Experimental Restriction of Sleep Opportunity in Children: Effects on Teacher Ratings

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Study Objective: To determine the effects of experimental restriction of sleep opportunity on teacher ratings of academic performance and behavior in healthy normal children.

Design: Home-based, within-subjects design in which participants followed 3 week-long sleep schedules—Baseline (self-selected), Optimized, and Restricted—while attending school, with order of conditions counterbalanced (Optimized and Restricted).

Participants: Seventy-four children (39 boys; aged 6 to 12 years, mean = 10) screened for medical and psychological health.

Measurements and Results: Teachers masked to assigned hours of sleep completed paper-and-pencil questionnaires at the end of each study condition. Questionnaire items were selected from several published measures. Summary scores included Academic Problems, Hyperactive-Impulsive Behaviors, Internalizing, Oppositional-Aggressive, Sleepiness, Total Attention Problems, and Mean Severity of Attention Problems. Main effects of sleep condition were found for Academic Problems, Sleepiness, Total Attention Problems, and Mean Severity of Attention Problems. Restricting sleep increased ratings of Academic Problems (medium effect) relative to both Baseline ($P < .01$, $\eta_p^2 = .11$) and Optimized ($P < .05$, $\eta_p^2 = .10$) conditions and increased the Mean Severity of Attention Problems (medium effect) relative to Baseline ($P < .01$, $\eta_p^2 = .12$).

Conclusions: These findings provide experimental support for widely held beliefs about the importance of sufficient time-in-bed for academic functioning in children. Reducing sleep opportunity had a direct effect on academic performance, as rated by teachers, even among healthy students with no history of behavioral problems or academic difficulty. Findings also support insufficient sleep as a direct source of variability in the manifestation of attention problems but not hyperactivity.

Keywords: Children, sleep restriction, academic performance, classroom behavior

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INTRODUCTION

LABORATORY- AND COMMUNITY-BASED RESEARCH INDICATES THAT MANY SCHOOL-AGED CHILDREN AND ADOLESCENTS OFTEN DO NOT SPEND AS MUCH TIME in bed (TIB) on school nights as would be required to optimize alertness at school the next day.[1,2] Students with habitually insufficient sleep on school nights may try to recover by extending TIB on weekend nights,[3] but the efficacy of this strategy is questionable and may produce unintended consequences for the biologic timing system.[4,5] Lower reported grades have been associated with shorter school-night sleep amounts and/or greater variability in weekday and weekend schedules in numerous cross-sectional studies (for review see Wolfson & Carskadon[6]), leading scientists and educators to target sleep in discussions about improving developmental outcomes.

While few would suggest that less sleep improves outcomes in school children, the overwhelming use of cross-sectional, correlational research designs makes interpretation of results difficult. For example, do poorly performing students tend to adopt inadequate schedules or do such schedules initiate a pattern of impaired performance in the classroom? In possibly the best longitudinal study to date, self-reports of sleep and grades were obtained at sixth, seventh, and eighth grades for more than 2000 students.[7] Habitual sleep amount at initial assessment was positively correlated with the child's grades at that time and predicted future depression and self-esteem ratings but did not significantly predict future grades. While this study was not without limitations, most notably the self-report of academic functioning, results continue to beg the question of directionality in the association between sleep amount and academic functioning.

Experimental sleep manipulation with school-aged children could help elucidate the direction of associations, but few studies have been reported. Five published studies have included an experimental design to examine daytime function after restricting or extending sleep opportunity in school-aged children,[8-12] with only 1 study attempting to change sleep across more than 1 night.[10] Results have failed to document robust effects of restricting nocturnal sleep opportunity on daytime function, other than increased daytime sleep tendency.[8,9,11,12] Subjective sleepiness ratings have been sensitive to reduced time-in-bed but have also shown significant daytime variability.[10-12] Cognitive testing was performed in all 5 studies, but only 3 found statistically significant decrements associated with shorter sleep opportunity.[9,10,12] Even in those studies that found differences, the cognitive decrements were not pervasive across measures. Therefore, results from experimental designs suggest that restricting sleep opportunity leads directly to increased sleep propensity during the day and will, at times, increase introspective ratings of sleepiness and reduce cognitive output. Nevertheless, implications for behavioral and academic functioning are unclear.

We agree with others[13] that more experimental research is needed to determine outcomes of insufficient sleep in children and that this research should be theory driven. Several authors,

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most notably Dahl,[13-16] have offered theories to predict the behavioral, cognitive, and emotional consequences of insufficient sleep in children and adolescents. Research on children with symptoms of sleep-disordered breathing, e.g., habitual snoring, suggests how pervasive such functional impairments could be. In addition to poor academic outcomes,[17,18] children with habitual snoring are at greater risk for inattentive and hyperactive-impulsive behaviors,[19-22] oppositional-aggressive behavior,[20-23] internalizing symptoms such as low mood,[21,24] and impaired quality of life.[24] Indeed, theories regarding the effects of insufficient sleep in children have been largely influenced by observed similarities between the behavioral manifestations of children with sleep disorders and children with attention-deficit/hyperactivity disorder (ADHD[25]), to the extent that behavioral changes related to sleep disturbance are often expected to be "paradoxic in nature"[26] with younger children, i.e., evidenced by increased activity and impulsivity.

Our experimental findings with healthy school-aged children were not consistent with these behavioral predictions, at least with regard to the effects of acute (1-night) sleep restriction.[11] Relative to well-slept controls, sleep-restricted children showed more stereotypically "sleepy" (e.g., dazed/daydreaming, yawning) and inattentive behavior in the laboratory, but no group differences emerged for observed hyperactive-impulsive behavior. We concluded that inattentive behaviors, such as those that characterize children with ADHD-predominantly inattentive type (ADHD-PIT), were more sensitive to sleep loss in healthy school-aged children than were hyperactive-impulsive behaviors. Whether a similar behavioral response would occur in more naturalistic environments (eg, home, classroom) is unknown.

The current study attempts to extend our previous investigation by obtaining teacher ratings of child behavior and academic functioning in children undergoing experimental sleep manipulation. If sleeping less increases risk for academic problems, we would expect teacher ratings of academic difficulty to increase when children were sleep restricted. Further, if sleep restriction is a condition that increases sleep tendency and attention problems, as we showed in our previous study, we would expect the child's behavior in the classroom to reflect this. Specifically, we predicted an increase in teacher ratings of sleepiness and attention problems but no change in ratings of hyperactive-impulsive behaviors as a result of restricted sleep. Numerous clinical studies have shown that children who display attention problems without excessive hyperactivity, such as those with ADHD-PIT, have less risk for oppositional-aggressive behavior than peers with significant hyperactive-impulsive behaviors.[27] Given these findings and our prediction regarding the effects of sleep loss on inattentive versus hyperactive-impulsive behavior, we expected no effect of sleep restriction on oppositional-aggressive behavior. Finally, results of studies such as Fredericksen et al[7] have suggested an association between short sleep amounts and internalizing symptoms, so we predicted that teacher ratings of internalizing behavior would increase as a result of experimental sleep restriction.

In summary, we expected teacher ratings of sleep tendency, academic problems, attention problems, and internalizing problems to increase when schoolchildren followed a restricted sleep schedule, with no change in ratings of hyperactive-impulsive and oppositional-aggressive behavior.

METHOD

Volunteers in this study participated in a 3-week home-based protocol under conditions of self-selected (baseline), optimized, and restricted sleep. The restricted schedule was designed to substantially decrease the sleep opportunity for all participants. The optimized schedule offered a controlled comparison to the restricted schedule and designated a nightly sleep opportunity consistent with the estimated sleep need for school-aged juveniles.[2] To assess academic outcomes, volunteers participated while attending school. Paper-and-pencil ratings were obtained from the child's teacher at the end of each week.

We recruited participants from local schools and communities in Rhode Island and southeastern Massachusetts and collected background information through interviews and rating scales completed by the volunteer and a parent or guardian. Hundreds of parents received information about the study via direct mail. Participants were included in the project if they were medically healthy and academically average or above. Volunteers were excluded if they had ever been diagnosed with a sleep disorder (eg, insomnia, sleep apnea, restless legs syndrome, etc.) or a psychiatric illness (e.g., ADHD, mood disorder, anxiety disorder). Healthy volunteers were excluded if they were behaviorally abnormal (i.e., T-score >70) on the Child Behavior Checklist,[28] if they reported sleep variability school-day-to-weekend of more than 3 hours per night, or if a self-report of morningness/eveningness[29] was greater than 2 SD from laboratory age norms. Healthy volunteers were also excluded from the study if a first-degree relative had been diagnosed with a sleep disorder (e.g., narcolepsy or sleep apnea) or had recently (past year) been treated for a psychiatric disorder. Finally, due to the increased familial risk for ADHD,[30] we excluded healthy volunteers if a full sibling had ever been diagnosed with ADHD. Eligible volunteers and their parents received a description of study procedures and provided informed consent at an information meeting in accordance with procedures approved by the Lifespan Institutional Review Board for the Protection of Human Subjects. Participants and parents received monetary compensation.

Study weeks were scheduled to avoid school holidays of more than 1 day. Each participant began the study on a school night and kept a baseline (self-selected) school-night sleep-wake schedule at home across 1 week (4 to 6 nights). We asked the children to follow their normal school-night schedule even if a school day was cancelled (e.g., for snow) during the baseline week. Individually determined experimental bedtime and rise-time schedules were counterbalanced for the second and third weeks. The restricted schedule required children in first or second grade to restrict TIB to 8 hours per night. Children in third grade or above were restricted to 6.5 hours per night. For the optimized schedule, children were assigned no fewer than 10 hours TIB per night. If the child's usual TIB on weekdays or weekends was discovered to be greater than 10 hours, then he or she was assigned the larger amount for the optimized schedule, rounded up to the nearest half hour.

Actigraphy and Self-Report of Sleep Schedules

Methods used to monitor and ensure compliance with home-based study protocols are described in a previous report[31] and included both continuous wrist-activity monitoring and daily reports of bedtime and rise-time schedules via diaries and daily phone calls to the laboratory. Actigraphs (Mini-Motionlogger; Ambulatory Monitoring Inc., Ardsley, NY) were worn on the non-dominant wrist throughout the day and night. Actigraph data for at-home nights were scored for sleep and wake using our standard method,[32] which applies a validated algorithm[33] to the portion of the records identified as nocturnal sleep episodes. This method yielded activity-based estimates of nightly sleep period between scored sleep-onset and sleep-offset times. Daily phone reports yielded estimates of total TIB from reported bedtime to rise time.

Teacher Ratings

One of the child's primary teachers was asked to complete weekly ratings of classroom behavior and performance. Teachers were informed that the child would be sleeping less than usual during 1 of the 3 weeks but were not told the order of experimental sleep conditions. To avoid burdening teachers with several lengthy rating forms, we reviewed relevant established instruments [34-36] and symptom clusters[37] and assembled a short questionnaire of 26 items to represent 4 functional domains likely to be sensitive to changes in sleep opportunity, i.e., academic problems, hyperactive-impulsive behavior, internalizing symptoms, and oppositional-aggressive behavior.[14] The five items rating academic problems assessed the quality of the child's work, percent completed, how much difficulty the child had recalling material, how careless or hasty the child was with work, and how quickly the child learned new material. For hyperactive-impulsive behaviors, teachers had five items to rate the frequency of behaviors characteristics of ADHD such as hyperactivity, impulsivity, and excessive talkativeness. Six items were used to rate internalizing symptoms and assessed how frequently the child expressed anxious or sad affect, complained of physical problems, or showed emotional lability. The nine items for rating frequency of oppositional-aggressive behaviors reflected common symptoms of Disruptive Behavior Disorders in young schoolchildren, including arguing, defiance, annoys others, blames others, easily annoyed, angry, vindictive, and aggressive. The final teacher rating questionnaire also included 1 behavioral sleepiness item adapted from our own survey instrument that assessed how often the child struggled to stay awake in class: "at least once a day," "occasionally", or "Alert and wide awake almost always."[38] A weekly rating format was used and all items except the sleepiness item were rated using a five-choice scale. For items with a five-choice scale, frequency options were (a) Never (b) Rarely (c) Sometimes (d) Often (e) Very Often, for all but three items. The three nonconforming items were percent work completed, quality of work, and how quickly the child learned new material, with five-choice scales of (a) 0-49% (b) 50-69% (c) 70-79% (d) 80-89% (e) 90-100%; (a) Poor (b) Fair (c) Average (d) Above Average (e) Excellent; and (a) Very Slowly (b) Slowly (c) Average (d) Quickly (e) Very Quickly, respectively. These three items and the sleep tendency item were reverse-scored prior to analysis so that high scores always indicate more difficulty or behavior problems.

Teachers also rated students using the School Situations Questionnaire-Revised,[39] which notes the presence and severity of "problems paying attention or concentrating" in 8 school-based activities (e.g., "during individual deskwork," "during class discussions"). Responses allow for assessment of the total number of problem settings (SSQR Total Problems) and mean severity of problems (SSQR Mean Severity) rated on a scale of 1 "mild" to 9 "severe." Developmental norms are available for these variables, which have been useful for discriminating children with disorders of attention.[39]

Analysis of internal-consistency reliability with coefficient α for each subset of items from the teacher questionnaire, i.e., academic problems, hyperactive-impulsive, internalizing, and oppositional-aggressive, confirmed the conceptual organization of our item subgroups for the teacher rating questionnaire. The α by study week for the hyperactive-impulsive subscale ranged from 0.87 to 0.92, and α for the oppositional-aggressive subscale ranged from 0.90 to 0.93. One item from the academic problems subgroup ("Percent work completed") and 1 from internalizing subgroup ("Withdrawn") showed relatively poor item-total correlations (< 0.50) and were removed from the respective subscales. The revised academic problems and internalizing subscales had acceptable internal reliability (average α = 0.86 and .84, respectively). Summary scores for these subscales and for the Total Problems and Mean Severity scores from the SSQ-R were examined for effects of sleep schedule (baseline, optimized, restricted) with repeated-measures analysis of variance. Ratings for the single sleepiness item from the teacher questionnaire were examined for effects of sleep schedule using the Friedman test for related samples and, if necessary, followed up with Wilcoxon signed ranks tests. We investigated the possibility of age-related differences in the effects of sleep restriction by looking for age-by-condition interactions between the youngest participants, i.e., our first and second-graders, and a similar number of the oldest participants, i.e., our sixth to seventh-graders.

Except where otherwise indicated, data are reported as mean value ± SD. Statistical analyses were performed with SPSS v.11.5. We report results of multivariate F tests for repeated-measures analysis of variance when the within-subjects factor was comprised of more than 2 levels. We then applied a Bonferroni correction to adjust significance levels for any posthoc paired contrasts. Effect sizes for F tests are reported using partial eta squared (η_p^2).

RESULTS

Of the 84 children who began the study, only 6 failed to complete 1 or both experimental conditions. Three dropped out of the study due to illness and 3 for personal reasons, and no differential effect of experimental condition was apparent when drop out occurred. Of the remaining sample, we obtained teacher ratings from all 3 study weeks for 74 children (39 boys; aged 6.5 to 12.9 years, mean = 10.1 years). The modal school-grade level for participants was sixth grade (43%), with 15 participants (20%) in either first or second grade. Most participants were "White/Caucasian" (81%) by parent report and prepubertal or early pubertal (81% Tanner stage 1 or 2) by physician assessment.[40] Three participants were not Tanner staged but were in first or second grade and can reasonably be assumed to be prepubertal or early pubertal. The average Child Behavior Checklist Total T-score was 41 ± 9 (range = 13 to 65), consistent with very low risk of behavioral and emotional difficulties. Estimates of socioeconomic status[41] showed this to be a middle- to upper-middle-class sample on average (mean = 44 ± 10; range = 26 to 66).

Table 1—Sleep Parameters Across Experimental Conditions

	Baseline	Optimized	Restricted
Average time-in-bed per night	570 ± 38	613 ± 26	406 ± 32
Average sleep period	538 ± 35	577 ± 23	399 ± 32

Values are presented as mean ± SD in minutes. Time-in-bed (TIB) from daily phone reports and sleep period from continuous actigraphy are averaged across each study week (condition). Baseline refers to self-selected sleep routines; Optimized, at least 10 hours scheduled TIB per night; Restricted, 8.0 hours scheduled TIB per night for first and second graders or 6.5 hours scheduled TIB for third graders or older.

Sleep Manipulation

Reported TIB

The majority of participants followed baseline (self-selected) sleep routines for 5 nights (range = 4 to 6 nights), optimized sleep schedules for 6 nights (range = 4 to 8 nights), and restricted sleep schedules for 6 nights (range = 5 to 8 nights). As previously reported, experimental changes in baseline TIB imposed by the assigned optimized and restricted schedules were almost entirely due to changes in bedtime.[31] Assigned bedtime–rise-time schedules for optimized nights averaged 47 minutes more TIB than reported across baseline nights, while assigned schedules for restricted nights averaged 165 minutes less TIB per night relative to baseline reports. Relative to their "normal" (baseline) sleep patterns at home, participants achieved an average of 43 ± 29 minutes (range = 0 to 106 min.) more TIB per night on optimized nights and 164 ± 35 minutes (range = 89 to 240 min.) less TIB per night on restricted nights. Table 1 shows reported TIB by sleep condition.

Actigraphy

Results from wrist activity monitoring confirmed reported TIB patterns and are summarized in Table 1. No child achieved a longer average sleep period on restricted nights relative to baseline, but the average sleep period on optimized nights was somewhat shorter than baseline for 5 children in our final sample. For 3 of these children, the relative deficit on optimized nights was small (i.e., less than 6 minutes per night), but, for other 2 participants, the relative deficit averaged more than 20 minutes per night. Nevertheless, we retained these participants in our sample because the average sleep-period differences across the 2 experimental schedules was consistently large (i.e., > 1.5 hours difference per night; mean = 177 minutes difference per night; range = 107 to 254 minutes).

Teacher Ratings

Four children—2 boys aged 6 and 8 years and 2 girls aged 7 and 10 years—showed SSQ-R Total Problems scores in a developmentally deviant range (i.e., > 1.5 SD above age- and sex-based norms) for the week of Baseline (self-selected) sleep, suggesting that these children had occult attention problems that would have excluded them from participation. As a result, they were removed from further analysis. Summary statistics for teacher ratings from the remaining sample are presented in Table 2. Analysis of effects of sleep schedule (Baseline, Restricted, Optimized) revealed effects of experimental schedule for the academic problem subscale ($F_{2,62} = 4.22$, $P < .05$, $\eta_p^2 = .12$), SSQ-R Total Problems ($F_{2,68} = 5.94$, $P < .01$, $\eta_p^2 = .15$), SSQ-R Mean Severity ($F_{2,68} = 4.90$, $P = .01$, $\eta_p^2 = .13$), and for the sleepiness item ($\chi^2_{2,66} = 12.03$, $P < .01$). Follow-up comparisons showed significantly more reported academic problems in the Restricted condition relative to both Baseline ($F_{1,63} = 7.61$, $P < .01$, $\eta_p^2 = .11$) and Optimized ($F_{1,63} = 6.45$, $P < .05$, $\eta_p^2 = .10$) condition. SSQ-R Total Problems scores were higher in both experimental conditions relative to Baseline (Restriction: $F_{1,69} = 9.24$, $P < .01$, $\eta_p^2 = .12$; Optimized: $F_{1,69} = 6.44$, $P < .02$, $\eta_p^2 = .08$), but Optimized and Restricted values did not reliably differ ($P > .3$). Mean severity ratings for SSQ-R attention problems tended to be higher in the Restricted condition relative to Baseline and Optimized weeks, though the increase over Optimized ratings only approached significance (Baseline: $F_{1,69} = 9.39$, $P < .01$, $\eta_p^2 = .12$; Optimized: $F_{1,69} = 3.27$, $P = .07$, $\eta_p^2 = .04$). Similarly, sleepiness ratings from both Restricted and Optimized conditions were higher than Baseline (Z values < -2.3, P values < .02), but across experimental sleep conditions, no significant differences were noted. Comparing ratings from questionnaire subscales and SSQ-R variables for our youngest and oldest participants revealed no significant age-group–by–condition interactions.

DISCUSSION

Consistent with our hypotheses, restricting sleep opportunity in healthy, normal schoolchildren for 1 week increased teacher ratings of academic difficulty in the classroom, as well as for severity of school-related attention problems. Effect sizes for observed increases were medium from a behavioral science standpoint,[42] and we believe that these findings may have broad implications for the assessment and remediation of academic and attention problems in schoolchildren. First, we have provided strong experimental support for the widely held belief that children who obtain less sleep have increased academic difficulty.[6] Therefore, children identified by teachers as having academic problems should be screened for insufficient sleep, which may be directly influencing the appearance of learning difficulties. Indeed, unaddressed sleep problems could interfere with attempts at remediation. Several pediatric sleep questionnaires are available that would be suitable for screening in school-aged children.[43-45] In addition, similar sleep screening is also indicated for children with attention or concentration problems, as these problems may increase in severity if patterns of insufficient sleep are sustained.

Although we were able to document an increase in the severity of attention problems as a result of sleep restriction, we found no evidence for a "paradoxical" increase in hyperactivity, even when examining the younger children separately. If anything, participants appeared to be more hypoactive in the classroom, as evidenced by a decline in ratings of hyperactive-impulsive behavior from Baseline to experimental weeks. These results are consistent with laboratory ratings of inattentive and hyperactive-impulsive behavior from our previous report on acute sleep restriction[11] and indicate that insufficient sleep may be a distinct source of variability in the manifestation of attention problems, such as those that are prominent in children with ADHD without hyperactivity. Our results also suggest that the increased hyperactive-impulsive behavior manifested by children with symptoms of sleep-disor-

Table 2—Subscale/Item Summaries for Teacher Ratings

Measure	(possible range)	Baseline	Optimized	Restricted
Teacher questionnaire				
Academic Problems scale	(2-18)	$6.86 \pm 3.05_{a}$	$7.03 \pm 3.00_{b}$	$7.67 \pm 3.11_{a,b}$
Hyperactive-Impulsive scale	(0-20)	4.91 ± 4.51	4.75 ± 4.06	4.73 ± 4.55
Internalizing scale	(0-20)	2.19 ± 2.79	2.50 ± 2.99	2.57 ± 3.67
Oppositional-Aggressive scale	(0-36)	2.12 ± 3.97	2.61 ± 4.92	2.24 ± 4.34
Sleepiness item	(1-3)	$1.06 \pm .24_{c,d}$	$1.27 \pm .51_{c}$	$1.29 \pm .57_{d}$
School Situations Questionnaire (SSQ-R)				
Total Attention Problems	(0-8)	$1.67 \pm 1.94_{e,f}$	$2.20 \pm 2.31_{e}$	$2.49 \pm 2.41_{f}$
Mean Severity of Problems	(0-9)	$.80 \pm 1.19_{g}$	.99 ± 1.33	$1.26 \pm 1.64_{g}$

Values are mean ± SD. Variables in bold indicate significant main effect of sleep condition. Cells that share subscripts were significantly different at corrected P < .017

dered breathing may be due to intrinsic factors such as gas-exchange abnormalities[46] and/or a chronic inflammatory syndrome (J. H. Nassau, personal communication, March, 2005) rather than insufficient sleep per se.

Controversy continues about whether the attention problems that tend to accompany prominent hyperactive-impulsive symptoms are fundamentally different in presentation, etiology, developmental trajectory, comorbidity patterns, treatment response, etc., from attention problems that occur without those symptoms.[27] Increasing evidence suggests that a few inattentive (and stereotypically sleepy) behaviors, i.e., sluggishness, drowsiness, daydreaming, and forgetfulness, may uniquely characterize attention problems that occur without hyperactivity.[47-50] These symptoms have been labeled “sluggish cognitive tempo.”[47] This report may serve to enlighten the controversy around attention problems without hyperactivity. To begin with, our findings indicate that insufficient sleep may be the core deficit for some children with attention problems, but it is not likely to be the core deficit when excessive hyperactivity and impulsivity are present. In addition, the restricted sleep condition produced selective effects on teacher ratings in a manner consistent with the distinct pattern of comorbidity attributed to ADHD without hyperactivity, namely less risk for oppositional-aggressive problems and worse academic achievement relative to the other ADHD subtypes.[27]

We strongly recommend that researchers investigating sleep and ADHD include symptoms of sluggish cognitive tempo in questionnaires and rating scales, as these behaviors may be more likely to identify children who are manifesting daytime outcomes of insufficient sleep. In this study, ratings of inattentive behaviors were limited to questions about the presence and severity of attention problems in different settings, and sleepy behavior was queried using only 1 item describing the child’s tendency to fall asleep in class. So, while sleep-tendency ratings increased during experimental weeks, we were unable to discriminate between Optimized and Restricted conditions based on the results of that 1 item.

Teacher ratings in this study indicate that children were slower to process new information and more forgetful with restricted sleep opportunity. This finding is consistent with the primary performance differences recorded in another study that experimentally manipulated sleep across multiple nights.[10] In that study, authors assessed changes in psychomotor performance following 3 nights of mild (< 1 hour per night) sleep extension or restriction. Two of the 3 significant differences reported from their neurobehavioral battery indicated faster reaction times in the extended group relative to the restricted group. The other significant finding was with performance on a working memory task (digits forward), showing that memory function was spared in the extended group relative to children who had been sleep restricted. Combining our results with their objective study of performance strongly suggests that the core effects of insufficient sleep in children are likely to appear in the form of slower processing speed and impaired memory function. Future studies of the effects of insufficient sleep on performance in children should highlight these cognitive components for further explication.

The rating form we utilized combined strengths of relevant existing instruments into a single form acceptable for repeated weekly use by teachers of schoolchildren. This research instrument tapped many of the manifestations of pediatric daytime sleepiness that had been suggested in clinical reports, correlational studies, and theoretical papers. Our results indicate that academic difficulty and severity of attention problems are more likely than hyperactive-impulsive, oppositional-aggressive, and internalizing behavior to be affected by reduced sleep opportunity at this age. However, we did not document the test-retest reliability of our instrument over 3 weeks under stabilized sleep conditions, raising the possibility that observed changes in weekly ratings across experimental conditions might be better accounted for by rating instability rather than the changes in sleep schedule. This possibility is unlikely, though, as teacher ratings of a child’s behavior tend to be very stable over similar intervals. For example, the Academic Performance Rating Scale, the source for the Academic Problems items in our form, had a 2-week test-retest reliability of 0.95 for the Total score and median reliability of 0.91 for the 3 subscale scores.[34] Similarly, teacher ratings of hyperactive-impulsive on the Child Attention Problems scale had test-retest reliabilities of 0.96 over 2 weeks[51] and Internalizing items from the Child Behavior Checklist Teacher Report Form had mean test-retest reliability of 0.91 over 2 weeks.[36] Two-week test-retest reliabilities for teacher ratings of the SSQ-R were 0.88 for the Mean Severity score and 0.78 for the Total Problems score.[39] With regard to ratings of symptoms of Disruptive Behavior Disorders such as Oppositional Defiant Disorder (ODD), Laurie et al[52] developed the New York Teacher Rating Scale for Disruptive and Antisocial behavior using the symptoms of ODD and conduct disorder from Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (e.g., ODD items: "Defiant," "Deliberately Annoys Others" etc.). Ratings for the ODD items formed a Defiance factor score with a test-retest reliability after 5 weeks of 0.83. More generally, any predictable "practice effect" in teacher ratings of child behavior over repeated administrations is actually in the direction of less impairment or problems.[53] Therefore, we find no reason to believe that normal rating instability could account for the selective and highly significant week-to-week differences in teacher ratings of academic and attention problems noted in our study, which used a counterbalanced design.

The limited diversity of our sample leads us to characterize our results as a conservative estimate of the magnitude of effects of reduced sleep opportunity in school-aged children. Most children in our sample were 9 to 12 years of age (62%), “White/Caucasian” (81%), and from middle- to upper-middle-class families, recruited primarily from third to sixth grade classrooms in a region that is largely European-American. We did not exclude volunteers with limited socioeconomic status, but the practical requirements of the protocol may have deterred participation of families with limited means. Families had to be willing and able to commit to helping the child follow the assigned schedules during experimental sleep conditions. Not only did a parent have to be home in the early evening on the optimized nights and be able to stay up with the child on restricted nights so as to maximize compliance with assigned bedtimes, but also had to help the child rise on schedule in the morning, even on weekends. Further, we actively limited enrollment to only those children who were functioning well and very healthy at the time of participation. Would the effects of reduced sleep opportunity be substantially different for much younger children, minority children, children of lower socioeconomic status, children from more chaotic households, or children with existing physical or psychiatric illness? Answers to those questions need further investigation. We hope that our success and the success of others[10] with experimental sleep manipulation across multiple nights will encourage the use of similar methods in these groups. We believe that experimental research is critical to describing the daytime manifestations of insufficient sleep across development and improving our ability to identify children who are primarily suffering from not getting enough sleep.

Our attempt to control for order effects by counterbalancing experimental sleep schedules may have introduced differential carryover effects. Bedtime scheduling for the optimized condition allowed sufficient TIB and was intended as a comparison to the restricted schedule, but whether that schedule could satiate any sleep debt accumulated while on the restricted schedule is unknown. The potential for differential carryover under these conditions may explain why teacher ratings of the single sleepiness item appeared to increase from baseline to experimental conditions and suggests additional caution in interpreting these findings. On the other hand, the impact of any differential carryover effects would have likely been to minimize condition-related differences.

We also cannot be sure that teachers remained “blind” to the order of experimental conditions throughout the study. We did not inform teachers, and we instructed participants not to inform them of the study order, but we did not query teachers about this at the end of the study and, therefore, have no way to assess whether the “blind” was ever broken by the child in the classroom. While some teachers may have inadvertently become aware of the study order, neither teachers nor participants were aware of our hypotheses regarding the specific behavioral domains likely to be more or less sensitive to reduced sleep. Therefore, we would be more concerned about biased reporting if ratings showed global differences among conditions, which they did not.

Notwithstanding these limitations, our results support a direct effect of reduced sleep opportunity on academic difficulty and attention problems in schoolchildren. Spending less time sleeping at night for 1 week had a significant negative effect on academic outcomes and severity of attention problems as rated by teachers, even among good students with no history of behavioral or emotional difficulties at school. We believe these results have broad implications for understanding academic underachievement and attention deficits in children and provide support for recommendations for routine assessment of sleep patterns in children with these symptoms.

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