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ORIGINAL RESEARCH

Sleep Duration Is Associated with Academic Achievement of Adolescent Girls in Mathematics

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Purpose: To examine the associations between objective measures of sleep during the school week and academic achievement in mathematics and languages in typically developing adolescent girls.

Methods: Eighty adolescent girls aged 12–17 years (M=14.74, SD=1.3) participated. For five consecutive weeknights, sleep was assessed in the home environment using an actigraph. Academic achievement was assessed using report card grades.

Results: Girls who obtained on average less sleep than the recommended amount of 8 to 10 hrs per night had significantly lower grades in mathematics compared to girls who obtained the recommended amount (77.61 vs 86.16, respectively; η_p^2=0.11). Hierarchical regression analyses adjusted for age, pubertal status, and socioeconomic status revealed that longer average sleep time was significantly associated with higher grades in mathematics (*B*=4.78, 95% CI [2.03,7.53]). No significant associations were found between sleep variables and grades in languages.

Conclusion: Longer average weekday sleep duration is associated with academic achievement of adolescent girls in mathematics.

Keywords: actigraphy, adolescence, grades, report card, gender

Introduction

Healthy sleep is associated with better academic achievement whereas insufficient, poor, and inconsistent sleep schedules have been shown to be associated with poor school achievement.[1,2]

Scientific evidence shows that sleep plays critical roles in the optimal execution of learning, memory, executive functions, sustained attention, emotional regulation, and mood regulation,[3–8] all of which are essential for academic success, adjustment, and mental health. This is because the neural areas that govern emotional regulation and executive functions are sensitive to sleep deficiency.[9–16]

The recommended amount of sleep for adolescents is 8 to 10 hrs per night[17] but at least one-third of adolescents get insufficient sleep,[18] and these estimates are increasing with time.[19] This is alarming, as adolescents with insufficient sleep are at an increased risk for poor school achievement.[20]

Several studies using subjective sleep measures have identified gender differences in the timing, duration, and quality of sleep in adolescence. Adolescent girls reported earlier waking times during the school week,[21,22] combined with long sleep latencies[23] and poor sleep quality.[24] Given the documented associations between inadequate sleep and subject-specific academic achievement, one might expect that the academic achievement of adolescent girls would suffer. However,

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research has shown that girls outperform boys academically[25–27] at all ages and across all subjects.

The apparent contradiction that girls outperform boys academically while experiencing less and poorer sleep may mainly reflect the use of subjective sleep measures in previous studies. Furthermore, an overall academic advantage of female students might mask the potential effects of short, inefficient, or inconsistent sleep duration in this population. It is therefore important to use objective measurement to examine the associations between sleep and academic achievement within a sample of adolescent girls.

Sleep health encompasses a combination of optimal sleep duration, continuity, efficiency, timing, and consistency.[28] We, therefore, set to examine the associations between these dimensions and academic achievement in adolescent girls. To our best knowledge, no other study has used objective measures to systematically investigate the extent to which the quality, quantity, and consistency of sleep during the school week are related to subject-specific academic achievement among adolescent girls.

Maturational changes in puberty combined with socio-environmental factors (eg, elevated academic demands, involvement with electronic devices) mean that adolescents shift to a much later bedtime than those of children and adults, with bedtime becoming approximately 2 hrs later during adolescence.[29] On school days, the timing of an adolescent's sleep period is determined by early wake-up times mandated by the school schedule. Because of this, adolescents typically accumulate a significant sleep debt over the school week.[29–31] The weeknights must be taken as reflecting the sleep amounts associated with academic achievement on a daily basis.

Greater intra-individual night-to-night variability (IIV) of sleep has been associated with poor performance in neurocognitive tasks, knowledge tests, and verbal reasoning in children.[32–34] However, only a few studies have examined the associations between sleep IIV and sleep means with academic achievement in adolescents, and these studies did not use objective sleep measures.[30,31] Another goal of the present study was to determine the extent to which the means and IIV in sleep parameters were associated with academic achievement.

Academic achievement is multidimensional, and students' academic strength could vary between subjects. Although female students have an overall academic advantage over males, this advantage is not even across all subjects; the smallest and largest advantages for female students are seen in mathematics and languages, respectively.[35] Previous studies have demonstrated that everyday variations in sleep duration have varied impacts on different cognitive tasks: the typical sleep duration had no bearing on relatively "easy" tasks, such as short-term memory performance, but had significant impacts on more challenging tasks, such as reasoning.[36] It is therefore likely that the achievement of adolescent girls in different subjects would be associated with inadequate sleep to different extents.

The objective of the present study was to examine the associations between objective measures of sleep during the school week and academic achievement in mathematics and languages in typically developing adolescent girls. We hypothesized that: 1) adolescent girls who sleep less than the recommended amount per school night would have poorer marks compared to adolescent girls who obtain the recommended amount of sleep for their age; 2) shorter, less efficient and more variable sleep would be associated with poorer grades; and 3) achievement in mathematics would be more strongly associated with inadequate sleep than achievement in languages.

Materials and Methods

Participants

Eighty typically developing adolescent girls (M age=14.74, SD=1.3, range=12–17 years) participated in the study. Participants were excluded from the study if there was any psychiatric illness, developmental disorder, and/or learning disability that might affect academic achievement, or any medical condition or medication that might interfere with sleep. Demographic characteristics of the sample are presented in Table 1.

Procedure

At the screening stage, prior to their participation in the study, each participant's eligibility was determined through detailed health-related questionnaires, which were used to rule out any existing sleep, health, or behavioral problem. Eligible participants were each given a wristwatch-like actigraph device (Actiwatch 64, Mini-Mitter, Bend, OR, USA) and were instructed to wear it on their nondominant wrist at bedtime for five consecutive school nights (Sunday to Thursday). During the same period, they were asked to fill in a daily sleep log. Thereafter, the parents were asked to complete a demographic questionnaire. Report cards were obtained from administrators in the participating schools. The study was approved by the Research Ethics board at the Douglas Mental Health University Institute (Montreal,

Table 1 Socioeconomic Status Measures of the Sample by Below/Within the 8 h Recommended Sleep Duration

Parameter	<8 h Sleep Duration (N=41)	≥8 h Sleep Duration (N=39)	All (N=80)
	Percent (%)	Percent (%)	Percent (%)
Annual household income			
$25,000–$45,000	7	5	6
$45,000–$65,000	12	13	13
$65,000–$95,000	37	21	29
> $95,000	44	62	53
Maternal education level			
High school	12	13	13
College	41	26	34
University	46	62	54

Canada) and the Research Ethics Board of Riverside School Board. Written informed consent was obtained from the parents of all participants and written informed assent was obtained from all participants.

Measures

Sleep

Actigraphy

Nighttime sleep was monitored by actigraphy, which has been shown to be a reliable method for evaluating sleep. The utilized Actiware Sleep 6.1 software package (Mini-Mitter) applies a sleep scoring algorithm that was previously validated and found to display a high degree of correspondence with polysomnographic data.[37,38] The actigraphic data were analyzed in 1-min epochs. The total number of activity events was computed for each epoch; if the threshold sensitivity value of the mean score during the active period was exceeded, the epoch was considered to be waking in nature. Otherwise, the epoch was considered to be sleep. Means and standard deviations (SDs; night-to-night variability) were determined for the following measures: 1) sleep schedule, including the times of sleep start and sleep end; 2) assumed sleep time, which was the total sleep period; 3) true sleep time, which was the amount of time between the sleep start and sleep end that was scored as sleep according to the Actiware Sleep algorithm; and 4) sleep efficiency, which was the percentage of time in bed spent sleeping. These measures were averaged over the five school nights (Sunday to Monday).

Daily Sleep Log

Participants recorded their bedtime and wake-up times for each night they wore the Actiwatch.

Academic Achievement

Report card grades given on a scale between 0 and 100 for the subjects of mathematics, English language arts, and French as a second language were recorded.

Health

A detailed questionnaire asked parents for information about their daughter's medical or psychological diagnoses in the present or past and the use of any medications.

Potential Confounders

Indices Reflecting Socioeconomic Status (SES)

Parents were asked to provide information regarding annual income from all sources received by all members of the household, and the highest level of education achieved by the mother.

Pubertal Stage

The Pubertal Development Scale[39] assesses the extent of participants' sex-specific bodily changes associated with puberty onset. This measure yields a mean score from 1 (puberty has not begun) to 4 (puberty is complete).

Data Analyses

Descriptive statistics were computed for all relevant variables. The mean and variability scores for each actigraphic measure were separately averaged across the five weeknights.

Descriptive statistics were computed for all relevant variables. The mean and variability scores for each actigraphic measure were separately averaged across the five weeknights. We reclassified the assumed and true sleep durations into relevant categories: <8 hrs and 8–10 hrs as no participant slept more than 10 hrs during the study period. Based on the recommendations made by the National Sleep Foundation, adolescent girls who obtained 8 to 10 hrs of sleep per night[17] during the school week were taken as obtaining the recommended amount of sleep.

To assess between-group differences in sleep and the subject-specific academic achievement of adolescent girls in the different sleep duration groups while controlling for multiple comparisons, we used three parallel multivariate analyses of covariance (MANCOVA) with the sleep duration group as the independent variable; the mean and night-to-night variability of actigraphic sleep measures and report-card grades as the dependent variables; and age and pubertal score as covariates. Before we carried out the MANCOVAs, we tested all potential independent variables for multicollinearity by assessing variance inflation factors (VIFs). There was no concern regarding multicollinearity, as the VIFs of the independent variables were all <5.

Power analysis for a MANCOVA with two levels and three dependent variables was conducted using G*Power to determine a sufficient sample size using an alpha of 0.05, a power of 0.80, and a moderate effect size (f2=0.15). Based on these assumptions, the desired sample size was calculated to be 78.

Principal component analyses employing Varimax rotation was used to integrate multiple sleep dimensions and aggregate sleep means and variability measures into reliable sleep indices. We then used Pearson product-moment correlations to examine the associations between age,[40] pubertal status,[41] SES indicators,[42–45] report-card grades, and the factor scores derived from the sleep measures.

Hierarchical regression analyses adjusted for the potential confounders of age, maternal education, household annual income, and the participant's pubertal score were used to examine the associations between sleep factors derived from the means or variability of school-night actigraphic sleep measures and report-card grades.

The variables used to explain the report-card grades were entered in three blocks as follows: in Step 1 the confounders of age, mother's education, household income, and pubertal status were entered; in Step 2, sleep factors based on average values, Sleep Duration and Sleep Timing, were entered; in Step 3, sleep factors based on night-to-night variability values were entered, enabling us to examine the association between report-card grades and the night-to-night variability of sleep measures above and beyond the contribution of the mean values of the sleep variables. The adjusted R^2 was measured at each step for the entered variable block. The change in R^2 was used to assess the explanatory power of each block of variables as the incremental contribution to the explained variance. Assumptions of hierarchical multiple regression were tested and found satisfying.

Power analysis for hierarchical regression analyses with three predictors tested and seven total predictors was conducted using G*Power to determine a sufficient sample size using an alpha of 0.05, a power of 0.80, and a moderate effect size (f2=0.15). Based on these assumptions, the desired sample size was calculated to be 77.

All statistical analyses were performed using SPSS Statistics for Windows, Version 22 (IBM Corp., Armonk, NY).

Results

The means (M) and standard deviations (SD) of all variables are presented in Tables 1 and 2.

The participants had an average (SD) of 7.9 hrs (47 min) of assumed sleep duration and 7 hrs (43 min) of true sleep. Their average bedtime and wake-up time were 23:07 (0:56) and 7:07 (0:38), respectively, and their average sleep efficiency was 82.7%. Of the participants, 48.8% had assumed sleep time within the range of 8 to 10 hrs, while the remaining 51.2% had sleep times below that. No participant had a sleep time longer than the recommended sleep duration. Given this, we categorized the participants to Sleep Groups by those who had a short sleep duration (<8 hrs) and those who had the recommended sleep duration (8–10 hrs). When true sleep was used as an indicator of sleep duration 90% obtained less than the recommended amount of sleep. Given the small number of participants with a actual sleep duration within the recommended amount of sleep, we focused on comparing the groups based on assumed sleep duration rather than true sleep.

Comparing Girls Who Did and Did Not Obtain the Recommended Sleep Duration

Sleep

MANCOVA revealed that Sleep Group (short vs recommended sleep duration) had a significant main effect on the average actigraphic sleep measures ($F(5, 75)=34.05$, $p<0.0001$ $\eta_p^2=0.49$). Post hoc analyses showed that adolescents classified as short sleepers, in comparison to recommended duration sleepers, had a significantly delayed bedtime ($F(1, 84)=46.09$, $p<0.0001$ $\eta_p^2=0.35$; 23:44 vs 22:31 pm, respectively), shorter true sleep ($F(1, 79)=81.5$, $p<0.0001$ $\eta_p^2=0.39$; 388 vs 451 mins, respectively), and fewer immobile minutes ($F(1, 79)=123.8$, $p<0.0001$ $\eta_p^2=0.43$; 385.1 vs 451.6 min, respectively). There was no significant between-group difference in wake-up time (7:04 vs 7:10) or sleep efficiency (83% vs 82.4%).

No significant main effect was found between the groups on the night-to-night variability measures.

Academic Achievement

MANCOVA revealed a significant main effect on academic achievement for the Sleep Groups (short vs recommended duration) ($F(5, 75)=5.86$, $p<0.001$ $\eta_p^2=0.218$).

Table 2 Means (M) and Standard Deviations (SD) of Age and Measures by Below/Within the 8 h Recommended Sleep Duration

Parameter	<8 h Sleep Duration (N=41)		≥8 h Sleep Duration (N=39)			All(N=80)	
	M	*SD*	*M*	*SD*	*p*	*M*	*SD*
Age	15.00	1.12	14.46	1.43	0.01	14.74	1.30
PDS	3.45	0.46	3.04	0.65	0.06	3.25	0.59
Report card grades (%)							
Mathematics	77.61	11.33	86.12	8.81	0.15	81.76	10.98
French as a second language	76.12	8.91	79.71	9.00	0.97	77.87	9.08
English language arts	83.40	5.90	84.36	6.93	0.32	83.87	6.40
Sleep							
Sleep time (mins)	438.53	30.59	517.57	22.01	0.25	477.06	47.83
True sleep time (mins)	387.18	32.37	451.31	27.92	0.40	418.45	44.11
Bedtime (hh:mm)	23:48	0:40	22:31	0:39	0.96	23:11	0:55
Wake-up time (hh:mm)	7:07	0:36	7:09	0:35	0.99	7:08	0:35
Sleep efficiency (%)	83.04	4.66	82.24	5.33	0.43	82.65	4.98
Immobile time (mins)	384.09	27.44	450.08	23.21	0.38	416.26	41.74
Sleep time variability (mins)	41.43	22.22	44.62	22.96	0.83	42.98	22.49
True sleep time variability (mins)	38.02	20.52	38.76	19.95	0.71	38.38	20.12
Bedtime variability (hh:mm:ss)	0:40:11	0:27:24	0:30:20	0:16:17	0.02	0:35:23	0:23:04
Wake-up time variability (hh:mm:ss)	0:27:52	0:25:49	0:31:38	0:20:52	0.99	0:29:42	0:23:28
Sleep efficiency variability (%)	3.66	1.82	3.47	1.94	0.72	3.57	1.87
Immobile time variability (mins)	37.32	19.56	38.86	20.92	0.46	38.07	20.12

Abbreviation: PDS, pubertal development scale mean score.

Post hoc analyses showed that adolescent girls classified as short sleepers, in comparison to recommended duration sleepers, had significantly poorer grades in mathematics ($F(1, 79)=12.63$, $p<0.001$ $\eta_p^2=0.112$.), but no significant difference was found for English language arts or French as a second language.

Testing the Associations Between Sleep Parameters and Grades in Mathematics and Languages

Principal Component Analysis for Sleep Means Measures

Principal component analysis (PCA) for the mean actigraphic values produced a two-factor solution that accounted for 83% of the variance. Components were extracted for factors with eigenvalues greater than 1. One component (eigenvalue=3.48) was weighted by the mean actigraphic values of sleep time, true sleep time, and the number of immobile minutes (factor loading=0.97, 0.96, 0.98, respectively), and was therefore termed Sleep Duration. A second component (eigenvalue=1.50) was weighed by the sleep start time, sleep end time, and sleep efficiency (factor loading=0.59, 0.90, 0.52, respectively), and was termed Sleep Timing. Factor loadings of the other sleep means measures yielded values <0.4.

Principal Component Analysis for Sleep Variability Measures

PCA for the night-to-night variability of actigraphic sleep measures produced a two-factor solution that accounted for 78% of the variance. Components were extracted for factors with eigenvalues greater than 1. One component (eigenvalue=3.68) was weighted by the night-to-night variability of assumed sleep, true sleep, sleep start time, sleep end time, and immobile minutes (factor loading=0.95, 0.94, 0.77, 0.58, 0.96, respectively), and was termed Sleep Variability. A second component (eigenvalue=1.01) was weighed by the variability of sleep efficiency (factor loading=0.96) and was termed Variability of Sleep Efficiency. Factor loadings of the other sleep means measures yielded values <0.4.

Correlations Between Variables

The correlations between actigraphic Sleep Factors, report-card grades, age, and household income are presented in Table 3 showing that older age was associated with poorer achievement in English language arts and mathematics, shorter Sleep Duration, and higher puberty

Table 3 Pearson Correlations Among Demographics, Report Card Grades, and Actigraphic Sleep Measures

	1	2	3	4	5	6	7	8	9	10	11
1. Age	–										
2. Household income	−0.10	–									
3. Maternal education	−0.24*	0.23*	–								
4. PDS	0.57***	−0.02	−0.06	–							
5. Mathematics grade	−0.29**	0.17	0.18	−0.13	–						
6. French as a Second Language grade	−0.21	0.20	0.20	−0.07	0.46**	–					
7. English Language Arts grade	−0.30**	−0.04	0.17	−0.11	0.55***	0.61***	–				
8. Sleep Duration factor	−0.38***	0.11	0.18	−0.43***	0.45***	0.30**	0.26*	–			
9. Sleep Timing factor	0.18	−0.16	−0.14	0.22*	0.08	−0.09	−0.08	−0.21*	–		
10. Sleep Variability factor	−0.10	−0.22*	−0.06	0.02	0.22	−0.11	−0.02	0.08	0.26*	–	
11. Variability of Sleep Efficiency factor	−0.10	−0.15	0.06	−0.06	0.02	−0.08	−0.08	−0.14	−0.12	0.00	–

Note: *$p<0.05$, **$p<0.01$, ***$p<0.001$.
Abbreviation: PDS, pubertal development scale mean score.

score ($r=-0.30$, $p<0.01$; $r=-0.29$, $p<0.01$; $r=-0.38$, $p<0.001$; $r=0.57$, $p<0.001$, respectively). Higher household income was associated with a decrease in Sleep Variability and with higher levels of maternal education ($r=-0.22$, $p<0.05$; $r=0.23$, $p<0.05$, respectively). Grades in mathematics, English, and French were positively associated with Sleep Duration ($r=0.45$, $p<0.001$; $r=0.26$, $p<0.05$; $r=0.30$, $p<0.01$, respectively) and with each other (mathematics-English $r=0.55$, $p<0.001$; mathematics-French $r=0.46$, $p<0.01$; English-French $r=0.61$, $p<0.001$).

Regression Analyses

Associations Between Sleep Means/Variability Factors and Grades in Mathematics

Step 1 was not statistically significant but the regression models obtained at Steps 2 and 3 were statistically significant ($F(4, 75)=4.82$, $p<0.0001$; $F(4, 75)=4.2$, $p<0.0001$, respectively), accounting for 25.0% of the variance in grades on mathematics after accounting for all other variables (see Table 4). The introduction of sleep variables in Step 2 explained an additional 17% of the variability in grades on mathematics, and this change in R^2 was statistically significant ($F(2, 73)=8.9$, $p<0.0001$). The grade in mathematics was significantly and positively associated with the Sleep Duration Factor, such that a longer sleep duration was associated with higher grades in mathematics ($B=4.78$, 95% CI [2.03,7.53]) (standardized $\beta=0.46$, $t(80)=3.91$, $p<0.001$). Further analyses demonstrated that the Sleep Duration Factor made the largest unique contribution. This variable remained significant at Step 3. No other variable was found to be significantly associated with achievement in mathematics in any of the other models, and the introduction of Sleep Variability Factors at Step 3 did not significantly add to the explained variance of grades in mathematics.

Table 4 Results of Hierarchical Regression Analysis of Associations Between Sleep Means and Variability Factors with Report Card Grades (N=80)

Variable	Mathematics		French as a Second Language		English Language Arts	
	β	p	β	p	β	p
Model 1						
Age	−0.27	0.06	−0.17	0.22	−0.32	0.02
PDS	0.02	0.91	0.03	0.83	0.07	0.58
Household income	0.12	0.30	0.15	0.18	−0.10	0.37
Maternal education	0.08	0.52	0.11	0.37	0.11	0.33
Adjusted R^2	0.06		0.04		0.06	
Model 2						
Age	−0.20	0.11	−0.14	0.33	−0.29	0.04
PDS	0.14	0.27	0.13	0.35	0.17	0.25
Household income	0.07	0.50	0.11	0.34	−0.14	0.22
Maternal education	0.06	0.58	0.08	0.48	0.09	0.44
Sleep Duration	0.46	0.00	0.27	0.04	0.23	0.08
Sleep Timing	0.20	0.06	−0.01	0.90	−0.02	0.83
Adjusted R^2	0.22		0.07		0.08	
Model 3						
Age	−0.15	0.23	−0.16	0.25	−0.32	0.03
PDS	0.13	0.32	0.15	0.30	0.17	0.23
Household income	0.12	0.27	0.08	0.49	−0.17	0.16
Maternal education	0.06	0.55	0.08	0.53	0.09	0.45
Sleep Duration	0.47	0.00	0.28	0.04	0.21	0.12
Sleep Timing	0.18	0.11	0.01	0.93	−0.02	0.87
Sleep Variability	0.16	0.15	−0.12	0.34	−0.08	0.49
Variability of Sleep Efficiency	0.14	0.20	−0.04	0.74	−0.09	0.43
Adjusted R^2	0.25		0.06		0.07	

Abbreviations: β, standardized regression coefficient; PDS, pubertal development scale.

Associations Between Sleep Means/Variability Factors and Grades in English Language Arts

The overall regression models at Steps 1, 2, or 3 were not statistically significant.

Associations Between Sleep Means/Variability Factors and Grades in French as a Second Language

The overall regression models at Steps 1, 2 or 3 were not statistically significant.

Although the overall regression models were not statistically significant at Steps 1, 2, or 3, the sleep duration was statistically significant ($p<0.05$) in its contributions to the explained variability in the grades for French.

Discussion

The goal of the present study was to investigate the associations between the means and night-to-night variability of objectively measured sleep and academic achievement in mathematics and languages in a sample of typically developing adolescent girls. The main findings are: 1) 48.8% of the participants had sleep duration within the recommended range of 8 to 10 hrs, whereas 51.2% of participants had a sleep time below the recommended amount; 2) adolescent girls who obtained less than the recommended amount of sleep per school night had significantly lower grades in mathematics compared to adolescent girls who obtained the recommended amount of sleep; 3) Sleep Duration factor contributed significantly to the explained variance of grades in mathematics after we statistically controlled for age, pubertal status, maternal education, and household income; 4) the Sleep Variability factors did not add significantly to the explained variance of grades in mathematics; 5) the associations between sleep parameters during the school week were stronger and accounted for a larger portion of the variance of grades in mathematics, compared to those in the English language arts or French as a second language; and 6) none of the regression models examining the associations between sleep variables and languages was statistically significant.

Our observation that about 50% of the sample of typically developing adolescent girls fell below the recommended sleep duration for their age is consistent with several recent large-scale studies examining the sleep duration of Canadian youth.[18] The present study extends these findings by showing that adolescent girls who fall under the recommended sleep duration and are not otherwise different from adolescent girls who obtain the recommended sleep duration in terms of their ethnicity, background, or SES have lower grades in mathematics. Given the cross-sectional nature of the study, we cannot determine the direction of the association between short sleep duration and poor grades in mathematics. Future research should be conducted to examine this directionality and contributing factors.

The findings of this study showing significant associations between sleep duration and academic achievement in mathematics are consistent with previous studies conducted with younger participants or using subjective sleep measures.[46,47] The study extends existing evidence by demonstrating this association using objective sleep measures.

Another contribution of this study is that it shows that sleep is associated differently with specific academic outcomes. Previous work in the field sought to identify sleep duration and quality parameters associated with primary domains of children's development, including cognitive performance,[48,49] and academic functioning,[2,50] as if these are independent of individual differences in cognitive abilities. We speculate that because adolescent girls have the smallest academic advantage in mathematics it could have rendered these skills more vulnerable to inadequate sleep, whereas they have the largest advantage in languages, where achievement seems to have been protected despite significant differences in sleep. Additional research is needed to the relative impact of inadequate sleep on different outcomes for people with different profiles of cognitive strength and weaknesses.

Most science, technology, engineering, and mathematics (STEM) career choices are made in adolescence, making the high school years a critical time period for determining the cognitive and motivational factors important for a future in STEM.[51] In contrast to past research which focused on absolute cognitive ability levels, recent studies suggest that relative cognitive strengths in mathematics, science, and verbal domains during high school may be more accurate predictors of future career trajectories.[51–53] Youth with asymmetrical cognitive ability profiles are more likely to select careers that utilize their cognitive strengths rather than their weaknesses, while symmetrical cognitive ability profiles may grant youth more flexibility in their options.[51] Future studies should examine how extending the sleep duration impacts the achievement of adolescent girls in mathematics. This could be a practical and currently overlooked strategy to enhance academic achievement in mathematics and could potentially yield a more even profile of cognitive strength that would support broader career choices. Empirical data supporting the benefit of small sleep extensions during the school week are supported by previous work showing that participation in a sleep education program was associated with an 18.2-min extension of true sleep per night and improvement in report-card grades for mathematics and English[54] and from studies documenting that delaying the school start time was associated with improved achievement in mathematics.[55]

A growing body of research supports the benefits of sleep as a means to optimize the cognitive performance of children and adolescents. Despite this evidence, however, relatively few educators and policymakers worldwide have sought to optimize sleep as a means to improve youth academic functioning. We herein suggest that prioritizing healthy sleep promotion programs could provide a good "return on the investment" by allowing students to optimize their achievement in mathematics.

The present study found that daily variability in sleep measures did not appear to be consequential for academic achievement beyond average sleep measures. This is inconsistent with previous studies in which higher variability in sleep duration was associated with better[30] and worse[56] academic outcomes. Several explanations could account for this apparent discrepancy. For one, we measured night-to-night differences during the week rather than considering week versus weekend differences. It might be that this level of variability could be tolerated and not impact achievement in a sample of typically developing adolescent girls. Another possible explanation for the apparent discrepancy between our findings and the previous reports is that the studies demonstrating these associations in adolescents relied on subjective sleep measures which might not have captured differences accurately. Our use of objective measures might, therefore, provide a more complete picture.

The present study has some limitations: First, the cross-sectional nature of the study means that the association between sleep and school achievement could be bidirectional. In the future, the application of an experimental or longitudinal design will be needed to address the question of causality. Second, this study did not examine mechanisms, meaning that we cannot at this time explain why a short sleep duration was associated with poorer grades in mathematics.

The study was conducted with typically developing adolescent girls in Quebec. It is not yet known whether the findings apply to populations with different sleep patterns, or to atypically developing adolescent girls or boys, such as those with intellectual and cognitive challenges, sleep problems, or any other medical condition. Future research should examine these questions in atypically developing adolescents to further characterize the interplay between sleep and academic achievement.

The present study focused on weeknight sleep given its documented impact on attention and executive functions in the day preceding sleep, and for memory consolidation of information obtained in the previous day. Future research should investigate similar questions regarding the interplay between weekend sleep and academic achievement.

In addition, future research should examine the joint effect of sleep plus physical activity and/or fitness on academic achievement.

Conclusion

Longer average weekday sleep duration is associated with academic achievement of adolescent girls in mathematics.

Disclosure

The authors report no conflicts of interest in this work.

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