

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

4 Sleep and cognition in adolescents

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6 Mireia Adelantado-Renau, MSc¹; adelantm@uji.es

7 Maria Reyes Beltran-Valls, PhD¹; vallsm@uji.es

8 Jairo H Migueles, MSc²; jairohm@ugr.es

9 Enrique G. Artero, PhD³; artero@ual.es

10 Alejandro Legaz-Arrese, PhD⁴; alegaz@unizar.es

11 Ana Capdevila-Seder, PhD¹; acapdevi@uji.es

12 Diego Moliner-Urdiales, PhD¹; dmoliner@uji.es

13

14 ¹LIFE Research Group, University Jaume I, Castellón, Spain

15 ²PROFITH “PROmoting FITness and Health through physical activity” Research
16 Group, Department of Physical Education and Sports, Faculty of Sport Sciences,
17 University of Granada, Granada, Spain.

18 ³SPORT Research Group (CTS-1024), CERNEP Research Center, University of Almería,
19 Almería, Spain

20 ⁴Section of Physical Education and Sports, University of Zaragoza, Zaragoza, Spain

21

22 **Corresponding author:** Diego Moliner-Urdiales, email address: dmoliner@uji.es;
23 postal address: Human Sciences Faculty, Department of Education, University Jaume I,
24 Av. Vicent Sos Baynat, PC 12071, Castellon, Spain. Telephone number: 00 34 964
25 729782; Fax: 00 34 964 729264. ORCID ID: 0000-0001-9868-3396

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

31 **ABSTRACT**

32 Adequate sleep has been positively related with health and school achievement outcomes
33 during adolescence. The aim of this study was to investigate the associations of
34 objectively-measured and self-reported sleep duration and quality with academic and
35 cognitive performance in adolescents. This study was conducted with 257 adolescents
36 (13.9 ± 0.3 years) from DADOS Study (Deporte, ADOlescencia y Salud). Objectively-
37 measured and self-reported sleep duration and quality were obtained by a wrist-worn
38 GENEActiv accelerometer and the Spanish version of Pittsburgh Sleep Quality Index
39 (PSQI) questionnaire, respectively. Academic performance was analyzed through school
40 records using four indicators: math, language, science and grade point average score.
41 Cognitive performance was measured using the Spanish version of the “SRA Test of
42 Educational Ability”. After Benjamini-Hochberg correction for the false discovery rate,
43 objectively-measured sleep duration was negatively associated with verbal ability ($\beta=-$
44 0.179 , $P=0.004$), whilst self-reported sleep quality was positively associated with
45 academic performance (β ranging from 0.209 to 0.273 ; all $P<0.001$). These associations
46 remained significant after further controlling for physical fitness and physical activity.
47 Conversely, there were no associations between self-reported sleep duration and objective
48 sleep quality with academic and cognitive performance. Our findings fit in line with
49 previous research showing that sleep quality may play an important role on adolescents’
50 academic performance. Further interventional research is needed to clarify the
51 mechanisms by which sleep is related to academic performance in youth.

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

53 INTRODUCTION

54 Sleep is defined as an active, repetitive and reversible brain process of reduced
55 perception and responsiveness to environmental stimuli (Dahl et al., 2002; Krueger et al.,
56 2016). Insufficient sleep duration and quality have emerged as critical indicators for
57 physical and mental health, being associated with adverse health consequences such as
58 obesity, diabetes, cardiovascular risk, cognitive diseases or cancer (Chaput et al., 2016;
59 Owens et al., 2014). During adolescence, often viewed as an important time frame in
60 terms of acquisition and development of academic and cognitive skills (Andersen, 2016;
61 Patton et al., 2007), sleep might play a key role in memory consolidation, brain plasticity
62 (Frank et al., 2006) and cognitive functioning (Shochat et al., 2014; Wheaton et al., 2016).
63 Likewise, sleep seems to be essential to achieve academic success, which is closely linked
64 to future work achievement, wealth and health status (French et al., 2015).

65 The relationship between sleep and cognition in youth has been the focus of a
66 considerable number of studies during the last decade. In 2010, Dewald et al. revealed
67 that sleepiness was the sleep variable more strongly related to school performance ($r=-$
68 0.133), followed by sleep quality ($r=0.096$), and sleep duration ($r=0.069$). Two years later,
69 a large meta-analysis conducted by Astill et al. (2012) reported a positive association of
70 sleep duration (but not sleep efficiency) with children's executive functioning and school
71 performance, but not with intelligence, attention or memory. In addition, experimental
72 sleep manipulation research has shown that restricted sleep had small or no effects on
73 cognitive functioning, while disrupted sleep could seriously affect cognitive processes in
74 adolescents (Bruin et al., 2016).

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

78 Wang et al., 2016). In fact, the vast majority of previous studies assessed sleep duration
79 and quality using subjective tools (e.g., sleep logs, questionnaires or interviews), included
80 only grade point average (GPA) score or indirect teachers' reports as academic
81 performance indicators, focused on adolescents with sleep disturbances, or did not control
82 for potential confounders with great influence on sleep and cognition such as
83 socioeconomic level, physical activity (PA) or physical fitness (Álvarez-Bueno et al.,
84 2017; Coe et al., 2013; Mota et al., 2010; Shochat et al., 2014). Thus, the present study
85 aimed to analyse the associations of objectively-measured and self-reported sleep
86 duration and quality with academic and cognitive performance in healthy adolescents.

87 **METHODS**

88 *Participants*

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

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

102 *Anthropometry*

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

110 *Objectively-measured and self-reported sleep duration*

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

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

126 *Objectively-measured and self-reported sleep quality*

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

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

141 *Academic and cognitive performance*

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

149 Cognitive performance was measured using the Spanish version of the validated
150 Science Research Associates Test of Academic Abilities (Thurstone et al., 2004). This
151 test measures the subject's ability to learn by evaluating three basic skills: verbal ability
152 (command of language), numeric ability (speed and precision in performing operations
153 with numbers and quantitative concepts) and reasoning ability (the aptitude to find logical
154 ordination criteria in sets of numbers, figures or letters). Scores for the three areas were
155 obtained by adding positive answers. Overall academic ability was calculated by adding
156 the three area scores (verbal + numeric + reasoning). This battery test provides three
157 complexity levels based on the age range of the sample. The present work used the level
158 3 designed for adolescents aged 14 to 18 years (reliability: verbal $\alpha=0.74$, numeric
159 $\alpha=0.87$, reasoning $\alpha=0.77$ and overall academic ability $\alpha=0.89$) (Thurstone et al., 2004).

160 *Covariates*

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

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

168 Cardiorespiratory fitness (CRF) was assessed using the 20m Shuttle Run Test
169 (SRT) as described by Léger et al. (1988). Number of finished laps was registered for
170 each participant. Likewise, maximum oxygen uptake (VO_{2max} , mL/kg/min) was estimated
171 using the equations reported by Léger et al. (1988). Since this equation uses stages

172 completed instead of laps, we decided to use the number of laps to not lose sensitivity in
173 the measure.

174 Participants' PA level was objectively measured using the GENEActiv
175 accelerometer. This device provides a reliable (coefficient of variation intrainstrument =
176 1.4% and coefficient of variation interinstrument = 2.1%) (Esliger et al., 2011) and valid
177 assessment of PA in young people ($r = 0.925$, $P = 0.001$) (Phillips et al., 2013). The raw
178 acceleration output was aggregated in 1-second epochs using the GENEActiv
179 postprocessing PC software, and PA was expressed as average minutes per day in
180 sedentary, light, moderate, and vigorous PA. According to Phillips et al. (2013).
181 GENEActiv cut points for sedentary, light, moderate, and vigorous intensities in children
182 are <7, 7–19, 20–60, and >60 mg.

183 *Data Analysis*

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

192 Sex differences were assessed using t-test for continuous variables and chi-square
193 test for nominal variables. The effect size, Cohen's d , was calculated and interpreted
194 following the cut-offs established by Cohen (1988): small (~ 0.20), medium (~ 0.5) or large
195 (~ 0.8). In addition, intra-class correlation coefficients (ICC) were performed by using

196 two-way mixed models to investigate the agreement between objectively-measured and
197 self-reported sleep variables.

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

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

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

217 **RESULTS**

218 Table 1 shows the descriptive characteristics of the participants. Boys presented
219 lower SES ($P < 0.05$), were taller, more physically active, and showed higher levels of

220 physical fitness than girls (all $P < 0.001$). Objective measurements of both sleep duration
221 and quality were significantly higher in girls, while self-reported sleep duration and
222 quality were significantly higher in boys (all $P < 0.05$). There were no differences between
223 sexes in academic performance, but regarding cognitive performance, boys showed
224 higher numeric ability than girls (14.8 vs. 12.0; $P < 0.001$). Intra-class correlation
225 coefficients showed very low agreement between objectively-measured and self-reported
226 sleep duration (ICC=0.16; $P=0.072$), and no agreement between objectively-measured
227 and self-reported sleep quality (ICC=0.00; $P=0.458$).

228 Partial correlations among the study variables, controlling for sex, pubertal stage
229 and SES are presented in Table S1 supplementary file. Objective sleep duration was
230 negatively correlated with verbal ability ($r=-0.178$; $P < 0.05$), and self-reported sleep
231 quality was positively correlated with numeric ability ($r=0.129$; $P < 0.05$) and all the
232 academic performance indicators (correlation coefficients ranged from 0.204 to 0.266; all
233 $P < 0.001$). However, after correcting for multiple comparisons, the association between
234 self-reported sleep quality and numeric ability disappeared. All the academic
235 performance indicators were positively related to all the cognitive performance indicators
236 (correlation coefficients ranged from 0.292 to 0.527; $P \leq 0.001$).

237 Tables 2 and 3 show linear regression models on the associations of objectively-
238 measured and self-reported sleep duration and quality with academic and cognitive
239 performance. Regarding sleep duration, only objective sleep duration was negatively
240 associated with verbal ability after controlling for sex, pubertal stage and SES ($\beta=-0.179$;
241 $P < 0.01$). According to sleep quality, only self-reported sleep quality was positively
242 associated with academic performance (β ranged from 0.209 to 0.273; $P < 0.001$) and
243 numeric ability ($\beta=0.127$; $P < 0.05$). The results remained significant after additional
244 adjustments for CRF and MVPA (models 2 and 3), but after Benjamini-Hochberg

245 correction, the association between self-reported sleep quality and numeric ability
246 disappeared.

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

256 **DISCUSSION**

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

265 Comparisons between sexes revealed contradictory results regarding sleep
266 variables; girls showed longer objective sleep duration and better objective sleep quality,
267 while boys showed better measurements of self-reported sleep variables. These
268 controversial results fit in line with Dewald et al. (2010) who analysed 50 studies

269 suggesting that differences between objective and self-reported sleep measurements
270 could be partially explained by individuals' distinct experiences of sleep (e.g.,
271 experiences in girls vs. boys) and different subjective sleep components (e.g., sleepiness,
272 feeling rested).

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

289 Sleep quality is defined as the satisfaction level of the sleep experience. Our
290 analyses indicate a significant positive association of self-reported sleep quality, but not
291 objectively-measured, with academic performance. Analysis according sleep quality
292 categories revealed higher scores in math among those adolescents with self-reported
293 good sleep quality ($PSQI \leq 5$). These results concur with previous studies revealing a

294 positive association of self-reported sleep quality and academic performance during youth
295 (Baert et al., 2015; Duarte et al., 2014; Mak et al., 2012). Good sleep quality reduces
296 sleepiness (Pilcher et al., 1997) at school time, with positive effects on attention and
297 memory (Carskadon, 2011), which might improve academic performance (Moore et al.,
298 2008). Differences between objective and self-reported sleep quality measurements could
299 be caused by methodological issues. Despite actigraphy is revealed as a validated method
300 for assessing sleep quality, this methodology only assesses sleep efficiency -without
301 capturing other large individual differences in the sleep experience- during few days,
302 while subjective tools such as the PSQI questionnaire assesses other specific components
303 (e.g., sleep latency, use of sleep medication, sleep disturbance) providing an overall sleep
304 quality index over the last month.

305 **Limitations**

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

316 **Conclusions**

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

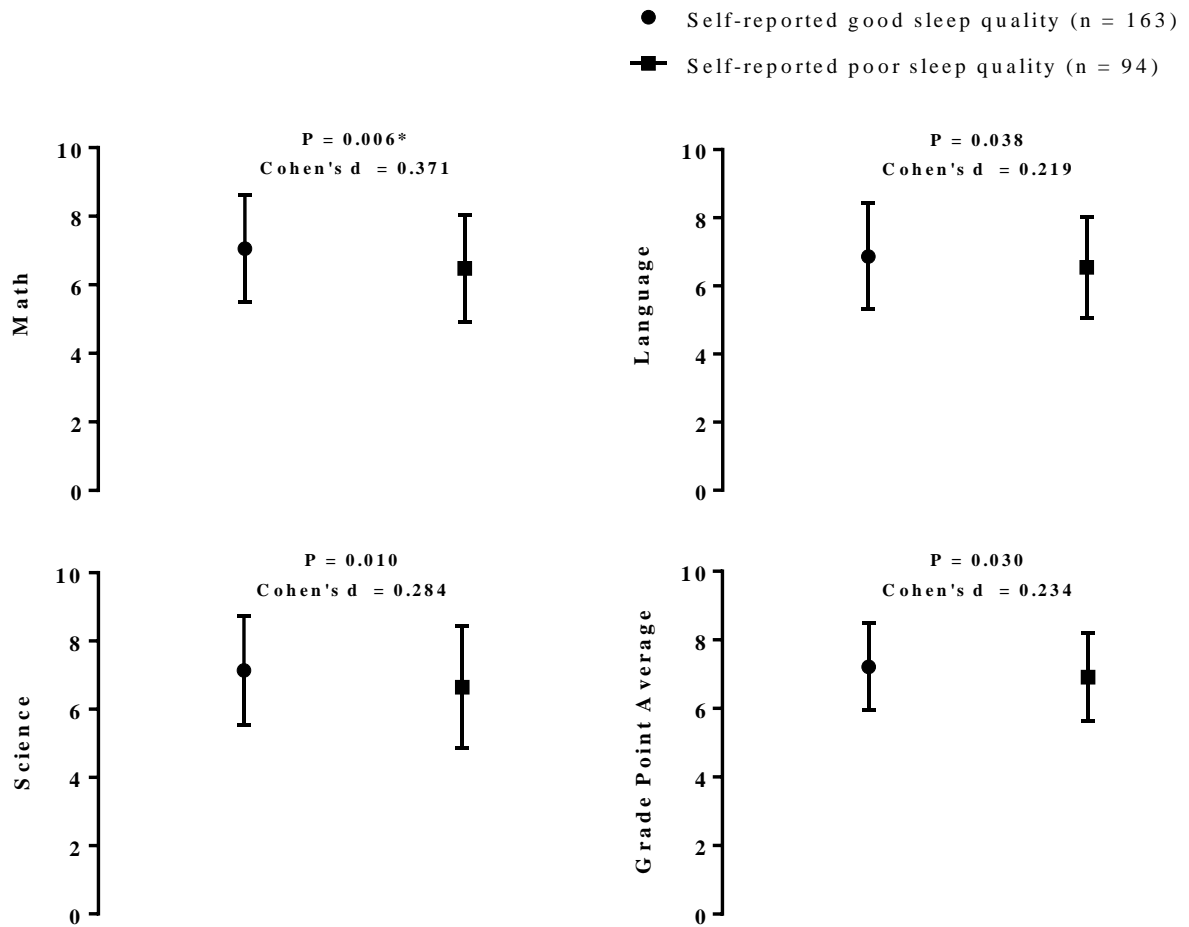


Figure 1. Analysis of covariance assessing differences in academic performance by self-reported sleep quality categories in adolescents. Estimated mean (dots) and 95% CIs (error bars) represent values after sex, pubertal stage and SES adjustments.

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.