Sleep Duration and Adiposity During Adolescence

WHAT’S KNOWN ON THIS SUBJECT: Some epidemiologic evidence suggests an inverse association between sleep duration and obesity in various age groups. However, in the case of adolescents, inconsistent results have been reported, which can be partly explained by methodologic options.

WHAT THIS STUDY ADDS: Our study supports an effect of sleep duration in adiposity during adolescence and found gender differences in this association. The results are consistent by using either the traditional longitudinal approach or cross-lagged modeling.

abstract

BACKGROUND AND OBJECTIVE: The association between sleep and obesity has been described in different age groups. However, there are not sufficient data to clarify the inconsistent results reported in adolescents. Our objective was to study the associations between sleep duration and adiposity at 13 and at 17 years of age, with both cross-sectional and longitudinal approaches.

METHODS: We evaluated, as part of an urban population-based cohort (EPITeen), 1171 adolescents at both 13 and 17 years of age. Sleep duration was estimated by self-reported bedtimes and wake-up times. Age- and gender-specific BMI z scores were calculated based on Centers for Disease Control and Prevention references. Body fat percentage (BF%) was assessed by bioelectrical impedance. Regression coefficients (β) and respective 95% confidence intervals (CIs) were used to estimate the association between sleep and BMI z scores and BF%. Additionally, a cross-lagged analysis was performed to investigate the causal relations.

RESULTS: In the cross-sectional analysis, at 13 years, sleep duration was inversely associated with BMI z score only in boys (β = −0.155, 95% CI: −0.267 to −0.043); at 17 years, a positive association was found among girls but was only significant for BF% (β = 0.510, 95% CI: 0.061–0.958). In the longitudinal approach, sleep duration at age 13 was inversely associated with BMI z score (β = −0.123, 95% CI: −0.233 to −0.012) and BF% (β = −0.731, 95% CI: −1.380 to −0.081) at 17 years only in boys. These significant associations disappeared after adjustment for adiposity at 13 years. These results were corroborated by those from cross-lagged analysis.

CONCLUSIONS: Our results showed an effect of sleep duration in adiposity at younger ages of adolescence and suggested gender differences in this association. Pediatrics 2012;130:1–9
Overweight is a major public health issue with high prevalence in both adulthood and childhood\textsuperscript{1-4} and negative health consequences in children and adolescents\textsuperscript{5,6} and in adulthood.\textsuperscript{5,7} Apart from direct health consequences, overweight also has social and economic repercussions. From the standpoint of public health,modifiable risk factors, such as environmental and behavioral factors, are those most promising in terms of prevention and control of the obesity epidemic. Therefore, several studies have focused their research on the role of food intake and physical activity in overweight. However, in recent years, the role of other factors, such as sleep duration, has gained attention.\textsuperscript{8,9} Sleep deprivation could influence the energy balance and consequently weight gain through various pathways, such as interfering in the regulation mechanisms of leptin, ghrelin, cortisol, and glucose or promoting patterns of behavior that cause weight gain (eating behavior and physical inactivity).\textsuperscript{10}

In children, a consistent association was found between short sleep duration and increased risk of obesity.\textsuperscript{11,12} In adolescents, fewer studies are available,\textsuperscript{13-17} and their results are not as consistent as in younger children. Although some of them found an inverse association,\textsuperscript{15,16,18} others, which used nationally representative surveys, reported inconsistent associations.\textsuperscript{15,17,19} The reasons for these differences among studies have not been clarified, making it necessary to produce new data that help us to understand the relation between sleep duration and weight gain in adolescents.

The importance of the effect of short sleep duration on weight gain has gained attention because there is evidence that sleep duration appears to have declined in recent decades.\textsuperscript{20} The analysis of 3 birth cohorts (1974, 1979, and 1986) from Switzerland showed a decreasing trend of the mean total sleep duration across cohorts due to progressively later bedtime and unchanged wake-up time across decades.\textsuperscript{20} Adolescence is also characterized by great changes in body composition\textsuperscript{21} that may not be detectable by BMI. Thus, if we intend to understand the effect of sleep on adiposity, other parameters such as body fat need to be examined. We therefore aimed to study the associations between sleep duration and adiposity (BMI and body fat) during adolescence by using both a cross-sectional and longitudinal approach.

**METHODS**

**Participants**

The study population consisted of urban adolescents, members of the EPITeen cohort. As previously reported,\textsuperscript{22} adolescents born in 1990 and enrolled at public and private schools in Porto during 2003–2004 were invited to participate. The evaluation included self-administered questionnaires and a physical examination, performed by a trained team.

The second evaluation took place in the 2007–2008 school year, and adolescents were evaluated by using the same procedures.

At baseline, 2160 adolescents agreed to participate (77.5\% of participation rate). Among these, 1716 (79.4\%) participated in the second evaluation of the cohort. Of the 1716 participants reevaluated, we excluded those participants who did not have complete information in both evaluations regarding weight or height (n = 95), body fat percentage (BF\%\%; n = 10), and sleep duration (n = 197). We also excluded those with missing values in potential confounders: parental education (n = 3), age at menarche (n = 9), and diet (n = 231), resulting in a final sample of 1171 participants.

We compared the 1171 participants included in this analysis with those not included (considering exclusions and losses of follow-up). Those not included tended to be more frequently from public schools (82.3\% vs 71.4\%, P < .001) and had less educated parents (parental education <6 years: 37.3\% vs 19.8\%). No significant differences were found according to gender and BMI at baseline.

**Variables**

Participants were asked to report usual bedtimes and wake-up times on weekdays. Sleep duration was estimated by the difference between self-reported bedtimes and wake-up times.

Parental education level was measured as the number of successfully completed years of formal schooling, and a new variable was created considering the information of the parent with the higher education level. The variable was used as continuous.

The questions used to assess physical activity and inactivity were based on a questionnaire usually applied to adolescents, the Young Finns Study.\textsuperscript{23} In our study, we used the self-perception of intensity of usual leisure-time activities according to 4 subjective categories (mainly sitting, mainly standing, active, or very active) for the measurement of physical activity.

Food intake was recorded by using a food frequency questionnaire (FFQ)\textsuperscript{24,25} regarding the previous 12 months, completed by the adolescents with the help of their parents or legal guardians. We computed a diet quality index based on the Mediterranean Diet Quality Index for children and adolescents (KIDMED).\textsuperscript{26} Because we did not have information about foods eaten at breakfast, we eliminated the 2 questions about “cereals or grains” and “a dairy product” for breakfast. Our index was thus based on 14 items, with a score ranging from −4 to 10, with
a higher score corresponding to a diet closer to the Mediterranean diet.

Weight and height were obtained with the subject in light indoor clothes and no shoes, by using standard procedures. BMI z scores were computed according to Centers for Disease Control and Prevention growth charts. BF% was estimated by bioelectrical impedance (Tanita TBF-300, Tanita Corporation of America, Inc, Arlington Heights, IL), and it is presented as the percentage of total body weight. Changes in BMI and in BF% were computed by a subtraction between the respective values at 17 years minus the values at 13 years. For BMI, we used the z scores of BMI, and for BF% we used the original variable in percentage.

Statistical Analyses

Statistical analyses were performed by using SPSS, version 17.0 (SPSS Inc, Chicago, IL). Quantitative variables between 2 independent samples were compared by using the Mann-Whitney or Kruskal-Wallis test. The χ² test was used to compare qualitative variables. Normality was checked by using the Shapiro-Wilk test.

To evaluate the association between participants’ characteristics and sleep duration, we used linear regression models, calculating regression coefficients (β) and respective 95% confidence intervals (CIs). Regression coefficients and 95% CIs were also used to estimate the association between sleep duration (independent variable) and either BMI z score or BF% at baseline, at follow-up, and their changes between the 2 time points. For the construction of final models, we included the variables that were significantly associated with the outcome in the univariate analysis. Additionally, to minimize other sources of confounding, we also included the variables KIDMED index and leisure-time activities, which, although not significantly associated, were relevant as possible confounders. In the first model, we adjusted the estimates for parental education and KIDMED index, when the exposure was sleep at 13 years, and we adjusted for parental education, when the exposure was sleep at 17 years. In model 2, we adjusted for the same variables in model 1 plus adiposity (BMI or BF%) at age 13.

Regarding the assumptions for regression analyses, we tested the homoscedasticity of the errors and the normality of the error distribution. Although in some cases, the assumptions were not completely achieved, they were considered acceptable. For instance, in some cases, the distribution of the errors was not normal, considering the Shapiro-Wilk test, but it was considered closer to the normal distribution on the basis of histogram interpretation and considering the central limit theorem.

Additionally, we performed a cross-lagged analysis examining the temporal relationship between sleep duration and BMI and also between sleep duration and BF%. These analyses were performed as path analyses within a structural equation modeling framework by using Mplus 5. In a first analysis, sleep duration and BMI at 17 years were the dependent variables and predictors were sleep and BMI at 13 years. The model has 3 components: an analysis between sleep and BMI at each age, a longitudinal analysis of each variable across the 2 ages, and the analysis of the cross-lags (sleep at 13 years with BMI at 17 years, and vice versa). Additionally, the analyses included parental education and KIDMED index as control variables.

The cross-lagged analyses were repeated in an identical manner but with BF% instead of BMI. The following criteria were used to assess the model fit: the χ² statistic test that evaluates the overall fit of the model (nonsignificant χ² values indicate that the model fits the data well; however, this index is sensitive to sample size), the root mean square error of approximation, which quantifies the divergence between the data and a proposed model per degree of freedom (values should be ≤.05), and the comparative fit index, which ranges between 0 and 1 and represents the proportionate improvement in model fit by comparing the fitted model with an independence model (indices >.90 are considered good).

Ethical Considerations

The study was approved by the Ethics Committee of Hospital São João, and policies and procedures were developed to guarantee data confidentiality and protection. Parents and adolescents received written and oral information explaining the purpose and the design of the study and written informed consent was obtained from both.

RESULTS

Participants’ characteristics at baseline and at follow-up are presented in Table 1.

The median (25th; 75th percentiles) sleep duration at baseline was 9.0 (range 8.5–9.5) hours, which decreased to 8.2 (range 7.5–9.0) hours at follow-up. In general, participants who presented higher sleep duration at baseline had the higher decrease in sleep duration but remained the ones with longer sleep duration at follow-up. Considering the association between participants’ characteristics and sleep duration (Table 2), only parental education was positively associated with sleep duration at age 17 (β = 0.026, 95% CI: 0.007–0.046) among boys.

To estimate cross-sectional and longitudinal associations between sleep at
13 years and BMI or BF%, we adjusted the model for parental education and KIDMED index. When the exposure was sleep duration at 17 years, we adjusted the model only for parental education. We also tested the effect of leisure time activities at 13 and 17 years, when the exposure was sleep at 13 or at 17 years, respectively. Additionally, because physical activity may change from baseline to follow-up, we also tested a model including the variable measuring the variation in physical activity between the 2 evaluations. The results were similar, and these variables were not included in the final model.

In the cross-sectional analysis at age 13, after adjustment, sleep duration was inversely associated with BMI z score only in boys ($\beta = -0.155, 95\% CI: -0.267 to -0.043$; Table 3), but it was not associated with BF% in either boys or girls (Table 4). Regarding cross-sectional analysis at 17 years, a significant and positive association was found only for BF% among girls ($\beta = 0.510, 95\% CI: 0.061–0.958$; Table 4).

In the longitudinal approach, we analyzed the effect of sleep duration by using 2 outcomes: adiposity at 17 years and the change in adiposity measured by the difference between 13 and 17 years. Regarding the difference in BMI z score, 48% presented differences higher than $-0.2$ SD, 33% maintained their BMI (differences in BMI between $-0.2$ and $+0.2$ SD), and 19% increased their BMI by $>0.2$ SD. Considering the linear regression models, sleep

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**TABLE 1** Participants' Characteristics at 13 and at 17 Years of Age

<table>
<thead>
<tr>
<th>Age at menarche, y*</th>
<th>Girls</th>
<th>Boys</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 y</td>
<td>12 (11–13)</td>
<td>12 (9–17)</td>
<td>.004</td>
</tr>
<tr>
<td>Parental education, y*</td>
<td>11 (7–15)</td>
<td>12 (9–17)</td>
<td>.004</td>
</tr>
</tbody>
</table>

**TABLE 2** Association Between Participants' Characteristics and Sleep Duration at Age 13 and 17 Years

<table>
<thead>
<tr>
<th>Exposures at 13 y</th>
<th>Girls</th>
<th>Boys</th>
<th>$F$</th>
<th>$R^2$</th>
<th>Girls</th>
<th>Boys</th>
<th>$F$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at menarche, y</td>
<td>$0.004 (−0.043 to 0.051)$</td>
<td>$0.028$</td>
<td>$0.001$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Parental education, y</td>
<td>$−0.011 (−0.025 to 0.003)$</td>
<td>$2.375$</td>
<td>$0.004$</td>
<td>$−0.007 (−0.021 to 0.007)$</td>
<td>$0.873$</td>
<td>$0.002$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure-time activities</td>
<td>$0.963$</td>
<td>$0.005$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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* Medians (25th – 75th).

* p (%).

* According to Centers for Disease Control and Statistics percentiles.27
duration at age 13 was inversely associated with adiposity at 17 years in boys (BMI z score: $\beta = -0.123$, 95% CI: $-0.233$ to $-0.012$; BF%: $\beta = -0.731$, 95% CI: $-1.380$ to $-0.081$) and positively associated with the changes in BMI z score between ages 13 and 17 years in girls ($\beta = 0.050$, 95% CI: 0.002–0.097; Tables 3 and 4). Regarding these longitudinal analyses, we created a second model, adjusting for the same variables in model 1 plus the adiposity...
(BMI z score or BF%) at age 13. We found that after adjustment for baseline adiposity, the associations previously described were no longer statistically significant (Tables 3 and 4).

Regarding cross-lagged analysis, Fig 1 presents the model examining the temporal relationship between sleep duration and BMI in girls and boys, adjusting for parental education and KIDMED score. Sleep duration at 17 was predicted by sleep duration at 13 years, and BMI at 17 was significantly predicted by BMI at 13 years in both girls and boys. Regarding the cross-lagged effect from sleep at 13 years to BMI at 17 years, there was not a statistically significant association in either girls ($\beta = 0.041, P = .085$) or boys ($\beta = 0.013, P = .635$). The correlations between sleep duration and BMI at the same age were only significant in boys at 13 years ($r = -.086, P = .016$).

The cross-lagged model for BF% is presented in Fig 2. The cross-lagged effects were also not significant in both girls and boys. The association between BF% at 13 and at 17 years was statistically significant in girls ($\beta = 0.661, P < .001$) and in boys ($\beta = 0.569, P < .001$). In addition to the significant association between sleep across the 2 ages, we also found a positive significant correlation between sleep at 17 years and BF% at 17 years in girls ($r = .506, P = .018$).

### DISCUSSION

Among girls, we found a positive association between sleep duration and adiposity, significant for BF%. In contrast, for boys, we found an inverse association between sleep duration and adiposity at 13 years, significant only for BMI. Also in boys, a significant inverse association was found between sleep duration at 13 years and BF% at 17 years, although the statistical significance disappeared after adjustment for BF% at age 13.

To address the problem of reverse causation and to investigate the causal relations, we also model the relationship between sleep and adiposity by

**FIGURE 1**
The temporal relationship between sleep duration and BMI: A, for girls; B, boys. Straight lines represent regression coefficients; curved lines represent correlations. Coefficients in the model are adjusted for parental education and KIDMED index, and those with $P < .05$ are printed in bold. CFI, comparative fit index; RMSEA, root-mean-square error of approximation.

**FIGURE 2**
The temporal relationship between sleep duration and body fat (BF%): A, for girls; B, for boys. Straight lines represent regression coefficients; curved lines represent correlations. Coefficients in the model are adjusted for parental education and KIDMED index, and those with $P < .05$ are printed in bold. CFI, comparative fit index; RMSEA, root-mean-square error of approximation.
using cross-lagged analysis. The results from these models corroborated those from linear regression models.

A large set of evidence supports the inverse association between sleep duration and BMI found in boys.\(^{14,16,31–33}\) Other studies, like ours, support the gender differences showing no association in girls.\(^{13,17}\) One possible explanation would be a different duration of sleep between girls and boys; however, the median sleep duration was similar according to gender at both 13 and 17 years. These gender differences might also be due to physiologic gender differences during adolescence. Because girls experience greater changes in fat mass during early adolescence compared with boys,\(^{44}\) the effect of sleep could be masked in girls and not in boys, especially at age 13 when endocrine changes are more pronounced for girls. At 17 years, when most changes have occurred, we were able to find an association between sleep duration and BF% in girls. However, we were not able to find a reasonable explanation for the direction of this association. A possible explanation would be a U-curve relationship between sleep duration and BMI, as described in some cross-sectional studies in adults.\(^{35,36}\) However, our data do not allow the quality of sleep to be taken into account. Another possible limitation is the methodology used to estimate sleep duration. However, for weeknights, a study of high school adolescents found high correlations between actigraphy and self-reported bedtimes (\(r = .70\)) and wake-up times (\(r = .77\)).\(^{39}\) Thus, even with limitations on the accurate quantification of sleep time, we can accept that our measure is good enough to discriminate our participants according to their sleep duration. Additionally, it is possible that a measurement error might have given rise to nondifferential misclassification and the associations between sleep and adiposity may be underestimated.

Regarding the measurements of body composition, because BMI does not distinguish fat mass from fat-free mass,\(^{40,41}\) we also studied the BF% as outcome. Bioelectrical impedance of 2 components is not the reference method, but it is one of the most widely used methods because of its ease of use, and it is considered an accurate technique in the measurement of body composition.\(^{42,43}\) Additionally, because the error in estimating fat mass by bioelectrical impedance is expected to be consistent across the range of body composition,\(^{44}\) this error would have a minor effect on the estimation of the association according to sleep duration by gender. The analysis with BF% allowed us to detect some effects from sleep duration in girls, not identified with BMI. In contrast, the association found between sleep and BMI in boys at 13 years was not significant by using BF%, although it was in the same direction. We cannot exclude the error on body fat measurement as a possible explanation for this loss of power in boys because an underestimation of fat mass among boys measured by bioelectrical impedance has been reported.\(^{44}\) These results support the theory of gender differences in the association between sleep and adiposity and should be better addressed and clarified.

In relation to the outcome variables, the limitations related with the use of raw differences in BMI z scores between the 2 ages must also be recognized. However, we examined the distribution of the difference in BMI z score, and this variable mainly represents those participants whose BMI decreased. Additional analysis (data not shown) of sleep duration according to changes in BMI z score showed that higher sleep duration is associated with smaller decreases in BMI. This is in accordance with the cross-sectional result in which higher sleep duration was inversely associated with BMI, and subjects with lower BMI at baseline were less likely to register a decrease in BMI between the 2 ages.

The dietary intake in our study was measured through an FFQ developed by our department, validated for an adult population and adapted to be applied in adolescents.\(^{45}\) The FFQ is a useful instrument for the evaluation of diet in population-based studies, allowing for discrimination according to usual energy and nutrient intakes.\(^{46}\) Although our FFQ was only validated in adults,
REFERENCES


CONCLUSIONS

Among girls, sleep duration was directly associated with body fat in the cross-sectional analysis at 17 years. Among boys, sleep duration was inversely associated with both adiposity measures in the cross-sectional analysis at age 13. The longitudinal effect found in boys disappears after adjustment for adiposity measures at 13 years, reinforcing the theory that the influence of sleep duration may be more relevant at younger ages in this group.

Our data and results from other studies underline the fact that sleep duration should be assessed in clinical practice to promote longer sleep duration in short sleepers. However, caution is necessary regarding upper limits of sleep duration because a possible U-shape association has not yet been clearly established.


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Pediatrics; originally published online October 1, 2012;
DOI: 10.1542/peds.2011-1116

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Pediatrics; originally published online October 1, 2012;
DOI: 10.1542/peds.2011-1116

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