Effect of Experimental Change in Children's Sleep Duration on Television Viewing and Physical Activity

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What is already known about this subject?

- Observational studies with children demonstrate associations between reported sleep duration, television viewing, and daytime activity.
- Experimental studies with adults demonstrate changes in daytime energy expenditure when sleep length is extended and restricted, but findings are not always consistent.

What this study adds

- The present study demonstrates that compared to when rested, when sleep is restricted, children report watching more television.
- Compared to when they are rested, when sleep is restricted, children are, on average, less active, but accrue greater activity given longer hours awake.
- Findings provide support for activity pathways influencing associations between sleep duration and child obesity risk.

Abstract

Background: Pediatric observational studies demonstrate associations between sleep, television viewing and potential changes in daytime activity levels.

Objective(s): To determine whether experimental changes in sleep lead to changes in children's sedentary and physical activities.

Methods: Using a within-subjects counterbalanced design, 37 children 8-11 years old completed a three-week study. Children slept their typical amount during a baseline week, and were then randomized to increase or decrease mean time in bed by 1.5 hours/night for one week; the alternate schedule was completed the final week. Children wore actigraphs on their nondominant wrist and completed three-day physical activity recalls each week.

Results: Children reported watching more television ($p < .001$), and demonstrated lower daytime actigraph-measured activity counts per epoch ($p = .03$) when sleep was decreased (compared to increased). However, total actigraph-measured activity counts accrued throughout the entire waking period were higher when sleep was decreased (and children were awake for longer) than when it was increased ($p < .001$).

Conclusion(s): Short sleep during childhood may lead to increased television viewing, and decreased mean activity levels. Although additional time awake may help to counteract negative effects of short sleep, increases in reported sedentary activities could contribute to weight gain over time.

Clinical Trials Registration: NCT01030107

Introduction

Studies consistently demonstrate cross-sectional and prospective associations between sleep and obesity risk in children[1-4] with emerging evidence also demonstrating associations with cardiometabolic outcomes as well. [5] A number of pathways have been implicated in the association between sleep and obesity risk[1] with most studies to date focusing on changes in the neuroendocrine control of food intake. Several experimental studies with adults provide support for this pathway by demonstrating that short sleep results in changes in hunger and satiety signaling hormones, ghrelin and leptin,[6-10] as well as changes in ad libitum food intake.[11-13] However, findings have not always been consistent,[9,10,14] including mixed findings in studies with adolescents.[15,16] Although observational studies demonstrate associations between sleep and eating behaviors in children,[17-19] less is known about how changes in sleep lead to changes in obesity risk. A recent experimental study with school-age children demonstrated that compared to one week of enhanced sleep, when sleep was restricted for one week, 8-11-year-old children reported consuming 134 kcal/day more and weighed approximately 0.5 lbs more.[20] Thus evidence suggests that similar changes in eating behaviors may account, in part, for associations between sleep and weight status in pediatric samples as well.

Fewer studies have assessed how changes in sleep may influence energy expenditure. Results from adult experimental studies have been mixed. Schmid and colleagues[14] found that, compared to a rested condition, when sleep was restricted, accelerometer-estimated physical activity under free-living conditions (i.e., outside of the laboratory) decreased. Similarly, Benedict and colleagues[9] found that, compared to a rested condition, daytime energy expenditure as measured by indirect calorimetry decreased following 24-hour sleep deprivation. In contrast, others have found either no effect of sleep on activity[12] or that sleep restriction leads to increased activity/energy expenditure[11,13] with additional hours awake accounting, in part, for observed increases.[13] We are unaware of any such studies with school-age children, yet observational studies suggest that shortened sleep duration is associated with increased sedentary activities, particularly television viewing.[21-24] However, similar to findings with adults, associations between sleep and physical activity in children have been mixed.[25-27]

The purpose of the present study was to determine whether experimental changes in children's sleep lead to changes in daytime activities. Specifically, we hypothesized that compared to a one-week increased sleep condition, one week of restricted sleep would lead to reported increases in television viewing and decreases in moderate to vigorous physical activity. During the decreased sleep condition, children would also evidence lower activity counts (as measured by actigraphy) during waking hours.

Methods

Participants

Thirty-nine children 8-11 years old who slept approximately 9.5 hours per night (i.e., between 9.25 and 9.75 hours per night based on parent report) were enrolled. The criterion for sleep duration was chosen given that national estimates suggest that mean sleep length for school-aged children is approximately 9.5 hours/night,[28] and to enable both extension and restriction of sleep duration without reaching a ceiling for what children could sleep and minimizing risks associated with sleep restriction, respectively. To ensure that undetected medical conditions would not affect outcomes, children also needed to be at or above the 5th percentile body mass index (BMI) for their age and gender, but no more than 100% overweight (i.e., having a BMI that is no more than twice the mean BMI for a given age and sex). They were considered ineligible if diagnosed with a medical/psychiatric condition or current medication that could affect sleep or weight status. Thirty-seven (95%) children completed the study. Two families chose to discontinue participation due to health concerns associated with sleeping too little during the decreased sleep condition. Mean (SD) age of participants was 9.6 (1.0) years old. Eighty-one percent were non-Hispanic White, 57% were male, and 27% were overweight/obese; mean (SD) body mass index z-score (zBMI) was 0.21 (0.89).

Procedures

Families were recruited between March 2009 and December 2011 from southeastern New England through the use of mailers, advertisements, and flyers posted throughout the community and on the Center website, which invited participation in a study assessing how changes in children's sleep affect their daytime behaviors. Families were first screened by phone and those who appeared eligible attended individual orientations during which written consent was obtained from parents and assent from children. Final eligibility for the study was determined during a baseline assessment of their typical week of sleep. During the baseline week, if the mean reported time in bed (TIB) was approximately 9.5 hours/night and the actigraph was consistent with self-report, children were enrolled. Sleep achieved during this week also served as the starting point for prescribing changes in TIB during the two experimental conditions.

Eligible participants were randomized using a variably sized permuted blocks randomization procedure (stratified by weight status: normal weight versus overweight/obese) to increase or decrease TIB by 1.5 hours/night for 1 week. The alternate schedule was completed the subsequent and final week of the study, which allowed for a prescribed 3 hour/night TIB difference between the increase and decrease conditions. Changes in TIB were achieved by changing bedtimes; wake times remained constant. Naps were not allowed. Throughout the study, children wore actigraphs on their non-dominant wrist, completed sleep diaries, and called the research center twice daily (to confirm adherence to the prescribed sleep schedule). Families completed three day (two weekdays and one weekend day) Previous Day Physical Activity Recalls (PDPARs)[29] during each week. They were compensated up to $75 each week ($5 per day for adhering to the sleep schedule and calling the Center; $40 for each in-laboratory assessment). All procedures were approved by the Institutional Review Board at the Miriam Hospital.

Measures

Anthropometrics. Child height and weight were measured by trained staff while children were in street clothes without shoes. Weight was measured using a calibrated digital scale (Tanita BWB-800; Arlington Heights, IL) to the nearest 0.1 pound. Height was measured to the nearest mm with wall-mounted stadiometers (Perspective Enterprises, Portage, MI). Weight status (normal weight versus overweight/obese) and zBMI were calculated using each child's age- and sex-appropriate sample from the Centers for Disease Control and Prevention (CDC) normative data.[30]

Sleep. Sleep was measured with Actiwatch 2 actigraphs (AW2; Phillips Respironics, Bend, OR), which children wore on their non-dominant wrist for 24-hours/day throughout the study. AW2s have demonstrated reliability and validity when compared with polysomnography in children.[31] Devices were configured to collect data in one-minute epochs using a medium sensitivity threshold. Data were scored for sleep versus wake using Actiware software, version 5.59.0015. Consistent with recommended procedures, children completed sleep diaries to help establish sleep onset and wake times.[32] Upon downloading the actigraph data using the Actiware software, discrepancies between self-report and actigraph-estimated sleep versus wake (e.g., actigraph demonstrates sleep onset occurring > 15 minutes earlier than self-report) were reviewed with families; issues remaining after this review (e.g., families could not remember) were rectified during consensus meeting with CNH, MAC and study staff. Sleep onset and wake times were then entered into the Actiware software to establish sleep periods for each night (i.e., the time between estimated sleep onset and wake the next day). All children had at least 5 nights of valid actigraph-measured sleep during each experimental condition.

Physical Activity. The Previous Day Physical Activity Recall (PDPAR), which has demonstrated reliability and validity,[29] was used to assess reported engagement in sedentary and physical activities. During each experimental week, study staff prescribed two weekdays and one weekend day for which families reported on children's activities in 30-min increments from 06:00–23:30. Staff reviewed PDPARs with families to ensure accuracy in completion. Metabolic equivalent (MET) values were computed for each 30-min block with reference to the compendium of energy expenditure in youth,[33] and categorized into different intensities of activity (i.e., very light, light, medium, and hard). Given its association with sleep[21-24] and obesity risk[34] and that the American Academy of Pediatrics (AAP) provides guidelines regarding television viewing in hours/day,[35] total time spent watching television each day was also computed by adding each 30-min block of time devoted to it. Variables of interest included mean percent time in moderate-to-vigorous intensity physical activity (MVPA), and mean hours watching television during each week.

To obtain an objective estimate of energy expenditure, daytime activity counts on the AW2s were examined. Two variables were of interest: 1) mean activity counts per epoch, and 2) total daily activity counts. These two different approaches to the data were of interest based on findings with adults suggesting that decreased sleep is associated with lower average activity levels, yet increased overall energy expenditure (possibly due to the additional time awake).[11-14,36]

Data Analysis

Data were analyzed using Stata version 14.0. Tukey's ladder of powers indicated that square root transformations were most appropriate for all study outcomes. Results were unaffected by whether raw or transformed data were analyzed. All participants experienced both increased and decreased sleep conditions, but order was counterbalanced. Cluster sandwich estimators were used to adjust standard errors for repeated measures. The statistical model that was applied adjusted for sleep condition, presentation order and trial, i.e., $y_{it} = b_{0i} + b_1 \times IncreasedSleep + b_2 \times PresentationOrder + b_3 \times Trial + e_{it}$. Interactions were not considered due to the incomplete nature of the experimental design. Because results were identical with raw and transformed data, and with and without adjusting for additional features of the design, results are reported here based on paired t-tests of raw data for greatest ease of interpretation.

Results

The table presents baseline values (i.e., prior to randomization) for reported television viewing and engagement in MVPA as well as average AW2 activity counts/epoch and total AW2 activity counts accrued throughout the day. Overall, baseline values fall between the values observed during the increased and decreased sleep conditions (Table 1). Supporting the success of the experimental manipulation, children achieved a mean 2 hour 21 minute difference in the actigraph-measured sleep period during the increase and decrease conditions, $t_{paired} = 38.00$, $p < .001$. Detailed information on experimental differences in actigraph-measured sleep was previously reported.[20]

Compared to when children increased their sleep, when they decreased their sleep, they reported watching an additional hour of television each day ($p < .001$) (Table 1). There were no reported differences on the PDPAR for percent time in MVPA ($p = .97$). During the decreased sleep condition, AW2 activity counts demonstrated that children were less active on average (i.e., per epoch) than during the increased condition ($p = .03$). However, total activity counts accrued throughout the entire day were higher during the decrease than the increase condition ($p < .001$).

Discussion

Findings demonstrate that experimental changes in sleep lead to changes in reported television viewing and objective assessment of activity in school-age children. Specifically, children reported watching one additional hour per day of television following sleep restriction, and on average, were less active. These findings build upon previous experimental studies by focusing on a pediatric sample and on energy expenditure (as opposed to pathways associated with energy intake) as well as assessing sedentary and physical activities outside of a laboratory setting.

The present findings suggest that compared to a rested condition, when sleep is restricted, objective estimates of daytime activity were, on average, lower. In contrast, we also observed a seemingly opposite effect of sleep restriction for total activity counts accrued throughout the day. Although children had lower activity counts per epoch during the decreased sleep condition, additional hours awake likely helped to compensate for these lower mean activity levels such that children were able to accumulate more activity throughout the day (given that they were awake for almost 2.5 hours more during this experimental condition). This observation is consistent with the mixed findings in the adult literature. In general, studies that focused on daytime activity/energy expenditure observed decreased activity/energy expenditure following sleep restriction.[9,14] However, studies that assessed energy expenditure throughout the 24-hour period and/or during all waking hours generally found that total activity/energy expenditure either did not differ[12] or was greater following sleep restriction than rest.[11,13] It is also interesting to note that, despite greater observed energy expenditure in some studies, even greater increases in energy intake have been observed, which was associated with weight gain when sleep was restricted.[13] This finding is consistent with what we have observed in this sample of school-aged children. Although children accrued more activity counts throughout the entire day during the decreased sleep condition, they also reported an increase in caloric intake, which resulted in a net increase in how much they weighed.[20]

In addition to children's objectively measured activity level, when sleep was decreased, children reported watching an additional hour of television each day. We are unaware of any additional experimental studies that have assessed how changes in sleep affect television viewing. However, findings are consistent with extant observational studies, which have demonstrated associations between greater television viewing and both short sleep, [21-24,37] and increased sleep disturbances[37] in pediatric samples. It is important to consider observed reported increases in television viewing reported herein in light of the previously reported findings from the present study, which demonstrated reported increases in caloric intake and higher measured weight following one week of sleep restriction.[20] Taken together with evidence suggesting that increased television viewing may be associated with weight gain via increased food intake,[38], findings from the present experimental study suggest that short sleep may predispose a child to be more sedentary, which in turn may lead to increased food intake. Particularly given high levels of insufficient sleep and a high proportion of children who exceed current recommendations for television viewing,[35] future work should explore how sedentary activities such as television viewing may mediate the effect of short sleep on obesity risk.

Strengths of the study include the use of an experimental study design in school-age children, and the high levels of participant adherence to the prescribed changes in sleep, which allows for a valid test of the influence of sleep on activity outcomes. In addition to these strengths, limitations include use of self-report to measure television viewing and engagement in MVPA. Thus, reporting bias cannot be ruled out. In particular, given research documenting that children accrue MVPA in short bouts,[39,40] the 30-minute blocks of time used for reporting activity in the present study may have precluded our ability to observe changes in MVPA engagement. Differences in findings in the present study for self-report and objective measures may be due, at least in part, to this limitation. They may also be due to the fact that the wrist-worn devices used in the present study only provide data on activity counts, which cannot be converted into metabolic equivalents; hip-worn devices are currently considered the best way to assess daytime physical activity.[41] Future studies would benefit from the use of hip-worn accelerometers to better capture engagement in MVPA. Given that this is, to our knowledge, the first study to assess changes in activity following experimental changes in children's sleep, findings nonetheless provide a signal for the effect of sleep on engagement in subsequent daytime activity.

In conclusion, changes in children's nocturnal sleep are associated with changes in reported television viewing and objectively estimated daytime activity. Findings suggest that in addition to changes in the neuroendocrine control of food intake, sleep may also affect activity pathways that could increase children's obesity risk. Thus, sleep may represent a modifiable health behavior to be considered for public health interventions that are aimed at obesity prevention.

Conflicts of Interest Statement

The authors have no conflicts of interests related to this work to disclose.

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CH conceptualized and designed the study, obtained funding, oversaw execution of the study, drafted the initial manuscript, and approved the final manuscript submitted. NH helped to conceptualize the present manuscript, and reviewed and revised it. AD carried out data analyses, and reviewed and revised the manuscript. MC, HR, RC, and RW helped with the design and execution of the study, and reviewed and revised the manuscript. EJ and JO helped design the study, and reviewed and revised the manuscript. All authors were involved in the writing of the paper and had final approval of the submitted and published versions.

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Table 1. Mean (SD) Reported Television Viewing, MVPA, and Objective Activity Counts During the Increased and Decreased Sleep Conditions (N = 37). [a]

	Baseline	Decreased Sleep	Increased Sleep	t_{paired}	p-value	Cohen's d
Reported Television Viewing (hours/day)	1.5 (1.1)	2.0 (1.3)	1.0 (0.8)	-6.48	<.001	-1.06
Reported Moderate to Vigorous Physical Activity (percent time/day)	16.9 (10.4)	14.2 (9.0)	14.4 (8.6)	-0.11	.97	-0.02
Average AW2 Activity Counts (counts/epoch)	551.0 (113.4)	540.7 (103.9)	561.2 (116.4)	2.33	.03	0.39
Total AW2 Activity Counts (total accrued/day)	477,916.2 (101125.8)	511,449.5 (101,018.2)	454,111.9 (96,436.7)	-7.20	< .001	-1.20

[a] For AW2 activity counts, n = 36.