ARTICLE

Short Sleep Duration in Infancy and Risk of Childhood Overweight

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Objective: To examine the extent to which infant sleep duration is associated with overweight at age 3 years.

Design: Longitudinal survey.

Setting: Multisite group practice in Massachusetts.

Participants: Nine hundred fifteen children in Project Viva, a prospective cohort.

Main Exposure: At children's ages 6 months, 1 year, and 2 years, mothers reported the number of hours their children slept in a 24-hour period, from which we calculated a weighted average of daily sleep.

Main Outcome Measures: We used multivariate regression analyses to predict the independent effects of sleep duration (<12 h/d vs ≥12 h/d) on body mass index (BMI) (calculated as the weight in kilograms divided by the height in meters squared) *z* score, the sum of subscapular and triceps skinfold thicknesses, and overweight (BMI for age and sex ≥95th percentile) at age 3 years.

Results: The children's mean (SD) duration of daily sleep was 12.3 (1.1) hours. At age 3 years, 83 children (9%) were overweight; the mean (SD) BMI *z* score and sum of subscapular and triceps skinfold thicknesses were 0.44 (1.03) and 16.66 (4.06) mm, respectively. After adjusting for maternal education, income, prepregnancy BMI, marital status, smoking history, and breastfeeding duration and child's race/ethnicity, birth weight, 6-month weight-for-length *z* score, daily television viewing, and daily participation in active play, we found that infant sleep of less than 12 h/d was associated with a higher BMI *z* score (β, 0.16; 95% confidence interval, 0.02-0.29), higher sum of subscapular and triceps skinfold thicknesses (β, 0.79 mm; 95% confidence interval, 0.18-1.40), and increased odds of overweight (odds ratio, 2.04; 95% confidence interval, 1.07-3.91).

Conclusion: Daily sleep duration of less than 12 hours during infancy appears to be a risk factor for overweight and adiposity in preschool-aged children.

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DURING THE LAST 30 YEARS in the United States, the prevalence of overweight among youth has dramatically increased, even among preschool-aged children.[1-5] Approximately 26% of children aged 2 through 5 years are overweight or at risk for it.[4] Overweight in young children is associated with later obesity, conditions such as hyperlipidemia, hypertension, asthma, and type II diabetes,[6-9] and higher morbidity and mortality in adulthood.[10] Thus, examining determinants of overweight in the preschool-aged group could inform prevention interventions to help avoid lifetime complications of excess weight.

Experimental studies in adults have shown that sleep restriction results in reduced levels of the fat-derived hormone leptin and increased levels of the stomach-derived hormone ghrelin, which in turn could stimulate hunger and increase weight gain.[11,12] In epidemiologic studies, short sleep duration has been linked to weight gain, obesity, coronary artery disease, and diabetes in adults.[13-15] A similar inverse association between sleep duration and overweight has been observed in cross-sectional studies of older children and adolescents.[16-27] In one of the larger cross-sectional studies in children, von Kries et al[17] studied 6862 children aged 5 to 6 years and found that the prevalence of overweight, obesity, and excessive body fat was lower among those with longer duration of sleep after adjusting for several potential confounders, including parental obesity, socioeconomic status, and child's television viewing.

Limited longitudinal evidence exists regarding the relationship between sleep duration and weight gain in children.[28-30] In a study of 150 US children followed from birth to age 9.5 years, Agras et al[28] found a negative correlation (–0.21) between hours of sleep measured from ages 3 to 5 years and weight measured at age 9.5 years. That study was limited by a relatively small sample. In a prospective cohort study of 8234 children, Reilly et al[29] found that short sleep duration (<10.5 hours) at age 3 years was associated with obesity prevalence at age 7 years. Finally, in a study of 2281 children, Snell et al[30] found that 3- to 12-year-old children who slept less, went to bed later, or woke earlier had higher body mass indices (BMIs) (calculated as the weight in kilograms divided by the height in meters squared) 5 years later. These studies were limited, however, by not having repeated measures of sleep and overweight for longitudinal analyses and by having BMI as the only measure of adiposity. Furthermore, to our knowledge, there are no longitudinal studies that have examined the association of sleep duration during infancy with later overweight.

The purpose of this study was to examine the longitudinal association of short sleep duration between ages 6 months and 2 years (herein referred to as infancy) with adiposity and overweight at age 3 years.

METHODS

SUBJECTS AND STUDY DESIGN

The subjects for this study were participants in Project Viva, a prospective cohort study of gestational factors, pregnancy outcomes, and offspring health.[31] We recruited women who were attending their initial prenatal visit at 8 urban and suburban obstetrical offices of a multispecialty group practice in eastern Massachusetts. Eligibility criteria included fluency in English, gestational age less than 22 weeks at the initial prenatal clinical appointment, and singleton pregnancy. Details of recruitment and retention procedures are available elsewhere.[31]

Of the 2128 women who delivered a live singleton infant, 1579 were eligible for 3-year follow-up and 1401 children completed the study visit at age 3 years. We excluded 125 participants who were missing 3-year height or weight data. Because our main exposure was a weighted average of sleep duration based on 3 time points (ages 6 months, 1 year, and 2 years), we excluded 361 participants who did not have data for all of these 3 time points. Thus, our sample size for analysis was 915 mother-infant pairs. Comparison of the 915 participants in this analysis with the full 2128 participants who delivered showed some differences. For example, the subjects in this analysis as compared with the full group had higher percentages of white participants (78% vs 66%, respectively) and educated participants (76% vs 64% ≥ college graduate, respectively) as well as slightly higher household incomes (69% vs 61% > $70 000/year, respectively), but the groups did not differ on mean maternal prepregnancy BMI or birth weight.

After obtaining informed consent, we performed in-person study visits with both mother and child immediately after delivery and at 6 months and 3 years post partum. At each in-person visit, we measured child length or height and weight; at 3 years, we also measured skinfold thicknesses. Mothers completed mailed questionnaires at 1 and 2 years post partum, on which they reported child sleep duration. Institutional review boards of participating institutions approved the study. All of the procedures were in accordance with the ethical standards for human experimentation established by the Declaration of Helsinki.

MEASUREMENTS

Main Exposure

At 6 months post partum, we asked mothers 3 questions about their child's sleep: (1) "In the past month, on average, for how long does your baby nap during the morning?"; (2) "In the past month, on average, for how long does your baby nap during the afternoon?"; and (3) "In the past month, on average, how many hours does your baby sleep during the night?" Response options were in hours and minutes. At 1 year post partum, we asked, "In the past month, on average, for how long does your child sleep in a usual 24-hour period? Please include morning naps, afternoon naps, and nighttime sleep." Response options were in hours and minutes. At 2 years post partum, we asked parents to report the number of hours their child slept in a usual 24-hour period on an average weekday and weekend day in the past month. Response categories included less than 9, 9, 10, 11, 12, 13, and 14 or more hours per day. To calculate a weighted average of sleep duration from ages 6 months to 2 years, we created a sum that was weighted by the interval of time between the data collection of all of the 3 data points and divided the sum by 2.

Outcome Measures

We measured height and weight of children using a calibrated stadiometer (Shorr Productions, Olney, Maryland) and scale (Seca model 881; Seca Corp, Hanover, Maryland). We calculated age- and sex-specific weight-for-length and BMI *z* scores using US national reference data.[32] At age 3 years, we also measured subscapular (SS) and triceps (TR) skinfold thicknesses using Holtain calipers (Holtain Ltd, Crosswell, Wales) and calculated the sum (SS + TR) and ratio (SS/TR) of the 2 thicknesses. We defined overweight as a BMI for age and sex at the 95th percentile or greater and at risk for overweight as a BMI for age and sex between the 85th and 95th percentiles.[32] Research assistants performing all of the measurements followed standardized techniques[33] and participated in biannual in-service training to ensure measurement validity (Irwin J. Shorr, MPH, MPS, Shorr Productions). Interrater and intrarater measurement errors were well within published reference ranges for all of the measurements.[34]

Other Measures

Using a combination of self-administered questionnaires and interviews, we collected information about maternal age, education, parity, and prenatal smoking (never, former, during pregnancy), household income, and child's race/ethnicity. Mothers reported their prepregnancy weight and height and paternal weight and height. We obtained infants' birth weights and 1- and 2-year lengths and weights from medical records. At 2 years, we asked mothers to report the number of hours their children were involved in active play (such as running, jumping, and climbing) on an average weekday and weekend day in the past month. We also asked parents to report the number of hours their children watched television or videos on an average weekday and weekend day in the past month. Response categories included 0, less than 1, 1 to 3, 4 to 6, 7 to 9, and 10 or more hours per day. We calculated a weighted average of television or video viewing from ages 6 months to 2 years by creating a sum that was weighted by the interval of time between the data collection of all of the 3 data points and dividing the sum by 2.

STATISTICAL ANALYSIS

Our main exposure of interest was infant sleep duration of less than 12 h/d vs 12 h/d or more. In secondary analyses, we also examined changes in sleep duration from ages 6 months to 1 year, 1 to 2 years, and 2 to 3 years with changes in weight-for-length *z* score during the same periods.

We first examined the bivariate relationships of sleep duration with other covariates and our main outcomes, which were BMI *z* score, SS + TR, SS/TR, and overweight. We then used multiple linear and logistic regression models to assess the independent effects of sleep duration on our main outcomes. In multivariate models, we included only those covariates that were of a priori interest or confounded associations of sleep duration with child adiposity. Model 1 was unadjusted except for age and sex in models predicting SS + TR and SS/TR. In addition, because we were interested in fat distribution after controlling for overall body size, we further adjusted for child's BMI *z* score in our analyses of SS/TR. Multivariate model 2 included maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity. In multivariate model 3, we additionally adjusted for child's birth weight and weight-for-length *z* score at age 6 months. Because television viewing and physical activity could be confounders or intermediates of the relationship between sleep and adiposity, in multivariate models 4 and 5, we additionally adjusted for child's average television or video viewing and child's daily hours of participation in active play. We report regression estimates (β) or odds ratios and 95% confidence intervals (CIs) for the main predictor. In our logistic regression models, the comparison group was those whose BMI was from the 5th percentile to lower than the 85th percentile.

Because television viewing is a known risk factor for overweight in children and was substantially related to sleep duration, we explored the extent to which our outcomes were modified by varying combinations of sleep duration and television viewing. Thus, we examined BMI *z* score, SS + TR, and odds of overweight within 4 strata: (1) high sleep duration and low television viewing duration; (2) high sleep duration and high television viewing duration; (3) low sleep duration and low television viewing duration; and (4) low sleep duration and high television viewing duration. For these analyses, we split television viewing duration above and below 2 h/d as recommended by the American Academy of Pediatrics and the Committee on Public Education.[35]

In secondary analyses, we studied the effects of contemporaneous changes in sleep duration with changes in weight-for-length *z* score. For these analyses, we included 1045 participants with 2250 observations who had at least 2 consecutive points of exposure and outcome data. In the multivariate longitudinal analyses, we related change in sleep duration from ages 6 months to 1 year to change in weight-for-length *z* score from ages 6 months to 1 year and likewise for the ages from 1 to 2 years and 2 to 3 years. Because each child could contribute up to 3 observations, the assumption of independent observations required by ordinary regression models was not met, so we used mixed linear regression models[36] with estimation by SAS PROC MIXED. We conducted all of the analyses using SAS version 9.1 statistical software (SAS Institute, Inc, Cary, North Carolina).

RESULTS

Children slept mean (SD) durations of 12.3 (1.9) h/d at age 6 months, 12.8 (1.6) h/d at age 1 year, and 12.0 (1.2) h/d at age 2 years. The weighted mean (SD) daily sleep duration from ages 6 months to 2 years was 12.3 (1.1) hours. At age 3 years, the mean (SD) for BMI *z* score was 0.44 (1.03), for SS + TR was 16.66 (4.06) mm, and for SS/TR was 0.64 (0.16); 9% of the children were overweight.

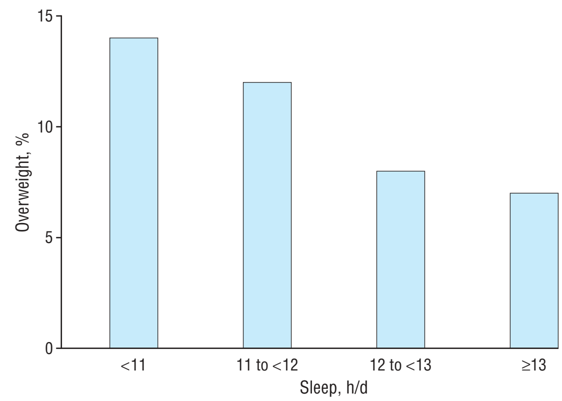

Figure 1. Unadjusted relationship of infant sleep duration with overweight prevalence at age 3 years. Data from 915 Project Viva participants.

In bivariate analyses (**Figure 1**), we observed an approximately 2-fold higher prevalence of overweight among children who slept less than 12 hours in a 24-hour period. Although fewer hours of sleep were associated with higher overweight prevalence across the range (Figure 1), we observed the steepest increase in overweight among children who slept less than 12 hours in a 24-hour period. We thus dichotomized infant sleep duration to less than 12 h/d vs 12 h/d or more in further analyses. Children whose parents were single or divorced or who lived in homes with lower household incomes and lower maternal educational attainment were more likely to sleep less than 12 h/d (**Table 1**). In addition, children who were black, Hispanic, or of other race/ethnicity were more likely than white children to sleep less than 12 h/d (Table 1). Shorter sleep duration was also associated with more hours of television viewing (Table 1).

In multivariate analyses, adjusting for maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity, birth weight, 6-month weight-for-length *z* score, average daily television viewing, and daily participation in active play, we found that infant sleep of less than 12 h/d was associated with a higher BMI *z* score (β, 0.16; 95% CI, 0.02-0.29), higher SS + TR (β, 0.79; 95% CI, 0.18-1.40), and increased odds of overweight (odds ratio, 2.04; 95% CI, 1.07-3.91). Adjustment for child's television viewing and participation in active play only minimally changed the observed associations between sleep duration and our anthropometric outcomes (**Table 2**).

Compared with children with high levels of sleep and low levels of television viewing, those with low levels of sleep *or* high levels of television viewing separately had somewhat increased odds of overweight and adiposity (**Table 3**). However, the combination of low levels of sleep *and* high levels of television viewing appeared to

Table 1. Bivariate Associations of Selected Parent and Child Characteristics With Infant Sleep Duration, With Data From 915 Mother-Infant Pairs From Project Viva

Characteristic	Overall (N = 915)	Sleep Duration From Ages 6 mo to 2 y, Mean, h/d: < 11 (n = 105)	11 to < 12 (n = 224)	12 to < 13 (n = 314)	≥ 13 (n = 272)	*P* for Trend
Maternal						
Age, mean (SD), y	32.6 (4.8)	32.4 (5.4)	32.6 (5.5)	32.9 (4.3)	32.4 (4.4)	.63
Prepregnancy BMI, mean (SD)	24.4 (4.9)	25.0 (4.6)	24.4 (4.9)	24.6 (5.2)	23.9 (4.5)	.19
Gestational weight gain, mean (SD), kg	15.6 (5.3)	15.0 (5.5)	15.9 (5.7)	15.5 (4.9)	15.7 (5.3)	.55
Household income > $70 000, %	66	56	65	76	74	< .001
College graduate or more, %	76	57	77	82	75	.007
Multipara, %	51	56	48	48	55	.71
Married or cohabiting, %	95	93	92	96	97	.01
Smoked during early pregnancy, %	8	12	10	8	7	.07
Paternal						
BMI, mean (SD)	26.4 (3.7)	26.3 (3.7)	26.4 (4.3)	26.2 (3.5)	26.5 (3.5)	.88
Child						
Male, %	50	45	55	51	47	.60
Race/ethnicity, %						< .001
White	73	45	66	80	83	
Black	10	22	13	6	6	
Hispanic	3	9	3	2	2	
Other	14	25	18	12	10	
Overweight at age 3 y, %	9	13	12	7	7	.05
Birth weight, mean (SD), kg	3.51 (0.56)	3.41 (0.64)	3.49 (0.49)	3.52 (0.58)	3.55 (0.56)	.18
BMI *z* score at age 3 y, mean (SD)	0.44 (1.03)	0.50 (1.12)	0.52 (1.05)	0.39 (1.02)	0.40 (0.98)	.43
Sum of SS and TR skinfold thicknesses at age 3 y, mean (SD), mm	16.66 (4.06)	16.63 (5.07)	17.00 (4.36)	16.39 (3.87)	16.71 (3.58)	.41
Ratio of SS and TR skinfold thicknesses at age 3 y, mean (SD)	0.64 (0.16)	0.68 (0.16)	0.64 (0.15)	0.63 (0.16)	0.63 (0.16)	.06
Duration of breastfeeding, mean (SD), mo	6.6 (4.5)	6.1 (4.8)	6.7 (4.6)	6.8 (4.5)	6.4 (4.3)	.50
Television viewing at age 2 y, mean (SD), h/d	1.4 (1.1)	1.8 (1.6)	1.5 (1.3)	1.4 (1.0)	1.2 (0.86)	< .001
Active play at age 2 y, mean (SD), h/d	3.1 (1.8)	3.2 (1.8)	3.3 (1.8)	3.0 (1.7)	3.0 (1.8)	.30

Abbreviations: BMI (calculated as the weight in kilograms divided by the height in meters squared); SS, subscapular; TR, triceps.

Table 2. Associations of Infant Sleep Duration With Child Anthropometry at Age 3 Years[a]

Model	β (95% CI): BMI *z* Score	Sum of SS and TR Skinfold Thicknesses, mm[b]	Ratio of SS and TR Skinfold Thicknesses[c]	OR (95% CI): BMI ≥ 95th Percentile[d]
Model 1, unadjusted	0.12 (−0.02 to 0.26)	0.34 (−0.21 to 0.89)	0.02 (0.002 to 0.04)	1.84 (1.16 to 2.92)
Model 2, model 1 + maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity	0.11 (−0.03 to 0.25)	0.53 (−0.03 to 1.08)	0.02 (−0.01 to 0.04)	1.78 (1.07 to 2.94)
Model 3, model 2 + child's birth weight and 6-mo weight-for-length *z* score	0.16 (0.03 to 0.29)	0.68 (0.10 to 1.25)	0.02 (−0.008 to 0.04)	1.94 (1.04 to 3.64)
Model 4, model 3 + daily television viewing	0.15 (0.01 to 0.29)	0.77 (0.16 to 1.37)	0.01 (−0.01 to 0.04)	1.96 (1.03 to 3.73)
Model 5, model 4 + daily active play	0.16 (0.02 to 0.29)	0.79 (0.18 to 1.40)	0.01 (−0.01 to 0.04)	2.04 (1.07 to 3.91)

Abbreviations: BMI, body mass index (calculated as the weight in kilograms divided by the height in meters squared); CI, confidence interval; OR, odds ratio; SS, subscapular; TR, triceps.
[a] Estimates are for sleep duration of less than 12 h/d vs 12 h/d or more.
[b] All of the models were adjusted for child's age and sex.
[c] All of the models were adjusted for child's age, sex, and BMI *z* score.
[d] The comparison group was children with a BMI from the 5th percentile to lower than the 85th percentile.

be synergistic and was associated with markedly higher BMI *z* scores, SS + TR, and SS/TR and increased odds of overweight (Table 3). In **Figure 2**, we show the covariate-adjusted predicted probability of overweight at age 3 years among the 4 combinations of sleep and television viewing. Children who slept less than 12 h/d and viewed 2

Table 3. Associations Between Infant Sleep Duration and Television Viewing With Child Anthropometry at Age 3 Years[a]

	Sleep and Television Viewing Duration Groups			
Multivariate-Adjusted Anthropometric Outcome at Age 3 y[b]	High Sleep, Low Television (n = 477)	High Sleep, High Television (n = 85)	Low Sleep, Low Television (n = 242)	Low Sleep, High Television (n = 54)
BMI *z* score, β (95% CI)	0 [Reference]	0.19 (−0.04 to 0.41)	0.16 (0.01 to 0.31)	0.35 (0.09 to 0.62)
Sum of SS and TR skinfold thicknesses, β (95% CI)	0 [Reference]	0.27 (−0.69 to 1.24)	0.61 (−0.05 to 1.27)	1.62 (0.47 to 2.78)
Ratio of SS and TR skinfold thicknesses, β (95% CI)	0 [Reference]	−0.01 (−0.05 to 0.03)	0.01 (−0.02 to 0.04)	0.04 (−0.01 to 0.09)
Overweight, OR (95% CI)[c]	1 [Reference]	1.91 (0.69 to 5.28)	1.83 (0.87 to 3.85)	5.93 (2.03 to 17.30)

Abbreviations: BMI, body mass index (calculated as the weight in kilograms divided by the height in meters squared); CI, confidence interval; OR, odds ratio; SS, subscapular; TR, triceps.

[a] Groups are split above and below sleep duration of 12 h/d and above and below television viewing of 2 h/d.

[b] Adjusted for maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity, daily active play, birth weight, and 6-month weight-for-length *z* score.

[c] Comparing BMI at the 95th percentile or higher vs BMI at the 5th percentile to lower than the 85th percentile.

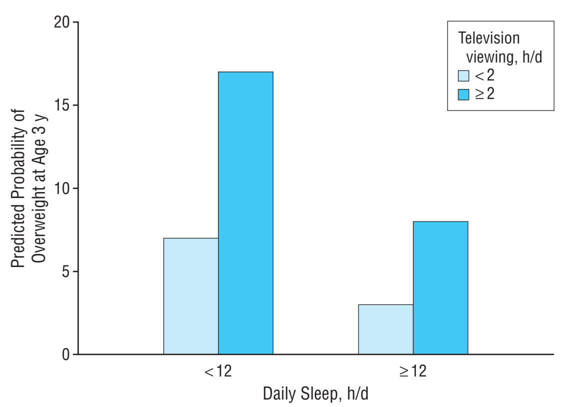

Figure 2. Predicted percentage of overweight at age 3 years according to daily sleep duration and television viewing, adjusted for child race/ethnicity, birth weight, and breastfeeding duration and maternal smoking status, education, household income, marital status, and prepregnancy body mass index (calculated as the weight in kilograms divided by the height in meters squared).

h/d or more of television had a predicted 3-year overweight probability of 17%.

In secondary analyses, we examined contemporaneous changes in sleep duration with changes in weight-for-length *z* score during a 3-year period. Between ages 6 months and 1 year, children increased their mean (SD) sleep duration by 0.50 (1.97) h/d and decreased their mean (SD) weight-for-length *z* scores by 0.43 (0.81). From ages 1 to 2 years, children decreased their mean (SD) sleep duration by 0.79 (1.48) h/d and decreased their mean (SD) weight-for-length *z* score by 0.29 (0.94). Finally, from ages 2 to 3 years, children decreased their mean (SD) sleep duration by 0.80 (1.26) h/d and increased their mean (SD) weight-for-length *z* score by 0.40 (0.85). After adjusting for maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity, change in television viewing, birth weight, and baseline adiposity, the mean weight-for-length *z* score increased by 0.02 (95% CI, 0.003-0.05) for each 1-h/d decrease in sleep duration (**Table 4**).

Table 4. Multivariate-Adjusted Interval Change in Weight-for-Length *z* Score Associated With Change in Sleep Duration From Ages 6 Months to 3 Years[a]

Model	Change in Weight-for-Length *z* Score per Sleep Decrement of 1 h/d, β (95% CI)[b]
Model 1, unadjusted	0.05 (0.02-0.07)
Model 2, model 1 + maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child's race/ethnicity and change in television viewing	0.05 (0.02-0.07)
Model 3, model 2 + child's birth weight and baseline weight-for-length *z* score	0.02 (0.003-0.05)

Abbreviations: BMI, body mass index (calculated as the weight in kilograms divided by the height in meters squared); CI, confidence interval.

[a] The longitudinal data are from 1045 mother-infant pairs (2250 observations) from Project Viva.

[b] Multivariate models combine associations of change in sleep duration from ages 6 months to 1 year with change in weight-for-length *z* score from ages 6 months to 1 year, change in sleep duration from ages 1 to 2 years with change in weight-for-length *z* score from ages 1 to 2 years, and change in sleep duration from ages 2 to 3 years with change in weight-for-length *z* score from ages 2 to 3 years.

COMMENT

In this prospective cohort of children, sleep duration of less than 12 h/d during infancy was associated with increased child adiposity, measured by both BMI and skinfold thickness, and with 2-fold increased odds of overweight at age 3 years. The adverse effect of sleep curtailment was especially marked among children who also watched at least 2 hours of television per day.

To our knowledge, this is the first study to report associations of *infant* sleep duration and child adiposity. Our findings are consistent with those from cross-sectional studies of older children and adolescents that have observed an inverse association between sleep duration and adiposity.[16-25] Our results extend to findings of recent longitudinal studies[28-30] of preschool-aged children that found an inverse association between sleep duration, measured at age 3 years and beyond, and childhood overweight, measured at ages 7 to 9 years. We were also able to examine contemporaneous changes in sleep duration with changes in adiposity and found that decreases in sleep during a 2½- to 3-year period were associated with small incremental increases in adiposity.

The mechanisms underlying the association between sleep duration and adiposity are unclear.[37] Experimental studies in adults have shown that sleep restriction can result in changes in levels of certain hormones controlling hunger and appetite. In a randomized crossover study of 12 healthy adult men, Spiegel et al[11] found that sleep restriction was associated with reductions in leptin levels and elevations in ghrelin levels as well as increased appetite. Similarly, Taheri et al[12] found low levels of leptin and high levels of ghrelin among a convenience sample of 1024 adult men and women who had short sleep duration. Lower leptin levels and higher ghrelin levels are likely to increase appetite, possibly leading to excessive energy intake and increased BMI. It is also possible that extra time awake may provide increased opportunity for food intake.[37] Alternatively, sleep duration may alter energy expenditure, ie, sleep restriction may lead to daytime somnolence and reduced activity, which may increase weight.[15]

In this study cohort, children who were nonwhite or of lower socioeconomic status slept fewer hours in a 24-hour period. Because these factors may also be associated with risk for childhood overweight, concern exists that the observed associations may reflect sociodemographic confounding rather than a causal relationship. However, adjustment for maternal education, income, and marital status and child's race/ethnicity only minimally influenced our observed effect estimates. Further research is warranted to determine the reasons for shorter sleep duration among children living in households of low socioeconomic status and among children of minority racial/ethnic groups.

Television viewing is a known risk factor for childhood overweight and could be a confounder of the relationship between sleep and adiposity. Although we found that child's sleep duration was inversely associated with television viewing, adjustment for television viewing in our multivariate models only minimally influenced our effect estimates. Alternatively, it is possible that the relationship between sleep and adiposity may differ for varying levels of television viewing. We found that the combination of low sleep duration and high television viewing duration predicted the greatest odds of overweight. Our findings lend support to childhood overweight prevention interventions that target both reduction in television viewing and ensuring adequate sleep duration.

Our study had several strengths. First, we collected longitudinal data on sleep duration beginning in early infancy (age 6 months) through age 2 years and used repeated measures of sleep and adiposity to examine contemporaneous changes in both. Second, we adjusted our analyses for a large number of potential sociodemographic and environmental predictors of childhood adiposity. Finally, we analyzed child skinfold thicknesses as well as heights and weights. Most previous studies used BMI as the only outcome. Our study also had limitations. Although mothers in the study had diverse racial/ethnic backgrounds, their education and income levels were relatively high. Our results may not be generalizable to more socioeconomically disadvantaged populations. Second, in any observational study, it is possible that unmeasured characteristics might explain the observed associations between exposure and outcome. Third, although we had research-level measures of weight and length at age 3 years, we obtained these measures from medical records at birth and age 2 years. Finally, we measured sleep duration by mother's report on the questionnaires as opposed to using an objective measure of sleep such as accelerometers or diaries. However, the potential misclassification of sleep duration is likely nondifferential with respect to overweight, and any resulting bias should be toward the null.

CONCLUSIONS

A growing body of evidence suggests that sleep deprivation has adverse effects on weight. In this prospective study of preschool-aged children, sleep duration of less than 12 hours in a 24-hour period in the first 2 years of life was associated with higher adiposity and greater odds of overweight at age 3 years. Strategies to improve sleep duration among young children may be an important component of behavioral interventions that promote childhood overweight prevention. Our findings suggest that clinicians and parents may wish to use evidence-based sleep hygiene techniques to improve sleep quality and perhaps increase sleep duration.[38]

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REFERENCES

1. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999-2000. *JAMA*. 2002;288(14):1728-1732.
2. Mei Z, Scanlon KS, Grummer-Strawn LM, Freedman DS, Yip R, Trowbridge FL. Increasing prevalence of overweight among US low-income preschool children: the Centers for Disease Control and Prevention pediatric nutrition surveillance, 1983 to 1995. *Pediatrics*. 1998;101(1):E12.
3. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999-2002. *JAMA*. 2004;291(23):2847-2850.
4. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA*. 2006;295(13):1549-1555.
5. Kim J, Peterson KE, Scanlon KS, et al. Trends in overweight from 1980 through 2001 among preschool-aged children enrolled in a health maintenance organization. *Obesity (Silver Spring)*. 2006;14(7):1107-1112.
6. Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord*. 1999;23(suppl 2):S2-S11.
7. Freedman DS, Khan LK, Dietz WH, Srinivasan SR, Berenson GS. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics*. 2001;108(3):712-718.
8. Dietz WH. Overweight and precursors of type 2 diabetes mellitus in children and adolescents. *J Pediatr*. 2001;138(4):453-454.
9. Taveras EM, Rifas-Shiman SL, Gold DR, et al. Infant weight-for-length as a predictor of wheeze in early childhood. *Pediatr Res*. 2005;58(5):1029.
10. Dietz WH. Childhood weight affects adult morbidity and mortality. *J Nutr*. 1998;128(2)(suppl):411S-414S.
11. Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Ann Intern Med*. 2004;141(11):846-850.
12. Taheri S, Lin L, Austin D, Young T, Mignot E. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. *PLoS Med*. 2004;1(3):e62. doi:10.1371/journal.pmed.0010062.
13. Ayas NT, White DP, Al-Delaimy WK, et al. A prospective study of self-reported sleep duration and incident diabetes in women. *Diabetes Care*. 2003;26(2):380-384.
14. Ayas NT, White DP, Manson JE, et al. A prospective study of sleep duration and coronary heart disease in women. *Arch Intern Med*. 2003;163(2):205-209.
15. Patel SR, Malhotra A, White DP, Gottlieb DJ, Hu FB. Association between reduced sleep and weight gain in women. *Am J Epidemiol*. 2006;164(10):947-954.
16. Locard E, Mamelle N, Billette A, Miginiac M, Munoz F, Rey S. Risk factors of obesity in a five year old population: parental vs environmental factors. *Int J Obes Relat Metab Disord*. 1992;16(10):721-729.
17. von Kries R, Toschke AM, Wurmser H, Sauerwald T, Koletzko B. Reduced risk for overweight and obesity in 5- and 6-y-old children by duration of sleep: a cross-sectional study. *Int J Obes Relat Metab Disord*. 2002;26(5):710-716.
18. Sekine M, Yamagami T, Handa K, et al. A dose-response relationship between short sleeping hours and childhood obesity: results of the Toyama Birth Cohort Study. *Child Care Health Dev*. 2002;28(2):163-170.
19. Chaput JP, Brunet M, Tremblay A. Relationship between short sleeping hours and childhood overweight/obesity: results from the “Québec en Forme” Project. *Int J Obes (Lond)*. 2006;30(7):1080-1085.
20. Gupta NK, Mueller WH, Chan W, Meininger JC. Is obesity associated with poor sleep quality in adolescents? *Am J Hum Biol*. 2002;14(6):762-768.
21. Kagamimori S, Yamagami T, Sokejima S, et al. The relationship between lifestyle, social characteristics and obesity in 3-year-old Japanese children. *Child Care Health Dev*. 1999;25(3):235-247.
22. Vioque J, Torres A, Quiles J. Time spent watching television, sleep duration and obesity in adults living in Valencia, Spain. *Int J Obes Relat Metab Disord*. 2000;24(12):1683-1688.
23. Padez C, Mourao I, Moreira P, Rosado V. Prevalence and risk factors for overweight and obesity in Portuguese children. *Acta Paediatr*. 2005;94(11):1550-1557.
24. Knutson KL. Sex differences in the association between sleep and body mass index in adolescents. *J Pediatr*. 2005;147(6):830-834.
25. Chen MY, Wang EK, Jeng YJ. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. *BMC Public Health*. 2006;6:59.
26. Seicean A, Redline S, Seicean S, et al. Association between short sleeping hours and overweight in adolescents: results from a US Suburban High School survey. *Sleep Breath*. 2007;11(4):285-293.
27. Eisenmann JC, Ekkekakis P, Holmes M. Sleep duration and overweight among Australian children and adolescents. *Acta Paediatr*. 2006;95(8):956-963.
28. Agras WS, Hammer LD, McNicholas F, Kraemer HC. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *J Pediatr*. 2004;145(1):20-25.
29. Reilly JJ, Armstrong J, Dorosty AR, et al; Avon Longitudinal Study of Parents and Children Study Team. Early life risk factors for obesity in childhood: cohort study. *BMJ*. 2005;330(7504):1357.
30. Snell EK, Adam EK, Duncan GJ. Sleep and the body mass index and overweight status of children and adolescents. *Child Dev*. 2007;78(1):309-323.
31. Gillman MW, Rich-Edwards JW, Rifas-Shiman SL, Lieberman ES, Kleinman KP, Lipshultz SE. Maternal age and other predictors of newborn blood pressure. *J Pediatr*. 2004;144(2):240-245.
32. National Center for Health Statistics. 2000 CDC growth charts: United States. http://www.cdc.gov/growthcharts/. Accessed January 4, 2008.
33. Shorr IJ. *How to Weigh and Measure Children*. New York, NY: United Nations; 1986.
34. Mueller WH, Martorell R. Reliability and accuracy of measurement. In: Lohman TG, Roche AF, Martorell R, eds. *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books; 1988.
35. American Academy of Pediatrics; Committee on Public Education. Children, adolescents, and television. *Pediatrics*. 2001;107(2):423-426.
36. Laird NM, Ware JH. Random-effects models for longitudinal data. *Biometrics*. 1982;38(4):963-974.
37. Taheri S. The link between short sleep duration and obesity: we should recommend more sleep to prevent obesity. *Arch Dis Child*. 2006;91(11):881-884.
38. Mindell JA, Kuhn B, Lewin DS, Meltzer LJ, Sadeh A. Behavioral treatment of bedtime problems and night wakings in infants and young children. *Sleep*. 2006;29(10):1263-1276.