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# Infant Sleep Problems and Childhood Overweight: Effects of Three Definitions of Sleep Problems

Arsham Alamian

*East Tennessee State University*, [alamian@etsu.edu](mailto:alamian@etsu.edu)

Liang Wang

*East Tennessee State University*, [wangl2@etsu.edu](mailto:wangl2@etsu.edu)

Amber M. Hall

*East Tennessee State University*

Melanie Pitts

*East Tennessee State University*

Joseph Ikekwere

*East Tennessee State University*, [ikekwere@etsu.edu](mailto:ikekwere@etsu.edu)

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# Infant Sleep Problems and Childhood Overweight: Effects of Three Definitions of Sleep Problems

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## Infant sleep problems and childhood overweight: Effects of three definitions of sleep problems

Arsham Alamian PhD, MSc, MACE\*, Liang Wang MD, MPH, DrPH, Amber M. Hall MPH<sup>1</sup>,  
Melanie Pitts MPH, Joseph Ikekwere MD, MPH<sup>2</sup>

Department of Biostatistics and Epidemiology, College of Public Health, East Tennessee State University, P.O. Box 70259, Johnson City, TN 37614, United States

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### ABSTRACT

Sleep problems have been defined using a variety of definitions. No study has assessed the longitudinal association between infant sleep problems and childhood overweight or obesity using existing definitions of sleep problems. This study used longitudinal data ( $n = 895$ ) from the multi-site Study of Early Child Care and Youth Development (SECCYD) to investigate the effects of infant sleep problems on childhood weight status in Grade 6. Infants with sleep problems in Phase I (1991) and with complete data through Phase III (2004) of SECCYD were included. Sleep problems were assessed using maternal reports of night wakings and duration of a waking episode. Sleep problems were defined using Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987) definitions. Multinomial logistic regression was used to examine the association between sleep problems during infancy and childhood weight status in Grade 6 while controlling for birth weight, race, sex, breastfeeding, maternal poverty, family structure, and maternal education. After adjusting for all covariates, children with a history of sleep problems were found to be overweight in Grade 6 using Zuckerman et al. (Odds ratio (OR) = 1.68; 95% confidence interval (CI): 1.11–2.55) and Richman (OR = 1.76; 95% CI: 1.05–2.97) definitions, but not using Lozoff et al. definition. Infant sleep problems were not found to be associated with being obese. The study found differential effects of infant sleep problems on childhood overweight in Grade 6 per different definitions of sleep problems. Findings highlight the need to construct a single definition of infant sleep problems.

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### 1. Introduction

The unhealthy accumulation of adiposity has become a major public health issue in the United States for all ages. During the past 30 years, the prevalence of obesity has doubled among children and quadrupled among adolescent population (Centers for Disease Control and Prevention, 2016). According to the latest National Health and Nutrition Examination Survey data, 8.1% of infants and toddlers had high weight for recumbent length, and 16.9% of 2 to 19 year-olds were obese in 2011–2012 (Ogden et al., 2014). Elevated levels of body mass index (BMI) place children and adolescents at an increased risk for heart disease, type 2 diabetes, stroke, osteoarthritis, multiple cancers, and adult obesity (Centers for Disease Control and Prevention, 2016; Daniels et al., 2005).

\* Corresponding author.

E-mail addresses: [alamian@etsu.edu](mailto:alamian@etsu.edu) (A. Alamian), [wangl2@etsu.edu](mailto:wangl2@etsu.edu) (L. Wang), [amber.hall@childrens.harvard.edu](mailto:amber.hall@childrens.harvard.edu) (A.M. Hall), [pittsmr@goldmail.etsu.edu](mailto:pittsmr@goldmail.etsu.edu) (M. Pitts), [ikekwere@etsu.edu](mailto:ikekwere@etsu.edu) (J. Ikekwere).

<sup>1</sup> Present Address: Department of Anesthesiology, Boston Children's Hospital, 300 Longwood Avenue, Boston, MA 02115, United States.

<sup>2</sup> Present Address: Department of Psychiatry, Quillen College of Medicine, East Tennessee State University, P.O. Box 70567, Johnson City, TN 37614, United States.

Sleep problems, such as frequent night waking and settling problems affect 20% to 30% of children one to five years of age. Among these children, 40% to 80% will continue to have sleep difficulties for an additional two to three years (Bruni & Novelli, 2010). Sleep problems are associated with a variety of comorbid conditions including obesity, metabolic syndrome, growth hormone deficiency, allergic conditions, neoplasms, and blood malignancies (Lazaratou et al., 2012). Despite the high prevalence and adverse health outcomes associated with sleep problems, assessment of the latter by medical professionals is often overlooked during routine care (Smaldone et al., 2007).

The deleterious and costly effects of an imminent overweight and obese generation have prompted immediate attention from various societal institutions. Several cross-sectional studies have shown an association between sleep problems and overweight and obesity in childhood and adolescence by primarily focusing on sleep duration as the measure of interest (Shi et al., 2010; Lumeng et al., 2007; Chaput et al., 2006; Padez et al., 2005), but only a few have examined beyond this component. A recent cross-sectional study examined the relation between a set of defined sleep dimensions (duration, disturbances, and patterns) and childhood and adolescent obesity (Jarrin et al., 2013). Results of this study revealed that sleep difficulties were reported by subjects with high BMI (Jarrin et al., 2013). Wake times and bed times have

also been observed to be predictive of youth BMI measures (Olds et al., 2011). A few mechanisms have been proposed to explain the association between sleep restriction and overweight. Several studies have found a link between sleep duration and changes in the levels of hormones including cortisol, leptin and ghrelin (Spiegel et al., 2004; Schmid et al., 2008; Omside et al., 2010). These changes lead to decreased energy expenditure and increased energy intake. Shorter sleep duration has been also associated with less physical activity (Taheri et al., 2004) and increased consumption of high-calorie foods (Fleig & Randler, 2009).

The association between infant sleep problems and weight status in children has received less attention (Taveras et al., 2008), perhaps because of the existence of varying definitions of sleep problems in the literature (Richman, 1981; Lozoff et al., 1985; Zuckerman et al., 1987; Wolke et al., 1995; Gaylor et al., 2001). For instance Richman (1981), defined sleep problems as waking 5 or more nights per week in addition to one of the following: co-sleeping with parents, waking 3 or more times per night, or waking event lasting at least 20 min. Lozoff et al. (1985) defined sleep problems as night waking occurring 3 or more times per week accompanied by parental report of disturbance. Zuckerman et al. (1987) defined sleep problems as waking 3 or more times per night, waking event lasting at least 1 h, or parental report of “severe” disturbance.

A few other investigators have attempted to provide a more contemporary definition of sleep problems in the hope to provide a more specific guide for classification. Wolke et al. (1995) assessed sleep problems among preterm and full term infants. For the age of 5 months, problems were indicated if night waking occurred 5 or more times per week at least one time per night (severity classification: slight), at least 2 times per night (severity classification: severe), arousal lasting 15 to 29 min (severity classification: moderate), arousal lasting 30 min or longer (severity classification: long), and report of parental distress. For the age of 20 months, problems were indicated if night waking occurred 5 or more times per week at least one time per night. Lastly Gaylor et al. (2001), constructed a definition of sleep problems using the Diagnostic and Statistical Manual of Mental Disorders, 4th edition; infant sleep problems were defined as waking >2 nights per week, difficulty falling asleep lasting >30 min for 1 to 2 year-olds, difficulty falling asleep lasting >20 min for children aged 2 years and older, and by degree of severity.

To our knowledge, no study has examined the long-term effects of infant sleep problems, as defined by existing definitions of sleep problems, on childhood overweight or obesity. In a multi-site longitudinal study conducted by the National Institute of Child Health and Human Development (NICHD), sleep problems were assessed using Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987) definitions along with an intra-study constructed definition. This study aimed to investigate the relation between sleep problems in infancy, as defined by Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987), and the risk of childhood overweight and obesity.

## 2. Methods

### 2.1. Participants

Prospective data from Phase I (1991) and Phase III (2004) of the Study of Early Child Care and Youth Development (SECCYD) of the NICHD were used. SECCYD was a longitudinal study that followed a cohort of children from birth through 9th Grade. Participants were recruited in 1991 from 24 designated hospitals at 10 data collection sites across the United States. Participant recruitment and selection procedures are described in detail elsewhere (National Institute of Child Health and Human Development Early Child Care Research Network, 2001). In brief, of the initial pool of 3015 eligible mothers with healthy newborns contacted at two weeks for participation, 1364 (45%) completed the 1-month home interview and became study participants. Eligibility

requirements specified that mothers be 18 years or older, English-speaking, and have no known or acknowledged history of substance abuse; and that infants not be hospitalized at birth for >7 days nor have any obvious disabilities. This resulted in screening out very low birth weight, premature, or sick infants. A study conducted by the NICHD compared characteristics of subjects who agreed to participate in SECCYD and those who refused to participate (National Institute of Child Health and Human Development Early Child Care Research Network, 2001). The results showed a few small differences. Mothers who agreed to participate were slightly better educated (65% with more than a high school degree vs 50%) and less likely to be minority (19% vs 24%). Children who participated were a little heavier at birth (3.49 kg vs 3.39 kg). At Phase III, 1061 subjects remained in the study. The follow-up attrition rate was 22.2%.

At 6th Grade (i.e., Phase III of SECCYD), 895 children had complete anthropometric data. Much of the missing anthropometric data were due to families' moving to other communities. Children with missing sleep problems' data in infancy or anthropometric measures at 6th Grade were excluded from the analysis, which resulted in a final sample size of 895 children (65.6% of the original cohort). This study was approved by the institutional review boards of all the participating institutions.

### 2.2. Data collection

#### 2.2.1. Measurement of sleep problems

Data regarding sleep problems were obtained by maternal reports of infant behaviors at 6 months and 15 months of age. Three sleep measures were used to assess infant sleep problems. *Night wakings in the last week* was assessed by asking the mothers to respond “yes” or “no” to the following question: “In the last week, has baby wakened you at night?” If the mothers answered “yes” to the previous question, they were then asked to record the frequency of waking events per week and the frequency of waking events per night; the response choices ranged from 1 to 7 for both questions. *Average length of night waking* was assessed by recording the number of minutes in response to the following question: “On average, for about how long would you say baby was up each time baby awakened?” *Maternal report of sleep disturbances* was based on the maternal response to the question, “How much of a problem has baby's awakening been for you? Response choices included: “Not much”, “Somewhat”, and “Quite a bit” (United States Department of Health and Human Services, National Institutes of Health, Eunice Kennedy Shriver National Institute of Child Health and Human Development, 1991–1995). Sleep problems were operationalized within SECCYD using Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987) definitions of sleep problems as defined above. Lozoff et al.'s definition was validated by applying discriminant analysis prediction to data from a second sample of children in their study (Lozoff et al., 1985). The intercorrelations between all three sleep measures were tested within SECCYD and results showed that all three definitions were significantly different from each other, indicating that each measure reflects different aspects of sleep problems (National Institute of Child and Human Development Study of Early Child Care and Youth Development, 1995) Infants with sleep problems at 6 months and/or 15 months were included in the analysis.

#### 2.2.2. Measurement of BMI

Height and weight were measured during laboratory visits in Grade 6 by trained research assistants using standardized procedures. BMI was calculated by dividing weight (kg) by height (m) squared. BMI was defined as normal: BMI 5th–<85th percentile; being overweight: BMI 85th–<95th percentile; or being obese: BMI ≥ 95th percentile according to the 2000 Centers for Disease Control and Prevention's sex-specific cut-offs for age-group (Barlow & Expert, 2007).

### 2.2.3. Child factors

Child sex and race recorded at one month were included as covariates given the associations between being male (Sugimori et al., 2004; Knutson, 2005) and of minority race with increased sleep problems (Crosby et al., 2005; Roberts et al., 2000; Spilsbury et al., 2004), and being overweight (Freedman et al., 2006). Race was categorized as white and non-white because the numbers within individual racial minority groups were not large enough to allow analyses of the groups separately. Child birth weight (in grams) obtained from the medical chart at the time of birth was also included.

### 2.2.4. Maternal factors

Maternal information when the child was one-month-old included breastfeeding status (breastfeeding, not breastfeeding), and maternal level of education (bachelor's degree or above, less than a bachelor's degree). Maternal information collected when the child was 24 months old included family structure (living single, not living single) and poverty (above poverty line, at or below poverty line). The poverty threshold for a household was determined by the year the income was earned, the total number of members in the household, and the number of full-time children living in the home. The income-to-needs ratios were used and were based on total family income. If the ratio of income-to-needs was 1.0 or less, the households were considered to be at or below poverty level, while households with values over 1.0 were considered above poverty level.

### 2.2.5. Statistical analyses

Baseline characteristics of the study population were analyzed against the excluded sample using the chi-squared test and *t*-test. The primary outcome of interest was overweight and obesity status at 6th Grade (mean child age: 11.0 ± 2.0 years). Differences in infant sleep problems definitions, child characteristics, and maternal characteristics by overweight/obesity status at 6th Grade were tested using the chi-squared test and *t*-test, as appropriate. All covariates significant at  $P \leq 0.25$  were included in the multivariate analyses. Multinomial logistic regression was used to assess the associations between infant sleep problems, as defined by Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987), and childhood overweight and obesity status at 6th Grade while controlling for all covariates. Adjusted odds ratios (ORs) and their corresponding 95% confidence intervals (CIs) were reported. All statistical tests were 2-sided and the analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC).

## 3. Results

Characteristics of the study population are presented in Table 1. Analyses comparing the sample with complete data for overweight/obesity status and sleep problems ( $n = 895$ ) and those with missing data for these two variables ( $n = 469$ ) showed some differences between the two groups (Table 1). Children excluded because of incomplete data had mothers with significantly lower educational levels ( $P = 0.0001$ ) and no breastfeeding history ( $P < 0.0001$ ). There were also more females in the analytic sample than in the excluded sample (51.0% vs. 43.3%;  $P = 0.007$ ).

At baseline, the mean birth weight was 3.50 ± 0.52 kg, the majority of infants were females (51.0%), and of white race (80.8%) (Table 1). The majority of mothers breastfed their children (62.0%), were not living single (86.0%), had less than a bachelor's degree (61.5%), and were living above the poverty level (88.4%). The prevalence of having sleep problems during infancy was 12.6% (Richman), 20.6% (Lozoff et al.), and 24.9% (Zuckerman et al.), per different definitions used. The prevalence of childhood overweight and obesity in Grade 6 was 15.6% and 19.0%, respectively.

Results of the univariate associations between sleep definitions, covariates, and being overweight or obese at 6th Grade are presented in Table 2. Infants with sleep problems were found to be more likely to

**Table 1**

Characteristics of participants in the analytic sample and those excluded due to missing data, NICHD SECCYD<sup>a</sup>, 1991–2004.

Characteristics <sup>b</sup>	Analytic sample <sup>c</sup> n = 895	Excluded sample <sup>d</sup> n = 469	P value <sup>e</sup>
<b>Maternal characteristics</b>			
Education			
Less than a bachelor's degree	550 (61.5)	331 (70.7)	0.0001
Bachelor's degree or above	345 (38.5)	137 (29.3)	
Poverty			
At or below poverty line	99 (11.6)	44 (13.3)	0.412
Above poverty line	757 (88.4)	287 (86.7)	
Family structure			
Living single	121 (14.0)	44 (13.2)	0.703
Not living single	742 (86.0)	290 (86.8)	
Breastfeeding			
Yes	555 (62.0)	222 (47.3)	<0.0001
No	340 (38.0)	247 (52.7)	
<b>Child characteristics</b>			
Birth weight (kg), mean ± SD	3.50 ± 0.52	3.47 ± 0.50	0.312
Sex			
Female	456 (51.0)	203 (43.3)	0.007
Male	439 (49.0)	266 (56.7)	
Race			
White	723 (80.8)	374 (79.7)	0.646
Nonwhite	172 (19.2)	95 (20.3)	

Abbreviation: SD, standard deviation.

<sup>a</sup> NICHD SECCYD = National Institute of Child Health and Human Development Study of Early Child Care and Youth Development.

<sup>b</sup> Poverty and family structure were assessed when child was 24 months. Other maternal and child characteristics were assessed when child was one month.

<sup>c</sup> There were 39 missing data on poverty and 32 missing data on family structure.

<sup>d</sup> There were 135 missing data on family structure, 138 missing data on poverty, and 1 missing data on education.

<sup>e</sup> P value was from a Chi-squared ( $\chi^2$ ) test or *t*-test.  $\chi^2$  tests were used to determine significance for categorical variables (expressed in frequencies with percentage values and *t*-tests were used to determine the significance for continuous variables (expressed as mean ± SD).

be overweight in Grade 6 using either Zuckerman et al. (OR = 1.62; 95% CI: 1.08–2.43) or Richman's definition (OR = 1.70; 95% CI: 1.03–2.78), but not using Lozoff et al.'s definition of sleep problems (OR = 0.92; 95% CI: 0.58–1.45). Child's birth weight ( $P = 0.0006$ ) was associated with an increased risk of being obese, being nonwhite was associated with an increased risk of being overweight ( $P = 0.048$ ) or obese ( $P = 0.009$ ) while child sex did not appear to be related to weight status in Grade 6. Having a mother with less than a bachelor's degree or living at or below poverty line were positively associated with being overweight ( $P = 0.029$ ;  $P < 0.0001$ , respectively) or obese ( $P < 0.0001$ ;  $P < 0.0001$ , respectively) in 6th Grade. Having a single mother increased the risk of being obese ( $P = 0.012$ ) while breastfeeding was found to be inversely related to being obese ( $P = 0.0002$ ) in Grade 6.

After adjusting for all covariates, infant sleep problems were found to be associated with an increased risk of being overweight in 6th Grade using either Zuckerman et al.'s (OR = 1.68; 95% CI: 1.11–2.55) or Richman's definition (OR = 1.76; 95% CI: 1.05–2.97), but not using Lozoff et al.'s definition (OR = 1.07; 95% CI: 0.66–1.74) (Table 3). Infant sleep problems were not found to be independently associated with being obese in 6th Grade using any of the three definitions of sleep problems. Children whose mothers had less than a bachelor's degree and those living at or below poverty line were more likely to be obese at Grade 6. Breastfeeding was negatively related to obesity while higher birth weight increased the risk of being obese in Grade 6.

## 4. Discussion

This 13-year prospective study investigated the long-term relationship between infant sleep problems, as defined by Richman (1981), Lozoff et al. (1985), and Zuckerman et al. (1987), and risk of childhood overweight and obesity in Grade 6. The risk of being overweight in 6th Grade were found to be greater in children with sleep problems during

**Table 2**  
Infant sleep problems, maternal and child characteristics, and childhood overweight and obesity in Grade 6, NICHD SECCYD<sup>a</sup>, 1991–2004 (n = 895).

Characteristics	Overweight <sup>b</sup> (n = 140)			Obesity <sup>b</sup> (n = 170)		
	n (%) or mean ± SD	OR <sup>c</sup> (95% CI)	P value <sup>d</sup>	n (%) or mean ± SD	OR <sup>c</sup> (95% CI)	P value <sup>d</sup>
Infant sleep problems <sup>e</sup>						
Zuckerman et al. definition	46 (21.2)	1.62 (1.08–2.43)	0.019	38 (17.5)	0.98 (0.65, 1.48)	0.927
Richman definition	26 (23.6)	1.70 (1.03–2.78)	0.037	16 (14.6)	0.79 (0.45–1.41)	0.424
Lozoff et al. definition	28 (15.6)	0.92 (0.58–1.45)	0.704	29 (16.1)	0.77 (0.49–1.21)	0.260
Maternal characteristics <sup>f</sup>						
Less than a bachelor's degree	93 (16.9)	1.54 (1.05–2.27)	0.029	128 (23.3)	2.37 (1.61–3.49)	<0.0001
At or below poverty line	26 (26.3)	2.90 (1.71–4.94)	<0.0001	31 (31.3)	2.91 (1.76–4.80)	<0.0001
Living single	19 (15.7)	1.19 (0.69–2.05)	0.542	33 (27.3)	1.79 (1.14–2.83)	0.012
Breastfeeding	81 (14.6)	0.70 (0.48–1.02)	0.060	86 (15.5)	0.52 (0.37–0.74)	0.0002
Child characteristics <sup>f</sup>						
Male	66 (15.0)	0.98 (0.68–1.42)	0.907	94 (21.4)	1.36 (0.96–1.91)	0.082
Nonwhite	33 (19.2)	1.57 (1.00–2.46)	0.048	43 (25.0)	1.73 (1.15–2.60)	0.009
Birth weight (kg), mean ± SD	3.49 ± 0.49	1.12 (0.78–1.61)	0.553	3.62 ± 0.58	1.80 (1.29–2.52)	0.0006

Abbreviations: OR, odds ratio; CI, confidence interval; SD, standard deviation.

<sup>a</sup> NICHD SECCYD = National Institute of Child Health and Human Development Study of Early Child Care and Youth Development.

<sup>b</sup> Being overweight: BMI ≥ 85th but <95th percentile; being obese: BMI ≥ 95th percentile.

<sup>c</sup> Odds ratio from univariate multinomial regression with normal weight (BMI >5th percentile and BMI <85th percentile of 2000 CDC cut-offs) as reference category.

<sup>d</sup> P value was from a Chi-squared ( $\chi^2$ ) test or t-test.  $\chi^2$  tests were used to determine significance for categorical variables (expressed in frequencies with percentage values and t tests were used to determine the significance for continuous variables (expressed as mean ± SD).

<sup>e</sup> Infant sleep problems assessed at 6 months and/or 15 months of age.

<sup>f</sup> Poverty and family structure were assessed when child was 24 months. Other maternal and child characteristics were assessed when child was one month.

their infancy than in children with no maternally reported sleep problems during the same age period, using Zuckerman et al. (1987) or Richman's (1981) definitions of sleep problems. To our knowledge, this is the first study to compare the independent relationship between infant sleep problems, as defined by three definitions of sleep disturbances, and later development of childhood overweight and obesity. Hence, it is difficult to compare results of this study with other relevant reports. In fact, the majority of previous studies have explored only one aspect of sleep problems, namely sleep duration (Patel & Hu, 2008). Some of these studies provide strong evidence for the association between short sleep duration in infancy and increased risk of becoming overweight or obese in childhood (Taveras et al., 2008; Reilly et al., 2005), and indeed those findings corroborate with findings presented herein. However, this prospective study investigated associations between three definitions of infant sleep problems, each of which included

multiple aspects of sleep problems including wake times, average night waking periods, and parental report of sleep disturbance, all of which contribute to excess weight (Jarrin et al., 2013; Olds et al., 2011; Liu et al., 2011).

A proposed hypothesis for the observed positive associations between sleep problems and childhood overweight in Grade 6 entails a behavioral and/or a biological explanation. From a behavioral standpoint, poor sleep practices observed in infancy, such as frequent night waking, late bedtime, co-sleeping, and/or lengthy sleep time arousal, can perpetuate into early childhood and adolescence; and these behavioral practices can potentially increase the risk of accumulation of adiposity (Richman, 1981; Zuckerman et al., 1987). These disruptions in sleep ultimately lead to an observed shorter sleep duration which is associated with a higher BMI (Jarrin et al., 2013). Indeed, a shorter duration of sleep generates more time to consume foods resulting in an

**Table 3**  
Associations between infant sleep problems per different definitions and childhood overweight and obesity in Grade 6, NICHD SECCYD<sup>a</sup>, 1991–2004 (n = 895).

	Zuckerman et al.		Richman		Lozoff et al.	
	Overweight <sup>b</sup> OR <sup>c</sup> (95% CI)	Obesity <sup>b</sup> OR <sup>c</sup> (95% CI)	Overweight <sup>b</sup> OR <sup>c</sup> (95% CI)	Obesity <sup>b</sup> OR <sup>c</sup> (95% CI)	Overweight <sup>b</sup> OR <sup>c</sup> (95% CI)	Obesity <sup>b</sup> OR <sup>c</sup> (95% CI)
Infant sleep problems <sup>d</sup>						
Yes	1.68 (1.11–2.55)	1.01 (0.65–1.56)	1.76 (1.05–2.97)	0.82 (0.45–1.50)	1.07 (0.66–1.74)	0.91 (0.57–1.47)
No	Referent	Referent	Referent	Referent	Referent	Referent
Maternal factors <sup>e</sup>						
Less than a bachelor's degree	1.21 (0.79–1.86)	1.96 (1.28–3.02)	1.17 (0.76–1.80)	1.98 (1.30–3.05)	1.22 (0.79–1.86)	1.97 (1.28–3.02)
At or below poverty line	2.52 (1.31–4.85)	2.11 (1.14–3.90)	2.59 (1.34–4.98)	2.15 (1.16–3.97)	2.65 (1.38–5.08)	2.12 (1.15–3.92)
Living single	0.66 (0.34–1.29)	0.88 (0.49–1.61)	0.67 (0.34–1.32)	0.88 (0.48–1.59)	0.66 (0.34–1.30)	0.89 (0.49–1.61)
Breastfeeding	0.80 (0.52–1.22)	0.63 (0.43–0.93)	0.77 (0.50–1.18)	0.64 (0.43–0.95)	0.80 (0.52–1.22)	0.64 (0.43–0.95)
Child factors <sup>e</sup>						
Male	0.93 (0.63–1.37)	1.17 (0.81–1.69)	0.93 (0.63–1.37)	1.16 (0.80–1.69)	0.94 (0.64–1.38)	1.17 (0.81–1.69)
Nonwhite	1.55 (0.90–2.65)	1.52 (0.92–2.53)	1.52 (0.89–2.61)	1.51 (0.91–2.51)	1.51 (0.88–2.58)	1.51 (0.91–2.51)
Birth weight (kg)	1.16 (0.79–1.72)	2.06 (1.42–2.99)	1.13 (0.76–1.67)	2.07 (1.43–3.01)	1.15 (0.78–1.70)	2.07 (1.43–3.00)

Abbreviations: OR, odds ratio; CI, confidence interval; NA, not available.

<sup>a</sup> NICHD SECCYD = National Institute of Child Health and Human Development Study of Early Child Care and Youth Development.

<sup>b</sup> Being overweight: BMI ≥ 85th but <95th percentile; Being obese: BMI ≥ 95th percentile.

<sup>c</sup> Odds ratio from multivariate multinomial regression adjusted for maternal characteristics (education, poverty, family structure, and breastfeeding) and child characteristics (sex, ethnicity, and birth weight).

<sup>d</sup> Infant sleep problems assessed at 6 months and/or 15 months of age.

<sup>e</sup> Poverty and family structure were assessed when child was 24 months. Other maternal and child characteristics were assessed when child was one month.

increase in caloric intake (Al Mamun et al., 2007). Likewise, a reduction in sleep produces daytime fatigue reducing the amount of physical activity (Al Mamun et al., 2007).

From a biological standpoint, it is believed that every somatic cell within the body has a circadian clock within, disruption of which renders a departure from metabolic homeostasis (Bray & Young, 2007). Problematic molecular effects can produce a disruption in normal endocrine functioning, such as a decline in leptin (appetite suppressor), and an elevation in ghrelin (appetite stimulator), insulin de-sensitivity, and changes in the autonomic nervous system— all of which are hormonal changes that directly contribute to the likelihood of developing an unfavorable BMI (Bray & Young, 2007).

Differences observed in the strength of associations between sleep problems, as defined by Richman (1981) and Zuckerman et al. (1987), and being overweight in Grade 6 are likely to be due to differential aspects of sleep behaviors assessed during infancy, and the operationalization of sleep problems, by these definitions. However, sleep problems were not found to be associated with being obese in Grade 6 using either Zuckerman et al. (OR = 1.01; 95% CI: 0.65–1.56) or Richman's (OR = 0.82; 95% CI: 0.45–1.50) definitions. Furthermore, sleep problems were not found to be related to being overweight or being obese using Lozoff et al. (1985) definition; this may be because Lozoff et al.'s definition is less severe, and that children defined as having disturbed sleep by Richman and Zuckerman et al. had likely worse problems.

Consistent with previous studies from developed countries (Barriuso et al., 2015), socioeconomic measures including low maternal education and low income (as measured by poverty status in this study) were associated with greater risk of childhood obesity. This finding highlights the importance of prevention strategies to improve the food and physical activity environments of low-income families including and not limited to increasing access to healthy foods, fresh food markets, and safe playgrounds and parks.

Also concordant with prior reports (McCrary & Layte, 2012; Marseglia et al., 2015), breastfeeding was negatively associated with childhood obesity in this study. While definitive underlying mechanisms are still unclear, inflammatory factors, particularly interleukin-6 and tumor necrosis factor- $\alpha$ , may be involved; these factors influence fat and lean body mass development in healthy infants (Fields & Demerath, 2012), enhance appetite signaling (Harder et al., 2005), promote child satiety-responsiveness and decrease over-eating (Davis et al., 2007). Thus, educational interventions targeting women of reproductive and child rearing ages may be useful.

Lastly, every 1 kg increase in birth weight doubled the risk of being obese in children in Grade 6 irrespective of how sleep problems were defined in infancy. Our findings of a positive association of higher birth weight and childhood obesity corroborates with results of a large systematic review of the literature where six studies from North America, Central America, Europe, and Asia were reported to have found strong and positive associations between higher birth weight and childhood overweight (Weng et al., 2012). Although there are no epigenetic studies of childhood overweight outcomes, two studies have recently found associations between placental and cord blood methylation levels of insulin growth factor 2 and higher birth weight (Soubry et al., 2015; St-Pierre et al., 2012).

The main strength of this study was its ability to test the independent prospective association between sleep problems in infancy and risk of overweight and obesity in Grade 6, while controlling for a range of potentially confounding factors. However, the results should be considered in the context of some limitations. There is a possibility of selection bias due to incomplete data or loss to follow-up. Further, the mothers who participated were slightly better educated and thus results may not be generalizable to subjects of all educational levels. Also, ethnic minority groups were not well represented in the sample to allow separate analyses for non-Hispanic African American or Hispanic children. This is mainly because SECCYD did not include a

representative sample of the U.S. population. Another limitation relates to use of maternal reports of infant sleep behaviors which generally lead to an underestimation of the frequency of night wakings; however, the overall pattern of night wakings tends to be undistorted. The SECCYD did not include parental height/weight data or data on dietary intake of the children in Phase I or Phase III; thus, neither of these two factors including the role of energy intake could be examined. Additional residual confounding remains possible due to other potential confounders such as duration of pregnancy. Moreover, although this study provides some evidence that less sleep during infancy results in a greater risk of being overweight in childhood, it remains uncertain whether the association in children is with duration of sleep or with sleep disturbance of another type. The current pediatric and adult literature suggests that it is the duration of sleep that is important. The confirmation of this may necessitate the development and provision of educational materials for mothers, child-care centers, and other caregivers of young children emphasizing recommended amounts of sleep as a way to achieve improved sleep, especially in children who are having sleep problems. Further research is needed to determine the magnitude of any effect of increasing sleep duration on population levels of obesity.

## 5. Conclusions

This study found that infant sleep problems, as defined by Richman (1981) and Zuckerman et al. (1987), increased the risk of childhood overweight in Grade 6 independent of child's birth weight, race, sex, breastfeeding, maternal education, family structure and poverty level. In contrast, infant sleep problems, as defined by Lozoff et al. (1985), were not found to be related to being overweight or being obese in Grade 6. More research is needed establish a standard definition of infant sleep problems to more accurately evaluate the link between sleep disturbances in infancy and future risk of childhood overweight and obesity.

## Conflict of interest statement

The authors declare that there are no conflicts of interest.

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