ASSOCIATIONS BETWEEN OBJECTIVELY-MEASURED AND SELF-REPORTED SLEEP WITH ACADEMIC AND COGNITIVE PERFORMANCE IN ADOLESCENTS: DADOS STUDY

Sleep and cognition in adolescents

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Associations between objectively-measured and self-reported sleep with academic and cognitive performance in adolescents: DADOS study

ABSTRACT

Adequate sleep has been positively related with health and school achievement outcomes during adolescence. The aim of this study was to investigate the associations of objectively-measured and self-reported sleep duration and quality with academic and cognitive performance in adolescents. This study was conducted with 257 adolescents (13.9 ± 0.3 years) from DADOS Study (Deporte, ADOlescencia y Salud). Objectively-measured and self-reported sleep duration and quality were obtained by a wrist-worn GENEActiv accelerometer and the Spanish version of Pittsburgh Sleep Quality Index (PSQI) questionnaire, respectively. Academic performance was analyzed through school records using four indicators: math, language, science and grade point average score. Cognitive performance was measured using the Spanish version of the "SRA Test of Educational Ability". After Benjamini-Hochberg correction for the false discovery rate, objectively-measured sleep duration was negatively associated with verbal ability (β=-0.179, P=0.004), whilst self-reported sleep quality was positively associated with academic performance (β ranging from 0.209 to 0.273; all P<0.001). These associations remained significant after further controlling for physical fitness and physical activity. Conversely, there were no associations between self-reported sleep duration and objective sleep quality with academic and cognitive performance. Our findings fit in line with previous research showing that sleep quality may play an important role on adolescents' academic performance. Further interventional research is needed to clarify the mechanisms by which sleep is related to academic performance in youth.

Keywords: sleep patterns, cognition, school performance, adolescence.

INTRODUCTION

Sleep is defined as an active, repetitive and reversible brain process of reduced perception and responsiveness to environmental stimuli (Dahl et al., 2002; Krueger et al., 2016). Insufficient sleep duration and quality have emerged as critical indicators for physical and mental health, being associated with adverse health consequences such as obesity, diabetes, cardiovascular risk, cognitive diseases or cancer (Chaput et al., 2016; Owens et al., 2014). During adolescence, often viewed as an important time frame in terms of acquisition and development of academic and cognitive skills (Andersen, 2016; Patton et al., 2007), sleep might play a key role in memory consolidation, brain plasticity (Frank et al., 2006) and cognitive functioning (Shochat et al., 2014; Wheaton et al., 2016). Likewise, sleep seems to be essential to achieve academic success, which is closely linked to future work achievement, wealth and health status (French et al., 2015).

The relationship between sleep and cognition in youth has been the focus of a considerable number of studies during the last decade. In 2010, Dewald et al. revealed that sleepiness was the sleep variable more strongly related to school performance (r=-0.133), followed by sleep quality (r=0.096), and sleep duration (r=0.069). Two years later, a large meta-analysis conducted by Astill et al. (2012) reported a positive association of sleep duration (but not sleep efficiency) with children's executive functioning and school performance, but not with intelligence, attention or memory. In addition, experimental sleep manipulation research has shown that restricted sleep had small or no effects on cognitive functioning, while disrupted sleep could seriously affect cognitive processes in adolescents (Bruin et al., 2016).

Despite the fact that most studies indicate a positive association of sleep variables with academic and cognitive performance, results are not conclusive probably due to methodological limitations (Bruin et al., 2016; Curcio et al., 2006; Dewald et al., 2010;

Wang et al., 2016). In fact, the vast majority of previous studies assessed sleep duration and quality using subjective tools (e.g., sleep logs, questionnaires or interviews), included only grade point average (GPA) score or indirect teachers' reports as academic performance indicators, focused on adolescents with sleep disturbances, or did not control for potential confounders with great influence on sleep and cognition such as socioeconomic level, physical activity (PA) or physical fitness (Álvarez-Bueno et al., 2017; Coe et al., 2013; Mota et al., 2010; Shochat et al., 2014). Thus, the present study aimed to analyse the associations of objectively-measured and self-reported sleep duration and quality with academic and cognitive performance in healthy adolescents.

METHODS

Participants

The DADOS (Deporte, ADOlescencia y Salud) Study is a 3-year longitudinal research project (from 2015 to 2017) aimed to assess the influence of competitive PA on health, cognition and psychological wellness through adolescence. All the participants were recruited from secondary schools and sport clubs and met the general DADOS inclusion criteria: born in 2001, enrolled in 2nd grade of secondary school and free of any chronic disease. From the total DADOS study sample (n=274), a subsample with 257 adolescents (135 boys) with valid baseline data for at least sleep variables and academic and cognitive performance were included in the analysis.

Adolescents and their parents or guardians were informed of the nature and characteristics of the study, and all provided a written informed consent. The DADOS study protocol was designed in accordance with the ethical guidelines of the Declaration of Helsinki 1961 (last revision of Fortaleza, Brazil, 2013) and approved by the Research Ethics Committee of the University Jaume I of Castellon.

Anthropometry

Anthropometric characteristics were assessed twice by trained members of the DADOS research group following standardized procedures (Beltran-Valls et al., 2017). Average measures were used for data analysis. Briefly, body weight was measured to the nearest 0.1 kg using an electronic scale (SECA 861, Hamburg, Germany) lightly dressed and without shoes. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (SECA 213, Hamburg, Germany). Body mass index (BMI) was calculated as weight/height square (kg/m^2).

Objectively-measured and self-reported sleep duration

Daily sleep duration was objectively measured using a triaxial GENEActiv accelerometer (Activinsights Ltd, Kimbolton, UK). Participants wore the accelerometer on their nondominant wrist for at least 4 consecutive 24-hour days, including 2 weekend days and 2 weekdays. This device has been found to be valid to examine sleep [$\kappa = .85$ (.06)] (te Lindert et al., 2013). Accelerometers were programmed to collect data at a sampling frequency of 100 Hz. Data were stored in gravity (g) units ($1g = 9.81\ m/s^2$). The raw acceleration output was aggregated in 1-second epochs using the GENEActiv postprocessing PC software (version 2.2; GENEActiv). Sleep duration was calculated using the Sadeh algorithm (1994), implemented in the Excel macro provided by the Activinsights company, and expressed as average hours per day.

Subjective information on sleep duration was estimated from the Pittsburgh Sleep Quality Index (PSQI) questionnaire (Royuela Rico et al., 1997) through the following questions: “during the past month, when have you usually gone to bed at night?” and “during the past month, when have you usually gotten up in the morning?” Sleep duration was calculated as the difference between bedtime and time for getting up.

Objectively-measured and self-reported sleep quality

We derived sleep efficiency (%, (total sleep time/assumed sleep time)x100) as an objective indicator of sleep quality assessed by GENEActiv accelerometer [κ = .85 (.06)] (te Lindert et al., 2013). The raw acceleration output was aggregated in 60-second epochs using the GENEActiv postprocessing PC software. Sleep efficiency was measured by the sleep-wake scoring algorithm (Sadeh et al., 1994) included in the macro provided by the Activinsights company and expressed as average percentage per day.

Likewise, the total score from the Spanish version of PSQI questionnaire was used as a subjective indicator of sleep quality over the last month (Royuela Rico et al., 1997). It includes 19 questions in 7 components of sleep quality: subjective sleep quality, sleep duration, sleep latency, habitual sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. The 7 component scores are rated on a 3-point ascending scale, ranging the global score of the PSQI from 0 to 21 (Cronbach's $\alpha = 0.81$). Since higher values in the global PSQI score indicates worse sleep quality, values were reversed.

Academic and cognitive performance

Based on the information provided by each school's secretary office, academic performance was assessed through the final grades from the 1st course of secondary school using four indicators: math, language, science and GPA score. Language is the grade of Catalan; the official teaching language at school. GPA score was defined as the single average for geography and history, science, math, Spanish, Catalan, English and physical education grades. All the subjects were rated with a ten-points scale, where 1 is the worst and 10 is the best.

Cognitive performance was measured using the Spanish version of the validated Science Research Associates Test of Academic Abilities (Thurstone et al., 2004). This test measures the subject's ability to learn by evaluating three basic skills: verbal ability (command of language), numeric ability (speed and precision in performing operations with numbers and quantitative concepts) and reasoning ability (the aptitude to find logical ordination criteria in sets of numbers, figures or letters). Scores for the three areas were obtained by adding positive answers. Overall academic ability was calculated by adding the three area scores (verbal + numeric + reasoning). This battery test provides three complexity levels based on the age range of the sample. The present work used the level 3 designed for adolescents aged 14 to 18 years (reliability: verbal α=0.74, numeric α=0.87, reasoning α=0.77 and overall academic ability α=0.89) (Thurstone et al., 2004).

Covariates

Pubertal stage was self-reported according to the 5 stages defined by Tanner (1976). It is based on external primary and secondary sex characteristics, which are described by the participants using standard pictures according to Tanner instructions.

The Family Affluence Scale "FAS" developed by Currie et al. (2008) was used as a proxy of socioeconomic status (SES), which is based on material conditions in the family such as car ownership, bedroom occupancy, computer ownership and home internet access.

Cardiorespiratory fitness (CRF) was assessed using the 20m Shuttle Run Test (SRT) as described by Léger et al. (1988). Number of finished laps was registered for each participant. Likewise, maximum oxygen uptake (VO_{2max}, mL/kg/min) was estimated using the equations reported by Léger at al. (1988). Since this equation uses stages completed instead of laps, we decided to use the number of laps to not lose sensitivity in the measure.

Participants' PA level was objectively measured using the GENEActiv accelerometer. This device provides a reliable (coefficient of variation intrainstrument = 1.4% and coefficient of variation interinstrument = 2.1%) (Esliger et al., 2011) and valid assessment of PA in young people ($r = 0.925$, $P = 0.001$) (Phillips et al., 2013). The raw acceleration output was aggregated in 1-second epochs using the GENEActiv postprocessing PC software, and PA was expressed as average minutes per day in sedentary, light, moderate, and vigorous PA. According to Phillips et al. (2013). GENEActiv cut points for sedentary, light, moderate, and vigorous intensities in children are <7, 7–19, 20–60, and >60 mg.

Data Analysis

Study sample characteristics are presented as mean ± standard deviation and percentages for continuous and categorical variables, respectively. All variables were checked for normality using both graphical (normal probability plots) and statistical (Kolmogorov-Smirnov test) procedures. Due to its skewed distribution, moderate PA, vigorous PA, and moderate-to-vigorous PA (MVPA) were log-transformed before analysis. As preliminary analyses showed no significant interactions of sex with sleep variables in relation to academic and cognitive performance (all $P>0.10$), all analyses were performed for the whole sample.

Sex differences were assessed using t-test for continuous variables and chi-square test for nominal variables. The effect size, Cohen's d, was calculated and interpreted following the cut-offs established by Cohen (1988): small (~0.20), medium (~0.5) or large (~0.8). In addition, intra-class correlation coefficients (ICC) were performed by using two-way mixed models to investigate the agreement between objectively-measured and self-reported sleep variables.

We performed partial correlations controlling for sex, pubertal stage and SES to examine the relationship among sleep variables, academic and cognitive performance. Likewise, linear regressions were used to analyse the associations of objectively-measured and self-reported sleep duration and quality with academic and cognitive performance. A total of 3 regression models were performed including different cofounders: Model 1 included sex, pubertal stage and SES; Model 2 included Model 1 plus CRF (laps); Model 3 included Model 1 plus MVPA.

Additionally, we divided the sample based on objective and self-reported sleep duration (short: < 8h vs. long: ≥ 8h) (Hirshkowitz et al., 2015) and sleep quality categories (poor vs. good; objective: < 85% vs. ≥ 85%; self-reported: PSQI > 5 vs. ≤ 5) (Buysse et al., 1989) and analyzed the differences between-groups in academic and cognitive performance using one-way analysis of covariance (ANCOVA) adjusted for sex, pubertal stage and SES. For each ANCOVA effect, a Cohen's d is reported (Cohen, 1988).

We conducted the Benjamini-Hochberg correction for assessing multiple comparisons between sleep (duration and quality) and academic and cognitive performance, by defining statistical significance as a Benjamini-Hochberg False Discovery Rate "Q" less than 0.05 (Benjamini et al., 1995). All the analyses were performed using the IBM SPSS Statistics for Windows version 22.0 (Armonk, NY: IBM Corp), and the level of significance was set to $P<0.05$.

RESULTS

Table 1 shows the descriptive characteristics of the participants. Boys presented lower SES ($P<0.05$), were taller, more physically active, and showed higher levels of physical fitness than girls (all $P<0.001$). Objective measurements of both sleep duration and quality were significantly higher in girls, while self-reported sleep duration and quality were significantly higher in boys (all $P<0.05$). There were no differences between sexes in academic performance, but regarding cognitive performance, boys showed higher numeric ability than girls (14.8 vs. 12.0; $P<0.001$). Intra-class correlation coefficients showed very low agreement between objectively-measured and self-reported sleep duration ($ICC=0.16$; $P=0.072$), and no agreement between objectively-measured and self-reported sleep quality ($ICC=0.00$; $P=0.458$).

Partial correlations among the study variables, controlling for sex, pubertal stage and SES are presented in Table S1 supplementary file. Objective sleep duration was negatively corelated with verbal ability ($r=-0.178$; $P<0.05$), and self-reported sleep quality was positively corelated with numeric ability ($r=0.129$; $P<0.05$) and all the academic performance indicators (correlation coefficients ranged from 0.204 to 0.266; all $P<0.001$). However, after correcting for multiple comparisons, the association between self-reported sleep quality and numeric ability disappeared. All the academic performance indicators were positively related to all the cognitive performance indicators (correlation coefficients ranged from 0.292 to 0.527; $P\leq0.001$).

Tables 2 and 3 show linear regression models on the associations of objectively-measured and self-reported sleep duration and quality with academic and cognitive performance. Regarding sleep duration, only objective sleep duration was negatively associated with verbal ability after controlling for sex, pubertal stage and SES ($\beta=-0.179$; $P<0.01$). According to sleep quality, only self-reported sleep quality was positively associated with academic performance (β ranged from 0.209 to 0.273; $P<0.001$) and numeric ability ($\beta=0.127$; $P<0.05$). The results remained significant after additional adjustments for CRF and MVPA (models 2 and 3), but after Benjamini-Hochberg correction, the association between self-reported sleep quality and numeric ability disappeared.

ANCOVA analyses adjusted for sex, pubertal stage and SES revealed that adolescents sleeping less than 8h per day, using the objective measurement, showed higher verbal ability (19.3 vs. 17.9; P=0.028, Cohen's d=0.271). No differences were found for academic and cognitive performance between self-reported sleep duration and objectively-measured sleep quality categories (data not shown). However, adolescents with self-reported good sleep quality showed higher scores in all the academic performance indicators (all P<0.05, Cohen's d ranging from 0.22 to 0.37; Figure 1). After conducting Benjamini-Hochberg corrections, only self-reported good sleep quality remained significantly related to higher scores in math.

DISCUSSION

The main findings of the present study revealed a positive association of self-reported sleep quality with academic performance in adolescents, showing that sleep quality could play an important role on academic outcomes. Moreover, regarding cognitive performance, objective sleep duration was negatively associated with verbal ability. This study adds new scientific evidence about the controversial relationship of sleep and cognition by using objective and standardized methods of assessing sleep (i.e., actigraphy) and by including in the analysis potential confounders such as pubertal stage, SES, fitness and physical activity levels.

Comparisons between sexes revealed contradictory results regarding sleep variables; girls showed longer objective sleep duration and better objective sleep quality, while boys showed better measurements of self-reported sleep variables. These controversial results fit in line with Dewald et al. (2010) who analysed 50 studies suggesting that differences between objective and self-reported sleep measurements could be partially explained by individuals' distinct experiences of sleep (e.g., experiences in girls vs. boys) and different subjective sleep components (e.g., sleepiness, feeling rested).

Sleep duration is defined as the total sleep time per night. Our study reveals no associations of sleep duration with academic and cognitive performance, except for verbal ability. Conversely, prior systematic reviews and meta-analysis have evidenced a generalized positive association of sleep duration with academic performance in children and adolescents (Chaput et al., 2016; Dewald et al., 2010), while contradictory results have been reported for cognitive performance (Astill et al., 2012; Chaput et al., 2016). In fact, Astill et al. (2012) found a positive association of sleep duration with children's cognition and performance, whilst Chaput et al. (2016) reported controversial results suggesting that those children and adolescents with sleep durations far outside the normal range could have other health disorders, which may impair academic and cognitive outcomes. Interestingly, Perkinson-Gloor et al. (2013) showed that adolescents sleeping less than 8h per night had lower school grades, and revealed a mediating effect of daytime tiredness and behavioural persistence in this association. The inter-studies differences could be partially explained by the use of different tools in order to measure sleep duration (subjective vs. objective), as well as, by the individual differences in adolescents' academic and cognitive performance.

Sleep quality is defined as the satisfaction level of the sleep experience. Our analyses indicate a significant positive association of self-reported sleep quality, but not objectively-measured, with academic performance. Analysis according sleep quality categories revealed higher scores in math among those adolescents with self-reported good sleep quality (PSQI $\leq$ 5). These results concur with previous studies revealing a positive association of self-reported sleep quality and academic performance during youth (Baert et al., 2015; Duarte et al., 2014; Mak et al., 2012). Good sleep quality reduces sleepiness (Pilcher et al., 1997) at school time, with positive effects on attention and memory (Carskadon, 2011), which might improve academic performance (Moore et al., 2008). Differences between objective and self-reported sleep quality measurements could be caused by methodological issues. Despite actigraphy is revealed as a validated method for assessing sleep quality, this methodology only assesses sleep efficiency -without capturing other large individual differences in the sleep experience- during few days, while subjective tools such as the PSQI questionnaire assesses other specific components (e.g., sleep latency, use of sleep medication, sleep disturbance) providing an overall sleep quality index over the last month.

Limitations

The main strengths of our study comprise the inclusion of objective and self-reported sleep duration and quality measurements, a wide range of academic and cognitive performance indicators and the relatively large and age-matched sample of healthy adolescents (13.9 ± 0.3 y). Moreover, potential confounders such as pubertal stage, SES, fitness and physical activity levels have been considered given its great influence on sleep and cognition during adolescence (Álvarez-Bueno et al. 2017; Carskadon, 2011; Coe et al., 2013; Mota et al., 2010; Shochat et al., 2014). However, our results should be interpreted cautiously due to the cross-sectional design of our study, which limits our ability to make assumptions about the causal nature of the relationships analysed.

Conclusions

In conclusion, the present study adds new information about the association of sleep duration and quality with academic and cognitive performance in adolescents, suggesting that sleep quality may play an important role on academic outcomes. Our findings are of great significance due to the growing body of evidence suggesting that promoting healthy sleep practices in adolescents may prevent academic failure with an important positive impact on adulthood. These facts reinforce the need of including sleep hygiene behaviours and practices and sleep assessment as part of school-based public health and educational support programs. Therefore, we consider that families, educators and policy makers should take into account our results in order to promote healthy sleep and to achieve academic success among children and adolescents. Further longitudinal and interventional studies examining the effects of different objectively-measured and self-reported sleep variables on academic and cognitive performance during adolescence are needed.

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Table 1. Characteristics of the study population by sex (n=257).

	All	Boys	Girls	P	Cohen's d
n (%)	257 (100)	135 (52.5)	122 (47.5)		
Demographics					
Age (y)	13.88 ± 0.30	13.88 ± 0.29	13.89 ± 0.30	0.817	0.029
Tanner stage					
Stage 2	21 (8)	14 (10)	7 (6)		
Stage 3	85 (33)	43 (32)	42 (34)	**0.044**	
Stage 4	127 (49)	60 (44)	67 (55)		
Stage 5	24 (9)	18 (13)	6 (5)		
SES score (0-8)	4.20 ± 1.38	4.02 ± 1.33	4.39 ± 1.42	**0.028**	0.275
Anthropometry					
Height (cm)	163.13 ± 7.83	164.75 ± 8.51	161.35 ± 6.58	**<0.001**	0.447
Weight (kg)	54.23 ± 9.33	54.56 ± 9.72	53.87 ± 8.91	0.551	0.075
Body mass index (kg/m^2)	20.30 ± 2.72	19.99 ± 2.56	20.64 ± 2.85	0.056	0.239
Sleep duration					
Objective (h/day)	8.00 ± 0.88	7.87 ± 0.92	8.16 ± 0.81	**0.007**	0.338
Objective good sleep duration	132 (51)	65 (48)	67 (55)	0.318	
Self-reported (h/day)	8.21 ± 0.81	8.33 ± 0.70	8.07 ± 0.90	**0.012**	0.321
Self-reported good sleep duration	164 (64)	95 (70)	69 (57)	**0.027**	
Sleep quality					
Objective (%)	82.96 ± 8.03	81.98 ± 8.11	84.05 ± 7.84	**0.039**	0.259
Objective good sleep quality	113 (44)	52 (39)	61 (50)	0.064	
Self-reported (0-21)	4.86 ± 2.81	4.23 ± 2.70	5.57 ± 2.76	**<0.001**	0.491
Self-reported good sleep quality	163 (63)	99 (73)	64 (53)	**<0.001**	
Academic performance (0-10)					
Math	6.84 ± 1.59	6.96 ± 1.60	6.71 ± 1.57	0.209	0.158
Language	6.75 ± 1.53	6.61 ± 1.51	6.89 ± 1.55	0.145	0.183
Science	6.96 ± 1.68	6.88 ± 1.68	7.04 ± 1.68	0.448	0.095
GPA	7.10 ± 1.28	7.03 ± 1.29	7.17 ± 1.27	0.381	0.110
Cognitive performance					
Verbal (0-50)	18.60 ± 5.31	19.01 ± 5.81	18.14 ± 4.68	0.186	0.165
Reasoning (0-30)	16.51 ± 5.89	16.09 ± 5.67	16.98 ± 6.11	0.229	0.151
Numeric (0-30)	13.44 ± 4.77	14.78 ± 4.56	11.96 ± 4.58	**<0.001**	0.617
Overall (0-110)	48.55 ± 12.68	49.87 ± 12.84	47.07 ± 12.38	0.077	0.222
Physical Fitness					
20-m SRT (laps)	64.43 ± 24.76	77.76 ± 20.90	49.69 ± 19.90	**<0.001**	1.375
VO_2 (ml/kg/min)	50.28 ± 6.72	53.99 ± 5.33	46.17 ± 5.64	**<0.001**	1.425
Physical Activity (min/day) [a]					
Moderate	75.87 ± 23.10	81.56 ± 25.00	69.57 ± 18.99	**<0.001**	0.540
Vigorous	12.28 ± 8.28	15.54 ± 7.80	8.67 ± 7.24	**<0.001**	0.912
Moderate-to-vigorous	88.15 ± 28.21	97.10 ± 29.18	78.24 ± 23.49	**<0.001**	0.712

Data are presented as mean ± standard deviation or frequency (%). Differences between sex were examined by t-test or chi-square test. SES: socioeconomic status; Good sleep duration: ≥ 8 h per night. Objective good sleep quality: efficiency ≥ 85%. Self-reported good sleep quality: Pittsburgh Sleep Quality Index ≤ 5. GPA: Grade Point Average. Overall indicates the sum of the three abilities scores. SRT: Shuttle Run Test; VO_{2max}: maximum oxygen uptake.

[a] Values were natural log-transformed before analysis, but non-transformed values are presented in the table.

Table 2. Associations of objectively-measured and self-reported sleep duration and quality with academic performance in adolescents (n=257).

	Sleep duration				Sleep quality			
	Objective		Self-reported		Objective		Self-reported	
	β	*P*	*β*	*P*	*β*	*P*	*β*	*P**
Model 1								
Math	-0.055	0.384	0.110	0.082	-0.003	0.960	0.245	**<0.001**
Language	-0.047	0.461	0.042	0.512	-0.015	0.817	0.209	**<0.001**
Science	-0.042	0.511	0.021	0.743	-0.049	0.437	0.273	**<0.001**
GPA	-0.071	0.260	0.048	0.449	-0.033	0.598	0.223	**<0.001**
Model 2								
Math	-0.041	0.510	0.113	0.071	-0.012	0.842	0.249	**<0.001**
Language	-0.038	0.551	0.044	0.489	-0.021	0.742	0.212	**<0.001**
Science	-0.034	0.598	0.023	0.719	-0.055	0.384	0.275	**<0.001**
GPA	-0.059	0.354	0.051	0.417	-0.042	0.500	0.227	**<0.001**
Model 3								
Math	-0.060	0.344	0.114	0.071	0.001	0.986	0.246	**<0.001**
Language	-0.056	0.382	0.049	0.442	-0.007	0.917	0.211	**<0.001**
Science	-0.045	0.484	0.023	0.726	-0.048	0.457	0.273	**<0.001**
GPA	-0.074	0.247	0.050	0.435	-0.032	0.612	0.223	**<0.001**

Values are standardized regression coefficients (β). Values in bold font indicate significant results. Confounders in Model 1: sex, pubertal stage and SES. Confounders in Model 2: Model 1 + Cardiorespiratory fitness (laps). Confounders in Model 3: Model 1 + moderate-to-vigorous physical activity. GPA: Grade Point Average.

*These associations remained significant after Benjamini-Hochberg correction.

Table 3. Associations of objectively-measured and self-reported sleep duration and quality with cognitive performance in adolescents (n=257).

	Sleep duration				Sleep quality			
	Objective		Self-reported		Objective		Self-reported	
	β	*P*	*β*	*P*	*β*	*P*	*β*	*P*
Model 1								
Verbal	-0.179	**0.004***	-0.075	0.235	-0.081	0.200	0.043	0.505
Reasoning	-0.003	0.967	-0.010	0.871	-0.017	0.793	0.073	0.258
Numeric	-0.009	0.883	0.044	0.470	0.075	0.217	0.127	**0.039**
Overall	-0.080	0.207	-0.020	0.755	-0.013	0.832	0.100	0.119
Model 2								
Verbal	-0.171	**0.007**	-0.073	0.247	-0.088	0.165	0.046	0.477
Reasoning	0.000	0.999	-0.010	0.879	-0.019	0.771	0.074	0.253
Numeric	0.003	0.958	0.047	0.439	0.067	0.267	0.131	**0.033**
Overall	-0.071	0.265	-0.017	0.782	-0.020	0.751	0.103	0.108
Model 3								
Verbal	-0.177	**0.005***	-0.080	0.210	-0.087	0.174	0.042	0.514
Reasoning	-0.016	0.801	0.001	0.992	-0.004	0.952	0.076	0.240
Numeric	-0.015	0.814	0.049	0.425	0.081	0.184	0.128	**0.038**
Overall	-0.087	0.171	-0.015	0.817	-0.007	0.908	0.101	0.115

Values are standardized regression coefficients (β). Values in bold font indicate significant results. Confounders in Model 1: sex, pubertal stage and SES. Confounders in Model 2: Model 1 + Cardiorespiratory fitness (laps). Confounders in Model 3: Model 1 + moderate-to-vigorous physical activity. Overall indicates the sum of the three abilities scores.
*This association remained significant after Benjamini-Hochberg correction.

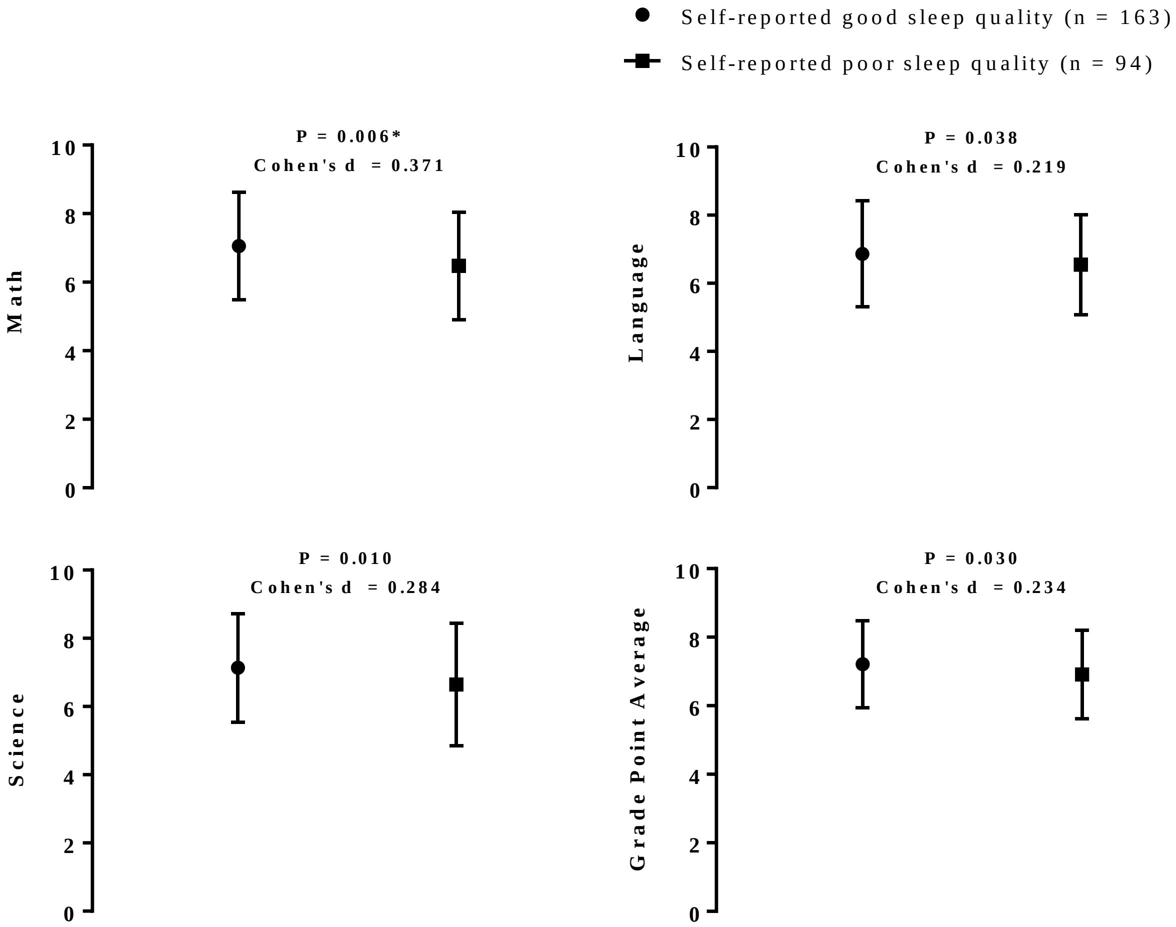

Figure 1. Analysis of covariance assessing differences in academic performance by self-reported sleep quality categories in adolescents. Estimated mean (dots) and 95% CIs (error bars) represent values after sex, pubertal stage and SES adjustments.

Self-reported good sleep quality: PSQI score ≤ 5. Poor sleep quality: PSQI score > 5. PSQI: Pittsburgh Sleep Quality Index; CIs: Confidence Intervals.

*This association remained significant after Benjamini-Hochberg correction.

Table S1. Partial correlation among sleep variables, and academic and cognitive performance controlling for sex, pubertal stage and SES (n=257).

	Math	Language	Science	GPA	Verbal	Reasoning	Numeric	Overall
Sleep duration								
Objective	-0.055	-0.046	-0.041	-0.071	-0.178*	-0.003	-0.009	-0.079
Self-reported	0.109	0.041	0.021	0.048	-0.075	-0.010	0.046	-0.020
Sleep quality								
Objective	-0.003	-0.015	-0.049	-0.033	-0.081	-0.017	0.078	-0.013
Self-reported	0.241**	0.204**	0.266**	0.218**	0.042	0.071	0.129*§	0.098
Math	-	0.719**	0.774**	0.872**	0.338**	0.416**	0.510**	0.522**
Language	-	-	0.751**	0.882**	0.292**	0.358**	0.412**	0.440**
Science	-	-	-	0.897**	0.351**	0.408**	0.457**	0.504**
GPA	-	-	-	-	0.352**	0.432**	0.489**	0.527**
Verbal	-	-	-	-	-	0.371**	0.432**	0.750**
Reasoning	-	-	-	-	-	-	0.576**	0.833**
Numeric	-	-	-	-	-	-	-	0.814**

Data are presented in the correlation coefficient R. GPA: Grade Point Average. Overall indicates the sum of the three abilities scores. *P<0.05 and **P≤0.001

§This significant association disappeared after Benjamini-Hochberg correction.