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.
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.

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. Research assistants performing all of the measurements followed standardized techniques 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.

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.

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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 ($\beta$) 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.

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 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.

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). 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 ($\beta$, 0.16; 95% CI, 0.02-0.29), higher SS + TR ($\beta$, 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
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 1. Bivariate Associations of Selected Parent and Child Characteristics With Infant Sleep Duration, With Data From 915 Mother-Infant Pairs From Project Viva

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Overall (N = 915)</th>
<th>&lt; 11 (n = 105)</th>
<th>11 to &lt; 12 (n = 224)</th>
<th>12 to &lt; 13 (n = 314)</th>
<th>≥ 13 (n = 272)</th>
<th>P for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maternal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>32.6 (4.8)</td>
<td>32.4 (5.4)</td>
<td>32.6 (5.5)</td>
<td>32.9 (4.3)</td>
<td>32.4 (4.4)</td>
<td>.63</td>
</tr>
<tr>
<td>Prepregnancy BMI, mean (SD)</td>
<td>24.4 (4.9)</td>
<td>25.0 (4.6)</td>
<td>24.4 (4.9)</td>
<td>24.6 (5.2)</td>
<td>23.9 (4.5)</td>
<td>.19</td>
</tr>
<tr>
<td>Gestational weight gain, mean (SD), kg</td>
<td>15.6 (5.3)</td>
<td>15.0 (5.5)</td>
<td>15.9 (5.7)</td>
<td>15.5 (4.9)</td>
<td>15.7 (5.3)</td>
<td>.55</td>
</tr>
<tr>
<td>Household income ≥ $70,000, %</td>
<td>66</td>
<td>56</td>
<td>65</td>
<td>76</td>
<td>74</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>College graduate or more, %</td>
<td>76</td>
<td>57</td>
<td>77</td>
<td>82</td>
<td>75</td>
<td>.007</td>
</tr>
<tr>
<td>Multitask, %</td>
<td>51</td>
<td>56</td>
<td>48</td>
<td>48</td>
<td>55</td>
<td>.71</td>
</tr>
<tr>
<td>Married or cohabiting, %</td>
<td>95</td>
<td>93</td>
<td>92</td>
<td>96</td>
<td>97</td>
<td>.01</td>
</tr>
<tr>
<td>Smoked during early pregnancy, %</td>
<td>8</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>.07</td>
</tr>
<tr>
<td><strong>Paternal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI, mean (SD)</td>
<td>26.4 (3.7)</td>
<td>26.3 (3.7)</td>
<td>26.4 (4.3)</td>
<td>26.2 (3.5)</td>
<td>26.5 (3.5)</td>
<td>.88</td>
</tr>
<tr>
<td><strong>Child</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male, %</td>
<td>50</td>
<td>45</td>
<td>55</td>
<td>51</td>
<td>47</td>
<td>.60</td>
</tr>
<tr>
<td>Race/ethnicity, %</td>
<td></td>
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<td></td>
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<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>White</td>
<td>73</td>
<td>45</td>
<td>66</td>
<td>80</td>
<td>83</td>
<td>.05</td>
</tr>
<tr>
<td>Black</td>
<td>10</td>
<td>22</td>
<td>13</td>
<td>6</td>
<td>6</td>
<td>.43</td>
</tr>
<tr>
<td>Hispanic</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>.05</td>
</tr>
<tr>
<td>Other</td>
<td>14</td>
<td>25</td>
<td>18</td>
<td>12</td>
<td>10</td>
<td>.06</td>
</tr>
<tr>
<td>Overweight at age 3 y, %</td>
<td>9</td>
<td>13</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>.05</td>
</tr>
<tr>
<td>Birth weight, mean (SD), kg</td>
<td>3.51 (0.56)</td>
<td>3.41 (0.64)</td>
<td>3.49 (0.49)</td>
<td>3.52 (0.58)</td>
<td>3.55 (0.56)</td>
<td>.18</td>
</tr>
<tr>
<td>BMI z score at age 3 y, mean (SD)</td>
<td>0.44 (1.03)</td>
<td>0.30 (1.12)</td>
<td>0.52 (1.05)</td>
<td>0.39 (1.02)</td>
<td>0.40 (0.98)</td>
<td>.43</td>
</tr>
<tr>
<td>Sum of SS and TR skinfold thicknesses</td>
<td>16.66 (4.06)</td>
<td>16.63 (5.07)</td>
<td>17.00 (4.36)</td>
<td>16.39 (3.87)</td>
<td>16.71 (3.58)</td>
<td>.41</td>
</tr>
<tr>
<td>Ratio of SS and TR skinfold thicknesses at age 3 y, mean (SD), mm</td>
<td>0.64 (0.16)</td>
<td>0.68 (0.16)</td>
<td>0.64 (0.15)</td>
<td>0.63 (0.16)</td>
<td>0.63 (0.16)</td>
<td>.06</td>
</tr>
<tr>
<td>Duration of breastfeeding, mean (SD), mo</td>
<td>6.6 (4.5)</td>
<td>6.1 (4.8)</td>
<td>6.7 (4.6)</td>
<td>6.8 (4.5)</td>
<td>6.4 (4.3)</td>
<td>.50</td>
</tr>
<tr>
<td>Television viewing at age 2 y, mean (SD), h/d</td>
<td>1.4 (1.1)</td>
<td>1.8 (1.6)</td>
<td>1.5 (1.3)</td>
<td>1.4 (1.0)</td>
<td>1.2 (0.86)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Active play at age 2 y, mean (SD), h/d</td>
<td>3.1 (1.8)</td>
<td>3.2 (1.8)</td>
<td>3.3 (1.8)</td>
<td>3.0 (1.7)</td>
<td>3.0 (1.8)</td>
<td>.30</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI z Score</td>
<td>Sum of SS and TR Skinfold Thicknesses, mm</td>
</tr>
<tr>
<td>Model 1, unadjusted</td>
<td>0.12 (0.02 to 0.26)</td>
</tr>
<tr>
<td>Model 2, model 1 + maternal education, income, prepregnancy BMI, marital status, prenatal smoking history, and breastfeeding duration and child’s race/ethnicity</td>
<td>0.11 (0.03 to 0.25)</td>
</tr>
<tr>
<td>Model 3, model 2 + child’s birth weight and 6-mo weight-for-length z score</td>
<td>0.16 (0.03 to 0.29)</td>
</tr>
<tr>
<td>Model 4, model 3 + daily television viewing</td>
<td>0.15 (0.01 to 0.29)</td>
</tr>
<tr>
<td>Model 5, model 4 + daily active play</td>
<td>0.16 (0.02 to 0.29)</td>
</tr>
</tbody>
</table>

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.
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 0.53 (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 (2.16) 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).

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. Our results extend to findings of recent longitudinal studies of preschool-aged children that found an inverse association between sleep du-
12 healthy adult men, Spiegel et al11 found that sleep is associated with hunger and appetite. In a randomized crossover study of 12 healthy adult men, Spiegel et al11 found that sleep restriction was associated with reductions in leptin levels and elevations in ghrelin levels as well as increased appetite. Similarly, Taheri et al12 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 Alternately, sleep duration may alter energy expenditure, ie, sleep restriction may lead to daytime somnolence and reduced activity, which may increase weight.13

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 lower 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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Correspondence: Elsie M. Taveras, MD, MPH, Obesity Prevention Program, Department of Ambulatory Care and Prevention, Harvard Pilgrim Health Care and Harvard Medical School, 133 Brookline Ave, Sixth Floor, Boston, MA 02215 (elsie_taveras@hpwc.org).

Author Contributions: Dr Taveras had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Taveras, Oken, Gunderson, and Gillman. Acquisition of data: Gillman. Analysis and interpretation of data: Taveras, Rifas-Shiman, and Oken. Drafting of the manuscript: Taveras, Rifas-Shiman, and Oken. Critical revision of the manuscript for important intellectual content: Rifas-Shiman, Oken, Gunderson, and Gillman. Statistical analysis: Rifas-Shiman. Obtained funding: Gillman. Administrative, technical, and material support: Taveras, Oken, and Gillman. Study supervision: Gillman.

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