JCSM
Journal of Clinical Sleep Medicine

http://dx.doi.org/10.5664/jcsm.2668

A Multi-Step Pathway Connecting Short Sleep Duration to Daytime Somnolence, Reduced Attention, and Poor Academic Performance: An Exploratory Cross-Sectional Study in Teenagers

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SCIENTIFIC INVESTIGATIONS

Background: A multi-step causality pathway connecting short sleep duration to daytime somnolence and sleepiness leading to reduced attention and poor academic performance as the final result can be envisaged. However this hypothesis has never been explored.

Objective: To explore consecutive correlations between sleep duration, daytime somnolence, attention levels, and academic performance in a sample of school-aged teenagers.

Methods: We carried out a survey assessing sleep duration and daytime somnolence using the Pediatric Daytime Sleepiness Scale (PDSS). Sleep duration variables included weekdays' total sleep time, usual bedtimes, and absolute weekday-to-weekend sleep time difference. Attention was assessed by d2 test and by the coding subtest from the WISC-IV scale. Academic performance was obtained from literature and math grades. Structural equation modeling was used to assess the independent relationships between these variables, while controlling for confounding effects of other variables, in one single model. Standardized regression weights (SWR) for relationships between these variables are reported.

Results: Study sample included 1,194 teenagers (mean age: 15 years; range: 13-17 y). Sleep duration was inversely associated with daytime somnolence (SWR = -0.36, $p < 0.01$) while sleepiness was negatively associated with attention (SWR = -0.13, $p < 0.01$). Attention scores correlated positively with academic results (SWR = 0.18, $p < 0.01$). Daytime somnolence correlated negatively with academic achievements (SWR = -0.16, $p < 0.01$). The model offered an acceptable fit according to usual measures (RMSEA = 0.0548, CFI = 0.874, NFI = 0.838). A Sobel test confirmed that short sleep duration influenced attention through daytime somnolence ($p < 0.02$), which in turn influenced academic achievements through reduced attention ($p < 0.002$).

Conclusions: Poor academic achievements correlated with reduced attention, which in turn was related to daytime somnolence. Somnolence correlated with short sleep duration.

Keywords: Sleep deprivation, daytime somnolence, attention, academic performance, structural equation modeling

Citation: Perez-Lloret S; Videla AJ; Richaudeau A; Vigo D; Rossi M; Cardinali DP; Perez-Chada D. A multi-step pathway connecting short sleep duration to daytime somnolence, reduced attention, and poor academic performance: an exploratory cross-sectional study in teenagers. *J Clin Sleep Med* 2013;9(5):469-473.

Insufficient sleep time in school-aged teenagers is a common phenomenon. A recent meta-analysis of 41 studies on adolescent sleep patterns surveys showed that weekdays total sleep time was 7.4 hours, 8.3 hours, and 7.6 hours for North American, European, and Asian teenagers, respectively.[1] In a recent study of Argentine teenagers, insufficient sleep was reported in 49% of the studied sample.[2]

Sleep deprivation among teenagers is associated with a wide range of behavioral, cognitive, and mood disruptions, including hyperactivity, reduced school grades, and depression.[3] Academic performance is strongly affected by insufficient sleep.[4-6] Kahn et al. reported that the risk of failing one or more years at school doubled in poor sleepers as compared to normal controls.[4] Similarly, lower grades usually correlate with later bedtimes on school nights and increased delay of sleep onset on weekends.[7]

Insufficient or fragmented sleep can induce sleepiness,[8,9] thereby impairing learning.[3,9] In a previous survey using the Pediatric Daytime Sleepiness Scale (PDSS), we found that somnolence was independently and significantly related to poor grades in language or math after adjusting for age, gender, body mass index (BMI), and the presence of snoring or apneas.[2] Daytime somnolence in sleep deprived children may lead to reduced attention, causing impaired learning and academic failure.[10]

BRIEF SUMMARY

Current Knowledge/Study Rationale: Academic performance is known to be strongly affected by insufficient sleep. The path connecting reduced sleep to impaired academic performance has been insufficiently explored.

Study Impact: It was observed that diurnal somnolence and reduced attention were in the middle of the pathway connecting insufficient sleep to poor academic outcomes. Therefore, short sleep duration should be discouraged in teenagers as it significantly impacts cognitive performance.

Based on the correlations between each pair of variables, we hypothesized that the effects of short sleep duration on poor academic performance may be mediated by increased daytime somnolence resulting in reduced attention. Our hypothesis proposes a multi-step causality pathway connecting short sleep duration to daytime somnolence in a first step, which in turn would lead to reduced attention, finally causing poor academic performance. We set out the present study to further explore this hypothesis by using structural equation modeling (SEM) on the data from a cross-sectional survey.

The main objective of using SEM was to assess the statistical significance of a multi-step pathway connecting short sleep duration to daytime somnolence and attention, ending up in academic performance, adjusting for the presence of potential confounding variables. We believe that such objective would not have been achievable by using simpler statistical methods. While frequently used in education sciences,[11,12] SEM is not commonly used in sleep research.

METHODS

Study Sample

Teenagers assisting to public schools in 3 suburban areas of low socioeconomic status in Buenos Aires, Argentina, were invited to participate in this study. Subjects in middle school (13 to 17 years old) attending morning classes were eligible for participation. Informed consent was obtained from parents and informed assent from participating students. A total of 1,264 students attended classes in the morning; 1,194 agreed to participate in this study (94% response rate).

This study was approved by the Institutional Review Board at Austral University.

Evaluations

The research team went to selected schools and invited children to participate. Some days later, subjects who fulfilled inclusion criteria, wanted to participate, and had brought parents' authorization completed a self-administered questionnaire. Finally, trained neuropsychologists conducted attention tests in the first available opportunity.

We used a survey including the Spanish version of the PDSS to evaluate sleepiness.[2,9] The scale consists of 8 questions dealing with several aspects of daytime somnolence in students, such as feeling sleepy in classroom or while doing homework, being alert during daytime, problems for getting up from bed, feelings of tiredness during daytime, the need of being woken up, falling asleep after being woken up in the morning, or feelings of insufficient sleep. PDSS scores range from 0 to 32, with higher scores indicating more severe daytime somnolence.

Data on bedtime and waking time on weekdays, hours slept during weekdays and weekend, and nap time during the week and weekend were also collected. The absolute difference between total sleep times on weekdays and weekends was also calculated. Gender, height and weight data were collected. Age- and gender-adjusted z-scores were calculated for BMI according to the parameters derived by LMS transformation as proposed by Cole et al.[13] Children's mathematics and literature grades as provided by teachers were used as indicators of academic achievement (possible range: 1-10, with higher values meaning better achievements).

As measures of attention, the d2 Test of attention (Brickenkamp's attention-concentration endurance test)[14] and code subtest of the WISC-IV (Wechsler Intelligence Scale for Children-IV)[15] were used. From the d2, the following parameters were calculated: (1) total number of items processed, corresponding to the sum of all items processed, whether correctly or incorrectly, to measure of processing speed; (2) total number of items processed minus errors, measuring effectiveness and inhibitory control; (3) concentration performance, calculated as the number of correctly processed items minus errors of commission, a measure of concentration. From code subtest, the total of correct marks was used as a measure of processing speed and sustained attention.[15] Positive indexes indicated increased attention.

Statistical Analysis

Bivariate correlations between studied variables were evaluated by Pearson coefficients. Multivariate analyses were then performed by SEM.[16-18] A more thorough review of this technique can be obtained from other sources.[18,19]

SEM is a method for representing, estimating and testing a theoretical network of linear association between variables. It is a generalization of both regression and factor analysis and allows the consideration of unobservable ("latent") variables, which may only be measured imperfectly by a series of indicators. In our study, the "latent" multidimensional variables were sleep duration, daytime somnolence, attention, and academic performance. Only indicators loading significantly to their corresponding latent variable were retained. This analysis was performed by built-in confirmatory factor analysis. Sleep duration reflected the combination of longer weekdays sleep time, earlier bedtimes and lower weekday-to-weekend sleep time absolute difference. Daytime somnolence resulted from the combination of PDSS survey items. Attention included correct marks and concentration index from D2 test as well as WISC-IV code subscore. Finally, academic performance included math and language grades as indicators.

SEM assesses whether a sample covariance matrix (i.e., the associations between all possible pair of variables) is consistent with a hypothetical matrix implied by a predefined model. SEM evaluates how well a prespecified model of postulated relationships between pairs of variables "fits the reality." Thus, SEM is highly dependent on predefined models. For our study, we constructed series of models before conducting the analysis. Such models were always built around the principal hypothesis, which postulated a set of linear correlations exist between sleep duration and daytime somnolence, daytime somnolence with attention, and finally, attention with academic performance. Models differed in the way of handling the confounding variables (i.e., all other variables measured in this study).

SEM is mainly a confirmatory technique rather than an exploratory one, and its use is recommended in order to determine if a certain model is valid, rather than to purely explore previously undefined models.[19] Model's validity is assessed by several indexes, such as the χ^2, the root mean square error of approximation (RMSEA), the Comparative Fit Index (CFI), and

Table 1—Descriptive data

Variable	Value	Cases with missing data
Age (years old)	15.53 ± 0.05	0
BMI (kg/m^2)	21.55 ± 0.11	77
Z-scores	0.23 ± 0.03	77
Males	650 (54%)	0
PDSS score	13.8 ± 0.18	0
Total sleep times (h)		
During weekdays	7.07 ± 0.04	89
During weekend	8.87 ± 0.07	96
Nap (h)		
During weekdays	1.11 ± 0.04	88
During weekend	0.77 ± 0.03	87
Weekdays' bedtime (h)	23.25 ± 0.04	79
Weekdays' wake up time (h)	6.44 ± 0.04	13
Math grade	6.60 ± 0.06	180
Language grade	6.67 ± 0.06	178
WISC-III attention score	57.61 ± 0.45	3
d2 test results		
Correct marks	361.75 ± 2.48	0
Concentration Index	122.19 ± 1.4	0
Variability index	22.84 ± 0.3	0

Table 2—Correlates of language and math grades

	Language grades	Mathematics grades
Age	r = 0.07 (p = 0.03)	r = 0.02 (p = 0.50)
Male gender	r = -0.15 (p < 0.01)	r = -0.20 (p < 0.01)
BMI Z-score	r = -0.01 (p = 0.69)	r = -0.03 (p = 0.37)
Sleep variables		
Weekdays sleep time	r = 0.04 (p = 0.19)	r = 0.10 (p < 0.01)
Weekdays going to bed time	r = -0.05 (p = 0.12)	r = -0.08 (p = 0.02)
Weekend sleep time	r = -0.01 (p = 0.83)	r = 0.04 (p = 0.26)
Weekdays-to-WE difference	r = -0.06 (p = 0.07)	r = -0.07 (p = 0.03)
Weekdays nap time	r = -0.11 (p < 0.01)	r = -0.12 (p < 0.01)
Weekend nap time	r = -0.13 (p < 0.01)	r = -0.11 (p < 0.01)
PDSS somnolence score	r = -0.08 (p = 0.01)	r = -0.11 (p < 0.01)
Attention measures		
WISC-III attention score	r = 0.15 (p < 0.01)	r = 0.11 (p < 0.01)
Correct marks (d2 test)	r = 0.09 (p = 0.01)	r = 0.03 (p = 0.30)
Concentration Index (d2 test)	r = 0.11 (p < 0.01)	r = 0.08 (p = 0.01)
Variability index (d2 test)	r = -0.12 (p < 0.01)	r = -0.15 (p < 0.01)

BMI, body mass index.

Normed Fit Index (NFI). For our study, models with RMSEA > 0.08, CFI < 0.8, or NFI < 0.8 were rejected because of poor fit. For comparisons between models, the Akaike information criterion (AIC) was also employed.[19]

Results from SEM are presented in terms of age-, gender-, and BMI-adjusted standardized regression weights (SWR) between pairs of variables. Such coefficients represent the strength of the relationship between any pair of variables independently from confounding factors. P-values < 0.05 were considered statistically significant.

IBM SPSS Statistics v.18 and AMOS v.18 software (Crawfordville, FL, USA) were used for the analyses. Alpha error was set at 0.05. Missing data were imputed by using AMOS built-in regression techniques. The Sobel test was used to further explore the possibility that the relationship between two variables could pass through a third variable (commonly called "mediating" variable).[20]

The "final model" was also fitted with (1) the subset of the dataset containing no missing cases, (2) excluding the WISC-IV coding subscore, as it may also measures other aspects of cognition besides attention. Results remained unchanged.

RESULTS

Population features and missing data for each variable are shown in **Table 1**. Mean age was 15 years; 54% were males; mean PDSS score was 13.8 points; and mean math and language grades were 6.6 and 6.7, respectively.

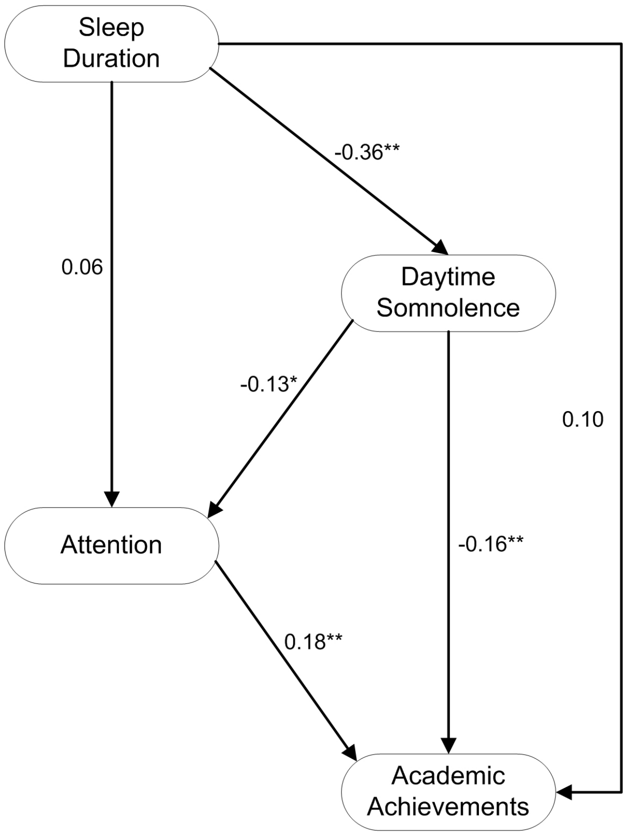
Significant unadjusted correlations were found between language and math grades and sleep duration (r = -0.14, p < 0.01), sleep duration with attention score (r = 0.06, p = 0.05), and attention scores with academic achievements (r = 0.29, p < 0.01). Other important correlates of language or math grade were age and gender, as shown in **Table 2**.

A possible multi-step relationship pathway from sleep duration to academic achievements was further explored by SEM. Through SEM we built a model which offered an acceptable fit according to usual measures (χ^2 = 794, RMSEA = 0.0548, CFI = 0.874, NFI = 0.838). As depicted in the path diagram shown in **Figure 1**, an age-, gender-, and BMI-adjusted positive correlation between sleep duration and somnolence was found (SWR = -0.36, p < 0.01), whereas correlation between somnolence and attention was negative (SWR = -0.13, p < 0.01). Furthermore, reduced attention correlated with lower academic achievements (SWR = 0.18, p < 0.01). Interestingly, we also found a negative direct correlation between somnolence and academic achievement (SWR = -0.16, p < 0.01). Conversely, the relationship between sleep duration and academic outcomes was not significant (SWR = 0.10, p = 0.2). A Sobel test confirmed that short sleep duration influenced attention through increased daytime somnolence (statistic = 2.27, p < 0.02), which in turn influenced academic achievements through reduced attention (statistic = 2.99, p < 0.002).

DISCUSSION

Our results suggest a multi-step pathway connecting short sleep duration with increased somnolence, which in turn correlated with reduced attention, ending up in lower academic achievements, as disclosed by a complex, holistic statistical method. While several studies have suggested the existence

Figure 1—Path diagram representing the relationships among sleep deprivation, daytime somnolence, attention, and academic achievements, as obtained by Structural Equation Modeling



Age-, gender-, and BMI-adjusted standardized regression weights for each relationship are given. *p < 0.05, **p < 0.01.

of associations between each pair of variables, this is the first time that all variables are connected in one single pathway by using an unselected large sample and a powerful statistical technique. Such a goal could not have been achieved by using simpler techniques such as correlation or multiple regression analysis. These results further suggest that improving sleep quality in teenagers could be an effective measure to increase academic efficiency.

Experimental studies have shown that sleep deprivation is related to inattentiveness, impaired learning, and reduced arousal. In a recent study, 16 subjects completed two sessions of five consecutive nights of restricted or unrestricted sleep in a crossover fashion.[10] In comparison with subjects with normal sleep, sleep deprived participants performed worse on quizzes and displayed more inattentive behaviors. These data lend support to our initial hypothesis. According to this paradigm, short sleep duration would set up a "chain reaction," with increased daytime somnolence and reduced attention as intermediate links leading to reduced academic efficiency. Interestingly, we observed that somnolence correlated negatively with academic performance in spite of its relationship with attention. Such findings may suggest that the somnolence effect may go beyond attention, thus involving other herein unstudied cognitive function. Therefore, further studies are needed to evaluate the effect of somnolence on other variables such as working memory or motivation. On the other hand, we found no significant direct correlation between sleep duration and academic achievements, suggesting that other factors besides somnolence and attention may be relatively less important in conveying the effect of the former on the latter.

Our study included a great sample size and applied a powerful statistical technique for assessing relationships among variables. Although SEM is not a new technique, it has been seldom used in neurosciences.[18] Detailed description of the technique can be found elsewhere.[19] One of the main advantages of this approach is that variables can serve as independent or dependent factors at the same time, thus allowing modeling of multi-step pathways and networks. Furthermore, complex theoretical constructs, such as somnolence or attention, could be modeled by using a wide range of indicators, which not only improve variable's validity but also reduce measurement error.

SEM analysis is not devoid of pitfalls and limitations. Firstly, paths essentially represent correlation between variables, which by themselves do not prove causality in cross-sectional studies.[21] Furthermore, temporal aspects of relationships between sleep duration, sleepiness, reduced attention, and academic performance could not be evaluated in this study, thus further limiting our ability to evaluate causality. Important variables connected with academic achievements such as motivation,[22] memory consolidation,[23] personality,[24] presence of behavioral disorders,[25,26] respiratory diseases[27,28] or other environmental factors[29,30] were not assessed in our study. Therefore, our model should be regarded as a hypothesis-generating one to be further refined and enriched by adding other variables. Finally, many variables were self-reported, which could have also introduced some bias or uncertainty in the evaluations.

In summary, our results suggest that increased somnolence and reduced attention may be in the middle of a multi-step pathway connecting short sleep duration to poor academic outcomes. These results may have important implications for public health. Short sleep duration resulting from unhealthy sleep habits should be discouraged, as it may significantly impact cognitive performance.

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ACKNOWLEDGMENTS

The study was funded by the Carrillo-Oñativia Grant, Ministry of Health, República Argentina. Drs. Perez-Lloret, Vigo and Perez-Chada are Research Career Awardees from the Argentine Research Council (CONICET). The authors are indebted to the member of the Buenos Aires Sleep Disorders Study Group: Esperanza Tamburini, Psychologist; Ana Pérez, Psychologist; Analía Giuzzi, M.D; and Pablo Vizzotti, Sociologist for their active participation on the field work.

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Submitted for publication April, 2012
Submitted in final revised form October, 2012
Accepted for publication November, 2012
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DISCLOSURE STATEMENT

This was not an industry supported study. The authors have indicated no financial conflicts of interest.