.34	−0.42*
True sleep time				
Total sample	−0.10	0.04	−0.13	−0.13
Boys	0.05	0.13	−0.03	0.00
Girls	−0.51***	−0.22	−0.39*	−0.47**
Reported measures				
Night-wakings				
Total sample	−0.07	−0.07	−0.03	−0.04
Boys	−0.14	−0.03	−0.14	−0.14
Girls	0.13	−0.16	0.24	0.20
Night sleep duration				
Total sample	−0.23*	−0.01	−0.25*	−0.26*
Boys	−0.21	0.01	−0.25	−0.25
Girls	−0.31	−0.15	−0.23	−0.28
Day sleep duration				
Total sample	0.10	0.04	0.08	0.09
Boys	0.10	0.03	0.10	0.11
Girls	0.10	0.05	0.07	0.08

WEFL: weight above weight expected for length; WLR: weight to length ratio.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.005$.

The following possible confounding factors were first forced into the model: sex, birth weight, gestational age and nocturnal breast feeding. These four variables explained 31.2% of the variance in weight (sex: $F = 17.9$, $P < 0.0001$; birth weight: $F = 10.6$, $P < 0.005$), 22.6% of the variance in length (sex: $F = 14.1$, $P < 0.0005$), 7.2% of the variance in WEFL (birth weight: $F = 6.4$, $P < 0.05$) and 22.1% of the variance in WLR (sex: $F = 9.8$, $P < 0.005$; birth weight: $F = 8.1$, $P < 0.01$).

After controlling these four confounding factors, we found that the only sleep measure to enter the analysis was sleep percentage at 6 months. This measure explained: (i) additional 5.4% of the variance in length ($\beta = 0.16$, $F = 6.29$, $P < 0.05$); (ii) additional 9.6% of the variance in WEFL ($\beta = -53.2$, $F = 9.6$, $P < 0.005$); and (iii) additional 6.3% of the variance in WLR ($\beta = -0.1$, $F = 7.41$, $P < 0.01$). Infant weight at 6 months was not explained by any of the sleep measures.

DISCUSSION

The main purpose of the present study was to assess the links between sleep patterns and physical growth in 6-month-old infants. To our knowledge, this is the first study that investigated these links during infancy, a period in life that is

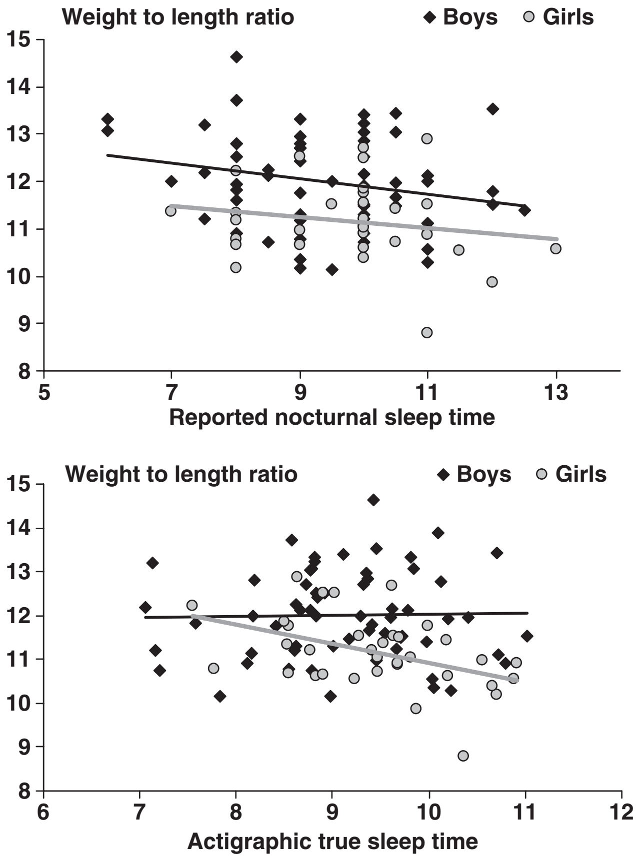

Figure 1. Associations between weight to length ratio and reported and actigraphic sleep times.

critical for the development and consolidation of sleep and for rapid physical growth (Anders *et al*., 1985; Darlington and Wright, 2006; Giani *et al*., 1996). In addition, the strength of the present study lies in the fact that infant sleep was assessed using both objective and subjective evaluation methods, contrary to earlier studies in this field that relied almost entirely upon subjective reports (Marshall *et al*., 2008). However, our study also had several limitations. The parents in this study represented a highly educated middle–upper SES and their infants were all first-born. Any interpretation of these preliminary findings should therefore be considered with caution. Another limitation is the potentially low statistical power of the distinct analyses for boys and girls. This is particularly true for the girls, who were less represented in the total sample. These power differences can account potentially for some of the sex differences in the findings. Finally, there are other potential confounders that were not assessed in our study, such as parental body size measures, maternal weight gain during pregnancy and maternal nutrition, etc. The role of these and other potential influences should be addressed in future studies.

Our preliminary findings suggest that there are significant associations between infant night-time sleep and physical growth, even after controlling for potential confounding factors such as sex, infant birth weight, breast feeding, sleep position and parental education. No associations were found between reported daytime sleep and physical growth measures. These results are in line with previous studies of older children demonstrating an association between shorter sleep duration and increased weight gain (Patel and Hu, 2008; Snell *et al*., 2007; Taveras *et al*., 2008). However, it is important to note that not all studies demonstrated links between sleep and physical growth (Jenni *et al*., 2007). In the present study, we found that shorter reported night sleep duration was correlated with higher WLR in 6-month-old infants. Moreover, a unique finding derived from our analysis demonstrates that not only was sleep duration related to physical growth, but male infants with poorer sleep quality (i.e. lower sleep percentage) also had a higher WLR. According to regression analysis, sleep percentage was the only sleep measure that contributed to the explained variance in physical growth, after adjusting for possible confounding factors. This finding raises the possibility that, in addition to shorter sleep, poor sleep quality is also associated with increased WLR during childhood, particularly in boys. More studies using objective methods of sleep assessment are needed to validate and explore these findings further. In addition, the results related to sleep time derived from actigraphy and from parental reports were not fully overlapping. This could be related to the fact that these different methods are not identical. Actigraphy measured sleep time during a certain limited period of monitoring, whereas parental reports reflect a more global (and subjective) perception of sleep time (Sadeh, 2004). Discrepancies between objective sleep measures and parental reports in the associations between sleep patterns and body size and weight should also be explored in future studies.

We found that boys gained weight significantly faster than girls during the first 6 months, in line with previous reports (Haschke and van't Hof, 2000; Tate *et al*., 2006; Wright *et al*., 1996). Therefore, we decided to examine whether there are distinct sex-related correlations between sleep and physical growth. We found that, for the girls only, the actigraphic night sleep duration measures were associated strongly with physical growth. However, the correlations between sleep percentage and physical growth were significant only for boys. This finding may be related to the length of the male infants, because it was length rather than weight in the male infants that was correlated significantly with sleep percentage. Sex differences in the relationship between sleep and BMI have been reported in three earlier studies on older children, suggesting that boys' BMI may be more vulnerable to sleep loss than girls' (Chaput *et al*., 2006; Knutson, 2005; Sekine *et al*., 2002). For example, in a study on adolescents, sleep duration was found to be associated significantly with BMI only among the males (Knutson, 2005). The author argued that these findings may be due to differences in the physiology of puberty or may be related to sex differences in sleep characteristics. Following this line, sex-related differences in the rate of weight gain and in sleep and motility patterns have been observed in infants (Haschke and van't Hof, 2000; Lampl *et al*., 2005; Sadeh *et al*., 1991; Wright *et al*., 1996).

Although findings regarding sex differences in infant sleep patterns yield inconsistent results (Bamford *et al*., 1990; Scher *et al*., 2004), a few studies based on actigraphy demonstrated some differences in the amount of motionless sleep and in sleep duration (Sadeh *et al*., 1991, 2000; So *et al*., 2007). In addition, sex differences in motility have been found in several studies reporting that male infants are more active than female infants (Almli *et al*., 2001). Furthermore, sex differences in growth hormone pulsation have been reported in different ages (Lampl *et al*., 2005), and these sex differences may explain the distinct sleep–growth relationships seen in boys and girls.

In sum, although speculative, physiological differences, such as hormonal secretion differences or motility differences, may underlie the sex-related differences in association between sleep and physical growth found in the present study. However, our results regarding these sex-related associations should be replicated and more research is needed to explore the physiological underlying mechanisms that may explain the sex-related associations.

Several plausible explanations have been suggested for the association between sleep curtailment and body weight. Studies in adults have shown that sleep restriction is associated with reduced levels of the hormone leptin that suppresses appetite and with elevated levels of the hormone ghrelin that stimulates appetite (Spiegel *et al*., 2004; Taheri *et al*., 2004). Another potential mechanism by which poor or insufficient sleep could result in increased WLR is related to the secretion of growth hormone (Al Mamun *et al*., 2007; Finkelstein *et al*., 1971; Sassin *et al*., 1969; Van Cauter *et al*., 1998). Growth hormone is responsible most noticeably for the increase of height throughout childhood. The largest and most predictable peak secretion of growth hormone occurs about an hour after onset of sleep (Takahashi *et al*., 1968). If the secretion of growth hormone is affected negatively by less efficient or shorter sleep, this could result in a higher weight for length ratio.

We examined the possibility that breast feeding mediates the link between infant sleep and physical growth. Consistent with previous studies (Burnham *et al*., 2002; DeLeon and Karraker, 2007), we found that breast feeding (but not bottle feeding) mainly at night was related to a more fragmented sleep. However, there were no significant associations between daytime or night-time breast feeding and the infant WLR, and the correlations between infant sleep and the body size measures remained significant even after controlling for breast feeding. Therefore, in this study, breast feeding does not seem to be a significant underlying factor for the association between infant sleep and physical growth.

CONCLUSIONS

Our study suggests that even as early as in the first 6 months of life, poorer sleep is associated with physical growth and specifically with higher WLR. Further prospective studies that will include also clinical populations of sleep-disturbed infants are needed to replicate these finding. If future studies could show that disturbed sleep has negative consequences for physical growth in infants, then the clinical implications would be evident in highlighting the need to address sleep problems in infancy.

DISCLOSURE

This was not an industry-supported study. The authors have no financial conflict of interest to report.

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