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ORIGINAL ARTICLE

Adolescent sleep and fluid intelligence performance

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Abstract

Fluid intelligence involves novel problem-solving and may be susceptible to poor sleep. This study examined relationships between adolescent sleep, fluid intelligence, and academic achievement. Participants were 217 adolescents (42% male) aged 13 to 18 years (mean age, 14.9 years; SD = 1.0) in grades 9–11. Fluid intelligence was predicted to mediate the relationship between adolescent sleep and academic achievement. Students completed online questionnaires of self-reported sleep, fluid intelligence (Letter Sets and Number Series), and self-reported grades. Total sleep time was not significantly related to fluid intelligence nor academic achievement (both $P > 0.05$); however, sleep difficulty (e.g. difficulty initiating sleep, unrefreshing sleep) was related to both ($P < 0.05$). The strength of the relationship between sleep difficulty and grades was reduced when fluid intelligence was introduced into the model; however, the *z*-score was not significant to confirm mediation. Nevertheless, fluid intelligence is a cognitive ability integral in academic achievement, and in this study has been shown it to be susceptible to sleep impairments (but not duration) in adolescents.

Key words: academic achievement, adolescent sleep, fluid intelligence, sleep difficulty.

INTRODUCTION

It is estimated that up to 45% of adolescents experience sleep problems.[1–6] Adolescents tend to go to bed later,[3–6] with many having difficulty falling asleep on school nights.[2–4] Thus, many obtain an inadequate amount of sleep to function on school days.[3] Of particular relevance to the present study is the relationship between sleeping problems and poor academic achievement in adolescents.[3,7–9] Studies have found that adolescent sleep disturbance is associated with poor school performance, lower grades, arriving late to class due to oversleeping, and poor school attendance (for reviews, see Dewald *et al*.[7] and Curcio *et al*.[8]). In a representative poll of 1602 US adolescents, those with an insufficient amount of sleep (<8 h) were more likely to have lower self-reported grades.[3]

What remains unclear, however, is *how* sleep disturbances result in poor academic consequences. One factor may be sleep's effect on day-to-day intellectual functioning, with some intellectual abilities more vulnerable to sleep loss than others (i.e. those reliant on the pre-frontal cortex).[10] As adolescents are required to use these abilities in their day-to-day school performance, it is important to analyze the relationships between poor sleep and vulnerable intellectual abilities. For example, working memory is an ability closely tied to achievement.[11] Adolescents with insufficient sleep (<8 h) perform worse on challenging working memory tasks when compared to adolescents with borderline sleep (8–9 h).[12]

Another ability possibly susceptible to sleep loss is fluid intelligence, particularly with its high concordance with working memory.[11] Fluid intelligence can be defined as "the use of deliberate and controlled mental

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operations to solve novel 'on the spot' problems" (p. 151).[11] Fluid intelligence utilizes frontal lobe function,[13–15] and the frontal lobes are sensitive to sleep loss.[10] Unfortunately, there are limited studies directly examining sleep and fluid intelligence. Hicks *et al*.[16] demonstrated that college students who naturally slept for 6 h or less each night had lower fluid intelligence scores than those who naturally slept for 8.5 h or more. The researchers suggested students who slept for longer had more capacity to use reason.[16] The routine of college students is likely to differ to that of adolescents (e.g. a consistent weekday start time). In the only study to investigate the relationship between poor sleep and fluid intelligence in adolescents, Goldstein *et al*.[17] found that performance on fluid intelligence tasks was best when adolescents were tested at their optimal times of day. They concluded that adolescents who identified as "evening types" (preferring later bedtimes) were at risk for poorer performance. However, according to recent theory, their measure tapped into short-term memory and visual processing – not fluid intelligence.[11]

Given the potential social and economic costs of sleep on academic achievement, identifying mechanisms involved is warranted, so that sleep interventions may supplement educational support targeting key intellectual abilities. The current study therefore aimed to examine the relationship between two areas of adolescent sleep and fluid intelligence, as well as academic performance. Specifically, we predicted a mediating relationship in that greater sleep problems would lead to decreased levels of fluid intelligence, which would in turn lead to poorer academic achievement (i.e. self-reported grades). Although many studies have measured sleep as sleep duration, seminal work has shown individual differences in the way adolescents function when given the same sleep opportunity.[18] Thus, the present study measured sleep as total sleep time and a more qualitative measure of sleep difficulty.

METHOD

Participants

Participants were 217 adolescents (42% male) aged 13–18 years (mean age, 14.9 years; SD = 1.0) in grades 9–11. Adolescents were recruited from two public (n = 104) and two private schools (n = 113) in the Adelaide metropolitan area. Students attending these schools were largely from middle to upper socioeconomic status groups. Eighty-two percent reported English as the main language spoken in the home, 89% resided with both parents living together, and 84% reported living in single or two-child households. This study was approved by the Flinders University Social and Behavioural Research Ethics Committee and the Department of Education and Children's Services (DECS) Ethics Committee.

Measures

Sleep

Total sleep time (TST). Students were asked questions about their usual sleep habits on school nights in order to calculate TST. Questions included, "What time do you usually go to bed on school nights?", "How long does it usually take you to fall asleep on school nights?", and "What time do you usually wake up on school days?". Sleep surveys are a valid method of measuring sleep on school days, given their strong correlation with other measures (e.g. sleep diary, actigraphy).[19]

Sleep difficulty. Four items were adapted for adolescents from the Insomnia Severity Index[20] in order to measure sleep-related complaints. Items included, "Do you have difficulty falling asleep?", "Do you have difficulty staying asleep?", "Do you have problems with waking up too early?", and "Do you wake up feeling that your sleep has not been refreshing?". Each item was scored on a five-point Likert-scale, with responses ranging from 0 (no) to 4 (very severe). A total score was created by summing the scores on the four items (range, 0–16), with higher scores indicating more severe sleep difficulty. Internal consistency was satisfactory (Cronbach's $\alpha = 0.68$) for the current sample.

Fluid intelligence

Letter Sets. This task consisted of 12 items measuring inductive and deductive reasoning abilities.[11,21,22] Each item consisted of five groups of letters. Four of the groups followed the same pattern as each other and one did not. Participants were then asked to select the odd one out (e.g. AB, BC, CD, XG, DE). Correct answers were scored 1 and incorrect answers scored 0. Total scores ranged from 0 to 12, with higher scores indicating better inductive and deductive reasoning, and hence, better fluid intelligence performance. Internal consistency was good (Cronbach's $\alpha = 0.92$).

Number Series. This task consisted of nine items measuring inductive, quantitative, and deductive reasoning

abilities.[11,21–23] Each consisted of a series of seven numbers that followed a mathematical pattern. Adolescents were instructed to choose the next number in the series (e.g. 2, 5, 8, 11, 14, 17, 20). A score of 1 was given for a correct answer and a score of 0 for an incorrect answer. Total scores ranged from 0 to 9, with higher scores indicating better reasoning, and therefore better fluid intelligence performance. Internal consistency was good (Cronbach's $\alpha = 0.86$).

Academic achievement

Academic achievement was assessed by asking students, "Think about how you have been doing at school in the past year. What grades do you usually get?".[3,9] Possible responses, ranging from As (scored as 9) to Es (scored as 1), were listed, with higher scores indicating higher grades. F grades were substituted with E grades to reflect the South Australian Government's South Australian Curriculum, Standards and Accountability Framework (SACSA).[24] The SACSA framework defines a set of school achievement grades (A to E), which are used across all government schools.

General intelligence

A vocabulary test was used to control for general intelligence in the event that adolescents who performed better on fluid intelligence tasks did so due to overall higher levels of general intelligence. Vocabulary tests load highly on crystallized intelligence[25] and have been shown to be resistant to sleep loss.[12,26] The test consisted of 16 words presented one at a time, with adolescents asked to examine each word (e.g. artery), and then select another word similar in meaning from four alternatives (e.g. muscle tissue, blood vessel, throat, spring). One point was awarded for each correct answer and these were then summed to give a total vocabulary score (range, 0–16), with higher scores indicating greater intelligence. Internal consistency was good (Cronbach's $\alpha = 0.90$).

Procedure

Following consent from the principal, adolescents participated voluntarily if they had written informed consent from a parent or guardian. The response rate was 56.5%. Data were collected using an online questionnaire administered via a password-protected Internet website. Testing sessions were scheduled during 50-min class times before the lunch break in order to minimize the effects of chronotype. Adolescents completed all measures during this 50-min class. Researchers used a standardized script to introduce the tasks to reduce any effects of experimenter bias. Five raffle prizes of $A40 iTunes vouchers were offered for participation in the present study.

Statistical analyses

Data were analyzed with SPSS (version 17; SPSS, Chicago, IL, USA). Mediational analyses were used to test the study's prediction.[27] Specifically, a series of linear regression analyses were conducted to test relationships between the independent variable (IV) and the mediator variable (MV) (criterion 1), the MV and the dependent variable (DV) (criterion 2), and the IV and DV when covariates were controlled for (criterion 3). Covariates in the present study were age, grade, sex, school attended, and whether English was the main language spoken at home. All of the relationships in these first three criteria were required to be significant (i.e. have significant standardized β values) to a level of $P < 0.05$ to meet the preconditions for mediation. To then establish whether the results were consistent with mediation, the relationship between the IV and DV needed to be significantly reduced after controlling for the MV and covariates (criterion 4). The significance level of the mediation in criterion 4 was determined by the *z*-value of the Sobel test.[27] As the amount of sleep on the night prior to participating in the study could influence performance on the intelligence tests, adolescents reported the total sleep time on that night. However, analyses indicated that the prior night's sleep was not related to any of the outcome variables (all $P > 0.05$).

RESULTS

Sleep, fluid intelligence, and self-reported grades

Adolescents obtained an average TST slightly above 8 h (see Table 1). They also typically went to bed at 10:20 PM, took more than 30 min to fall asleep (35.5 min), and woke at 6:59 AM on school days. The mean sleep difficulty severity score was 3.3 out of a possible 16. However, 59% of students reported some degree of difficulty falling asleep, 23% reported difficulty staying asleep, 45% had difficulty with waking too early, and 61% felt that their sleep had been unrefreshing.

The Number Series and Letter Sets tasks were significantly correlated with each other ($r(181) = 0.45$, $P < 0.001$) indicating that these tasks did measure a similar

construct (in this case, fluid intelligence). However, the moderate correlation coefficient suggested that these tasks measured different parts of the same construct (e.g. deductive reasoning compared to quantitative reasoning). The correlation was not considered strong enough to warrant combining the two; thus analyses were conducted for each.

Relationship between sleep, fluid intelligence, and academic achievement

It was predicted that fluid intelligence would mediate the relationship between adolescent sleep (TST, sleep difficulty) and academic achievement. TST did not account for a significant amount of variance in either Letter Sets, $R^2 = 0.00$, F (1189) = 0.04, $P = 0.84$, or Number Series, $R^2 = 0.00$, $F(1181) = 0.002$, $P = 0.96$. As this did not meet the first criterion, it was clear that fluid intelligence did not mediate the relationship between sleep duration and grades (see Table 2).

When sleep was conceptualized as sleep difficulty, it explained a significant amount of variance in both Letter Sets, $R^2 = 0.04$, $F(1189) = 8.06$, $P = 0.005$, and Number Series, $R^2 = 0.02$, $F(1181) = 4.62$, $P = 0.03$ (criterion 1). The βs (see Table 2) indicated that these relationships were in the expected directions, with higher sleep difficulty severity related to worse performance on both fluid intelligence tasks. Examining criterion 2 demonstrated that Letter Sets explained a significant but small variance in grades, $R^2 = 0.03$, $F(1186) = 5.81$, $P = 0.02$, while Number Series explained a significant 10.9% of the variance in grades, $R^2 = 0.109$, $F(1178) = 21.84$, $P < 0.001$. Higher performance on both of the fluid intelligence tasks was related to better grades (see Table 2).

In step 1 of criterion 3, the covariates accounted for a significant 6.7% of the variance in grades, $R^2 = 0.067$, $F(3175) = 4.17$, $P = 0.007$. In step 2, sleep difficulty explained a further 2.9% of the variance in grades, which was significant but small, $R^2_{change} = 0.029$, $F_{change}(1174) = 5.68$, $P = 0.02$. Thus, grades became worse as sleep difficulty became more severe, when controlling for covariates. These regressions collectively demonstrated that the preconditions for mediation were met. In step 3 of criterion 4, sleep difficulty explained 1.9% of the variance in grades after controlling for covariates and Letter Sets score, $R^2_{change} = 0.019$, $F_{change}(1173) = 3.77$, $P = 0.054$, and explained 1.6% of the variance in grades after controlling for covariates and Number Series score, $R^2_{change} = 0.016$, $F_{change}(1170) = 3.38$, $P = 0.07$. Thus, negative relationships were found between

Table 1 Descriptive statistics (means, SDs) for age, sleep, and academic achievement variables for the sample

	Mean	SD
Demographic variables		
Age	14.90	1.00
Year level	9.77	0.85
Sleep variables		
Total sleep time (hours)†	8.03	1.20
Sleep difficulty severity	3.26	2.98
Bedtime†	10:22 PM	52.25 min
Sleep onset latency (minutes)†	35.54	40.88
Wake-up time†	6:59 AM	32.56 min
Out-of-bed time†	7:05 AM	44.05 min
Amount of sleep needed to feel at your best†	8 h, 55 min	90.75 min
Academic variables		
Grades	7.12 (B grades)	1.37
Letter Sets total	5.44	4.07
Number Series total	4.21	2.61
Vocabulary total (raw scores)	10.35	3.30

†Variables refer to sleep during the school week.

Table 2 Testing mediational relationships for total sleep time, fluid intelligence tasks, and academic achievement

Mediational chain: IV→MV→DV	Standardized beta coefficients (β)				Significance of mediation
	IV→MV	MV→DV	IV→DV	IV→DV | MV	
1. IV – Total Sleep Time					
Letter Sets (MV)	−0.01	0.17*	0.12	0.11	Cannot test
Number Series (MV)	−0.002	0.33**	0.12	0.13	Cannot test
2. IV – Sleep Difficulty					
Letter Sets (MV)	−0.20*	0.17*	−0.18*	−0.14	1.42
Number Series (MV)	−0.16*	0.33**	−0.18*	−0.13	1.39

DV, dependent variable (academic achievement); IV, independent variable (1. total sleep time, 2. sleep difficulty); MV, mediator variable. *$P < 0.05$, **$P < 0.01$.

Table 3 Testing mediational relationships for individual sleep difficulty severity items (IVs), fluid intelligence tasks (MV), and academic achievement (DV)

	Standardized beta coefficients (β)			
Preconditions for medation:	IV→MV	MV→DV	IV→DV	Met?
Difficulty falling asleep (IV)				
Letter Sets (MV)	−0.17*	0.17*	−0.13	No
Number Series (MV)	−0.17*	0.33**	−0.13	No
Difficulty staying asleep (IV)				
Letter Sets (MV)	−0.10	0.17*	−0.17*	No
Number Series (MV)	−0.06	0.33**	−0.17*	No
Waking too early (IV)				
Letter Sets (MV)	−0.12	0.17*	−0.15*	No
Number Series (MV)	−0.10	0.33**	−0.15*	No
Unrefreshing sleep (IV)				
Letter Sets (MV)	−0.19*	0.17*	−0.08	No
Number Series (MV)	−0.12	0.33**	−0.08	No

*$P < 0.05$, **$P < 0.01$.
DV, dependent variable (academic achievement); IV, independent variable, MV, mediator variable.

sleep difficulty and grades after controlling for covariates and both Letter Sets, $\beta = -0.14$, $P = 0.054$, and Number Series, $\beta = -0.13$, $P = 0.07$.

Sobel's significance test[27] demonstrated that the decrease in variance explained was not significant for either Letter Sets scores ($z = 1.42$, $P = 0.16$) or Number Series scores ($z = 1.39$, $P = 0.17$). Thus, despite the significant relationships between sleep difficulty, fluid intelligence, and academic achievement, and a reduction in the relationship between sleep difficulty and academic achievement when fluid intelligence was introduced, this reduction was not enough to conclude that fluid intelligence mediates the relationship between sleep difficulty and academic achievement.

Analyses of individual sleep difficulty severity items

The items of sleep difficulty were individually examined, as they might provide insight into particular aspects of sleep related to academic achievement and fluid intelligence. The items were: difficulty falling asleep, difficulty staying asleep, difficulty with waking too early, and unrefreshing sleep (Table 3). Several significant linear relationships were found. In particular, adolescents who had difficulty falling asleep performed worse on both fluid intelligence tasks. Adolescents with unrefreshing sleep had lower Letter Sets scores, whereas the relationship with Number Series was not significant. In addition, adolescents who had difficulty staying asleep or waking too early had lower grades. Finally, a positive relationship was found between scores on the Number Series task and academic achievement.

DISCUSSION

The present study investigated the relationships between sleep (sleep duration and sleep difficulties), fluid intelligence, and academic performance. Although fluid intelligence did not mediate these relationships, the data indicated that sleep is related to fluid intelligence, and confirmed fluid intelligence is related to academic achievement.[11] Contrary to previous findings, TST was not significantly related to fluid intelligence[16] nor to academic achievement.[3,9] These are unexpected findings as sleep duration has previously been found to relate to self-reported grades.[3,9] Previously, lower grades in this age range (approx. 15 years) have been related to sleep durations of 7.3[3] and 7.5 h.[9] It may be that adolescents in the present study may not have been sleep restricted enough for their mean sleep duration of just over 8 h to have an effect on either their academic achievement or fluid intelligence. This suggests that a threshold between 7.5 and 8 h of sleep may exist, and that intellectual abilities may begin to suffer if sleep occurs below this general threshold. In support of this, Gradisar *et al.*[12] found working memory performance (another task reliant on the prefrontal cortex[28]) was impaired for adolescents obtaining less than 8 h of

sleep. However, sleep duration may not be the only way to operationalize "sleep" due to individually different responses to the same sleep duration.[18] Thus, it is important to examine adolescents' perceptions of their sleep, which in the present study was measured by sleep difficulty.

Although fluid intelligence did not mediate the relationship between sleep difficulty and academic performance, a number of interesting relationships were found. Specifically, adolescents with more severe sleep difficulty had worse performance on fluid intelligence tasks, and also reported poorer grades. As mentioned earlier, previous studies linking sleep with fluid intelligence have either used college students,[16] or not measured fluid intelligence.[17] Thus, this is the first study to demonstrate a link between sleep and fluid intelligence in adolescents. That is, the more severe the sleep difficulty the poorer the adolescent's inductive, deductive, and quantitative reasoning. In other words, adolescents' ability to discover and apply rules to solve novel problems (that may involve mathematical operations[11]) is compromised by severe sleep disturbance.

When exploring specific sleep difficulties in the present sample, the most commonly reported were experiencing unrefreshing sleep (61% of students) and difficulty falling asleep (59%). These findings are comparable to recent poll findings, with over 50% reporting unrefreshing sleep, whilst 51% reported difficulty falling asleep at least once a week.[3] Difficulty staying asleep and waking too early were experienced to a much lesser extent. These various sleep difficulties were linked to different aspects of fluid intelligence. Experiencing unrefreshing sleep was associated only with poorer inductive and deductive reasoning (i.e. Letter Sets performance), whereas difficulty falling asleep was associated with overall poorer performance on inductive, deductive, and quantitative reasoning (i.e. both Letter Sets and Number Series performance). Thus, the additional process of mathematical operations was only hindered by difficulty falling asleep.

Intuitively, if adolescents feel unrested then this feeling carries into the school morning, affecting their novel problem solving ability. It is worth noting here that adolescents completed these tasks in the morning. However, an explanation for the link with difficulty falling asleep is less clear, but may be evidence of insomnia influencing the daytime functioning of adolescents. It should be noted though, that neither difficulty falling asleep nor unrefreshing sleep were related to self-reported grades. Instead, the few students who experienced difficulty staying asleep and/or waking early reported worse grades, yet without any associated deficits in fluid intelligence.

It is clear from the findings of this study and others[12,29] that the link between adolescent sleep, intellectual abilities, and academic achievement is multifaceted. Various studies have investigated specific intellectual abilities separately, and each have conceptualized and measured adolescent "sleep" differently. What is needed is simultaneous measurement of intellectual abilities vulnerable to sleep disturbance in the same population in order to build a more comprehensive model of these links in adolescents. Thus, the present study is not without its own limitations.

First, the response rate was low and may have resulted in recruitment biases. Second, as this study was cross-sectional, causal claims cannot be asserted. Third, retrospective, self-reported measures were used for sleep and grades. Ideally sleep diaries would reduce memory bias,[30] and standardized measures of academic achievement (e.g. the Weschler Individual Achievement Test[31]) would be objective and translate better across studies. Notwithstanding these limitations, this is the first study known to look at the influence of sleep on fluid intelligence and academic grades in adolescents. As fluid intelligence is believed to be influenced mainly by biological and neurological factors (as opposed to education and acculturation),[11] interventions to correct fluid intelligence deficits are difficult. The alternative may be to correct the sleep disturbance with focused[32] or broad sleep interventions.[33,34]

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