The influence of adherence to the Mediterranean diet on academic performance is mediated by sleep quality in adolescents

Mireia Adelantado-Renau[1], Maria Reyes Beltran-Valls[1,2], Irene Esteban-Cornejo[3,4], Vicente Martínez-Vizcaíno[5,6], Alba María Santaliestra-Pasía[7,8,9,10], Diego Moliner-Urdiales[1]

[1]LIFE Research Group, Department of Education, University Jaume I, Castellon, Spain. University Jaume I

[2]Escola Universitària de la Salut i l'Esport (EUSES), Universitat Rovira i Virgili, Tarragona, Spain

[3]Center for Cognitive and Brain Health, Department of Psychology, Northeastern University, Boston, MA, USA.

[4]PROFITH "PROmoting FITness and Health through physical activity" research group, Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain.

[5]Health and Social Research Center, Universidad de Castilla-La Mancha, Spain

[6]Universidad Autónoma de Chile. Facultad de Ciencias de la Salud. Talca, Chile University of Castilla-La Mancha

[7]GENUD (Growth, Exercise, NUtrition and Development) Research Group, Facultad de Ciencias de la Salud. Universidad de Zaragoza, Spain

[8]Instituto Agroalimentario de Aragón (IA2), Zaragoza, Spain

[9]Instituto de Investigación Sanitaria Aragón (IIS Aragón), Zaragoza, Spain

[10]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Zaragoza, Spain

Short title: Diet, sleep and academic performance

Corresponding Author: Diego Moliner-Urdiales. Department of Education, University Jaume I. Av. de Vicent Sos Baynat, s/n, 12071 Castellón, Spain. Phone: +34964729782. mail: dmoliner@uji.es

ABSTRACT

Aim: This study examined the association of adherence to the Mediterranean diet with academic performance and tested whether this association was mediated by sleep in Spanish adolescents.

Methods: We recruited 269 adolescents (52% boys) aged 13.9 ±0.3 years from the *Deporte, ADOlescencia y Salud* study of 38 secondary schools and sport clubs in Castellon, Spain, between February and May 2015. Adherence to the Mediterranean diet was assessed by the KIDMED questionnaire, sleep quality was evaluated with the Pittsburgh Sleep Quality Index test and sleep duration was objectively computed using a wrist-worn accelerometer. Academic performance was assessed through final school grades and a validated test.

Results: Greater adherence to the Mediterranean diet was associated with higher scores in language, core subjects, grade point average and verbal ability ($p<0.05$). Sleep quality acted as a significant mediator of the association between adherence to the Mediterranean diet and final grades in maths, language, core subjects and the grade point average.

Conclusion: Our data show that the influence of adherence to the Mediterranean diet on academic performance was mediated by sleep quality in adolescents. Education and public health professionals should work together to achieve both improved health status and academic performance in adolescents.

Key Notes

- We recruited 269 adolescents (52% boys) aged 13.9 ±0.3 years from a study of 38 secondary schools and sport clubs in Castellon, Spain.,
- Our results showed that adherence to the Mediterranean diet was positively associated with academic grades and verbal ability in our cohort.
- The study carried out between February and May 2015 also revealed the potential mediating effect that sleep quality had on that association.

Key words. academic achievement, adolescence, Mediterranean diet, school performance, sleep patterns.

INTRODUCTION

The Mediterranean diet is characterised by a high consumption of fruit, vegetables, breads, legumes, nuts and seeds, a low intake of red meat, a low-to-moderate consumption of wine, fish and poultry and the use of olive oil as the principal source of fat (1). In terms of nutrients, the Mediterranean diet is rich in polyunsaturated fatty acids, fibre, antioxidants and vegetable proteins (2). Greater adherence to the Mediterranean diet has been associated with a lower risk of morbidity and mortality (3), as well as better sleep patterns (4,5) and cognition (6,7).

Academic performance during adolescence has a significant influence on future health (8) and work conditions (9). Individual behaviours, such as diet, may differently influence cognition (10), and in turn, academic performance. For instance, consuming fish, milk, fruits and vegetables, and a lower intake of soft drinks and salty snacks, have been associated with better academic and cognitive performance in adolescents (11). However, dietary patterns seem to be more strongly associated with cognition than individual foods, due to the synergistic effects of each food component (11). Despite this growing evidence of the influence of diet on cognition, the effect of adherence to the Mediterranean diet on academic performance in adolescents has been poorly investigated (7).

Greater adherence to the Mediterranean diet has also been associated with better sleep patterns, such as duration and quality (4,5), as a result of the effect of different nutrients (12,13). Interestingly, prior research has shown that sleep has also been related to memory consolidation, brain plasticity and cognition (14), which, in turn, may improve academic performance in adolescents (15).

Given the association between adherence to the Mediterranean diet and academic performance in adolescents, and the independent associations of sleep patterns with Mediterranean diet and cognition mentioned above, the aims of the present study were: (i) to examine the association of adherence to Mediterranean diet with academic performance and (ii) to test whether the association of adherence to the Mediterranean diet with academic performance was mediated by sleep patterns in healthy adolescents.

METHODS

Study design and sample selection

A national three-year longitudinal research project, DADOS (Deporte, ADOlescencia y Salud; from 2015 to 2017), was performed to assess the influence of physical activity on health, cognition and psychological wellness through adolescence. Participants meeting the general inclusion criteria were recruited from secondary schools and sport clubs in Castellon; adolescents born in 2001, enrolled in the second grade of secondary school and free from any chronic disease. The results presented in this study come from baseline data obtained from February to May 2015. The sample analysed comprised 269 adolescents (52% boys) aged 13.9 ±0.3 years with valid baseline data on sleep variables, Mediterranean dietary patterns and academic performance.

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

Adherence to the Mediterranean diet

Adherence to the Mediterranean diet was assessed by using KIDMED (16), a questionnaire that was based on the Mediterranean dietary guidelines for children and adolescents and provides an overall indication of their diet. The KIDMED includes 16 questions about if subjects consume fast food, sweets and soft drinks, daily fruit and vegetables and weekly fish and legumes, with yes or no answers required. The score for the subjects' adherence to the Mediterranean diet was calculated as the sum of each answer, ranging from zero to 12. Levels of adherence were classified into three groups: poor (0-3), average (4-7) and good (8-12).

Sleep patterns

Sleep quality over the last month was assessed by using the Spanish version of the Pittsburgh Sleep Quality Index (PSQI) test (17). The overall PSQI score ranges from zero to 21, with scores ≤ 5 defined as good sleep quality. Because the overall PSQI score is inversely related to sleep quality, it was multiplied by -1 in the first instance.

Daily sleep duration was objectively measured by a GENEActiv accelerometer (Activinsights Ltd, Cambridgeshire, UK), which is a lightweight 16 grams, triaxial and waterproof. It has been found to be reliable for examining sleep (kappa = 0.85 ±0.06) (18). Participants were instructed to wear 24-hours day the accelerometer on their left wrist for at least four consecutive days, including two weekend days and two weekdays. If the unit was removed, the data for that day were excluded from the analyses. Sleep duration was calculated by the algorithm included in the macro provided by the manufacturer. By combining all the registered days for each participant, sleep duration was then expressed as the average number of hours per day. Short sleep duration was defined as less than eight hours per night, as defined by the American National Sleep Foundation for the adolescent population (19).

130 **Academic performance**

131 Academic performance was assessed by two components. First, we looked at the
132 final academic grades from the first year of secondary school, which were provided by
133 each school. The following subjects were included in the analyses: individual grades for
134 the core subjects of maths and the Catalan language, the official language taught at the
135 school, an average of these core subjects and the grade point average score. The grade
136 point average score was defined as the single average for geography and history, natural
137 sciences, maths, Spanish, Catalan and English languages and physical education grades.
138 All the subjects are measured on a ten-point scale, where one was the worst and 10 was
139 the best. Second, we used the Spanish version of the validated Science Research
140 Associates Test of Educational Abilities (20). This test measures the subject's ability to
141 learn by evaluating three basic skills: verbal ability, which is their command of language;
142 numerical ability, which refers to their speed and precision in performing operations with
143 numbers and quantitative concepts and reasoning ability, which refers to their aptitude to
144 find logical ordination criteria in sets of numbers, figures or letters. Scores for the three
145 areas were obtained by adding positive answers. Overall academic ability was calculated
146 by adding the scores for the three areas of ability. This battery test provides three
147 complexity levels based on the age range of the sample. The present study used level
148 three, which is designed for adolescents aged 14 to 18 years. The alpha scores for its
149 reliability have been reported to be 0.74 for verbal ability, 0.87 for numerical ability, 0.77
150 for reasoning ability and 0.89 for overall academic ability (20).

151 **Covariates**

152 Briefly, body weight was measured to the nearest 0.1 kilograms using a seca 861
153 electronic scale (seca, Hamburg, Germany) with the subjects lightly dressed and without
154 shoes. Height was measured to the nearest 0.1 centimetres using a wall-mounted seca 213

stadiometer (seca, Hamburg, Germany). Measures were assessed in duplicate by trained members of the project's research group following standardised procedures and average measures were used for the data analysis (21). Body mass index (BMI) was calculated as weight/height square (kg/m^2). Pubertal status was self-reported according to the five stages defined by Tanner and Whitehouse. Physical activity (PA) was objectively measured using the GENEActiv accelerometer, as stated above, which has shown an intra-assay and inter-assay precision coefficient of variation of 1.4% and 2.1%, respectively. By combining all registered days for each participant and using the Excel macro (Microsoft Corp, Washington, USA) to summarise the data, PA was expressed as the average minutes per day spent in light, moderate, and vigorous PA. Moderate and vigorous PA (MVPA) was calculated by adding moderate PA and vigorous PA.

Statistical analyses

The descriptive characteristics are presented as means and standard deviations (SD) or percentages. Differences between sexes were examined using the t-test and chi-square test for continuous and nominal 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, the PSQI score was log-transformed when required. As the preliminary analyses showed no significant interactions between sex and adherence to the Mediterranean diet and sleep variables in relation to academic performance (all $p>0.10$), all the analyses were performed for the whole sample.

Partial correlations coefficients were used to confirm the relationships between adherence to the Mediterranean diet, sleep variables and academic performance indicators, controlled for sex, pubertal stage, BMI and MVPA.

Multiple linear regression was used to study the association of adherence to the Mediterranean diet and academic performance using three separate models: model 1 comprised sex, pubertal stage, BMI and MVPA; model 2 comprised model 1 plus sleep duration and model 3 comprised model 1 plus sleep quality.

In order to elucidate whether the associations between adherence to the Mediterranean diet and academic performance were mediated by sleep patterns, mediation analyses were conducted using the PROCESS macro according to the procedures proposed by Hayes (22) and controlling for sex, pubertal stage, BMI and MVPA. The first equation regressed the mediator (sleep) on the independent variable (adherence to the Mediterranean diet). The second equation regressed the dependent variable (academic performance) on the independent variable. The third equation regressed the dependent variable on both the independent and mediator variables. The mediation analyses included continuous variables and was considered significant when zero was not in the 95% confidence interval of the indirect effects, estimated by bootstrapping, as recommended by Preacher and Hayes (23). The part of the total effect that was explained by the mediation, namely the percentage of mediation (P_M) was calculated as follows: (indirect effect/total effect) x 100. All the analyses were performed using SPSS Statistics for Windows version 22.0 (IBM Corp, New York, USA) and the level of significance was set to $p<0.05$.

RESULTS

The descriptive characteristics of the study population are presented in Table 1. Overall, boys were taller, more physically active ($p<0.001$) and had greater adherence to the Mediterranean diet than girls ($p<0.01$). We found that 74% of boys and 54% of girls showed good sleep quality ($p<0.001$). The boys also had a better mean sleep quality score

(4.2 versus 5.5, $p<0.01$), shorter sleep duration (7.8 versus 8.1 hours; $p<0.01$) and higher numerical ability (14.8 versus 11.9; $p<0.001$) than the girls.

Partial correlations controlling for sex, pubertal stage, BMI and MVPA are shown in Table 2. Adherence to the Mediterranean diet was positively correlated with sleep quality, language, core subjects, grade point average and verbal ability (all $p<0.05$). Sleep quality was positively correlated with academic grades (all $p<0.01$), while sleep duration was negatively correlated with verbal ability ($p<0.01$).

The results of the multiple linear regression models showing the association of adherence to the Mediterranean diet with academic performance are presented in Table 3. According to the academic grades, adherence to the Mediterranean diet was positively associated with language, core subjects and the grade point average (all $p<0.05$) after controlling for sex, pubertal stage, BMI and MVPA (model 1). These associations disappeared after further controlling for sleep duration (model 2) and sleep quality (model 3). Regarding academic abilities, adherence to the Mediterranean diet was positively associated with verbal ability (model 1), even after controlling for potential confounders (models 2 and 3).

Mediation analyses were carried out to test whether the associations between adherence to the Mediterranean diet (independent variable) and academic performance (dependent variables) were mediated by sleep patterns (mediator variables). Mediation analyses were not significant for the association of adherence to the Mediterranean diet with academic performance when sleep duration was included as a mediator variable (data not shown). According to our mediation analyses (Figure 1), sleep quality acted as a mediator for the relationship of adherence to the Mediterranean diet with academic grades, but not with academic abilities (data not shown). In the first equation, adherence to the Mediterranean diet was positively associated with sleep quality ($p<0.05$). In the

second equation, adherence to the Mediterranean diet was also positively associated with final grades ($p<0.05$). Finally, in the third equation, sleep quality was positively associated with final grades ($p<0.01$) and adherence to the Mediterranean diet was positively related with final grades, although the associations were not statistically significant. These results suggest that adherence to the Mediterranean diet could indirectly influence some academic performance variables through its effects on sleep quality: maths $P_M = 20.24\%$; language $P_M = 15.44\%$; core subjects $P_M = 15.52\%$ and grade point average $P_M = 16.83\%$.

DISCUSSION

To our knowledge this is the first study investigating the potential mediator role of sleep quality in the association between adherence to Mediterranean diet and academic performance in adolescents. The main finding of the present study indicates a positive association between adherence to the Mediterranean diet and academic performance in adolescents, revealing a mediating effect of sleep quality on this association.

No previous studies have investigated the association between adherence to the Mediterranean diet and academic abilities. However, we found three studies examining the association between adherence to the Mediterranean diet and school grades. In consonance with our results, Vassiloudis et al found a positive association between adherence to the Mediterranean diet and self-reported academic performance in Greek children (6) and adolescents (24). Similarly, Esteban-Cornejo et al (7) showed that greater adherence to the Mediterranean diet was related with higher academic performance scores in Spanish children and adolescents aged 10-15 years.

Our data show that adherence to the Mediterranean diet may have positively influenced the adolescents' academic grades, but not their academic abilities. The

252 divergent results obtained for academic performance variables could have been due to
253 methodological differences. In fact, academic abilities were assessed through a
254 standardised test that evaluates individually specific content abilities in a single time-
255 point trial, whilst the multifactorial character of academic grades involve other social,
256 cultural and biological variables that have an impact on a final grade.

257 The association between the Mediterranean diet and academic performance could
258 be related to the key role that dietary patterns and nutrients exert on brain. The
259 consumption of polyunsaturated fatty acids, abundant in olives, nuts and fish, increases
260 the levels of brain-derived neurotrophic factors, which stimulates cognitive functioning.
261 This, in turn, may improve academic performance (25). Conversely, overconsumption of
262 saturated fat and simple sugars decreases the levels of brain-derived neurotrophic factors
263 and increases oxidative stress, which may impair cognitive processes (26,27). In addition,
264 the intake of flavonoid and non-flavonoid polyphenols, which are mainly found in fruits
265 and vegetables, has antioxidant and anti-inflammatory properties and promotes neuronal
266 signalling with positive effects on learning and memory (25). Therefore, the foods rich in
267 micronutrients and macronutrients that are found in the Mediterranean diet could act as
268 key factors leading to better academic performance.

269 When we examined whether sleep duration and quality could be underlying
270 mechanisms of the association between adherence to the Mediterranean diet and
271 academic performance, only sleep quality was revealed as a mediator. Few studies have
272 investigated the association between the Mediterranean diet and academic performance,
273 and none of them has evaluated the mediating role of sleep quality. Our results add
274 important information in relation to the relevance of sleep on academic performance and
275 highlight that sleep quality could play a more important role than sleep duration in
276 academic performance, which has also been previously suggested (15,28).

Several aspects of the Mediterranean diet, including specific nutrients, have been shown to modulate sleep quality. In fact, adequate amounts of proteins, fibre, carbohydrates, polyphenols, and monosaturated and polyunsaturated fatty acids intake have been associated with better sleep quality (12,13). Moreover, the Mediterranean diet includes foods, such as seeds, nuts, fish and chicken that are rich in tryptophan, an amino acid that is related to the regulation of the circadian rhythms and which has been proposed as the most helpful promotor of sleep (29). On the other hand, better sleep quality has been positively related to synaptic plasticity and learning (30), with improvements in attention and working memory, which might contribute to better academic performance in adolescents (15). Therefore, despite the fact that we did not analyse the physiological mechanisms involved in the processes of diet, sleep and cognition, we speculate that high levels of specific compounds provided by the Mediterranean diet could contribute to better sleep (12), with benefits in cognitive functioning (15,30), leading to higher academic performances in adolescents.

Limitations and strengths

The limitations of our study include its cross-sectional design, which prevents us from infering causal relationships, and the use of a questionnaire to assess adherence to the Mediterranean diet. Nonetheless, our mediation analysis strategy allowed us to provide data supporting the importance of improving adherence to the Mediterranean diet in order to enhance sleep and academic performance in adolescents. Moreover, the study included the use of objective and standardised measures of sleep duration and quality, respectively, and a relatively large and age-matched sample of adolescents aged 13.9 ±0.3 years with no academic performance differences. In addition, the statistical analyses were controlled for sex, pubertal status, BMI and MVPA, which are relevant given their associations with diet, sleep and academic performance.

CONCLUSION

The current study showed that sleep quality plays a key mediating role in the relationship between adherence to the Mediterranean diet and academic performance in adolescents. If our findings are confirmed in prospective studies, they would indicate that following Mediterranean dietary patterns may improve sleep quality, which could have potentially positive effects on academic performance in adolescents. Due to the benefits of healthy dietary patterns and good sleep behaviours, further longitudinal and intervention studies should examine the effects of diet and sleep patterns on academic performances in adolescents. Families, educators and policy makers should take into account our results in order to promote school-based public health and educational support programmes that consider nutrition and sleep patterns as key behaviours that can improve academic performance.

FINANCE

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

Abbreviations: BMI, body mass index; PA, physical activity; MVPA, moderate and vigorous physical activity; PSQI, Pittsburg Sleep Quality Index.

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Table 1. Descriptive characteristics of the Spanish adolescents from the DADOS study by sex.

	All	**Boys**	**Girls**	**p**
n (%)	269 (100)	140 (52)	129 (48)	
Demographics				
Age (years)	13.9 ± 0.3	13.9 ± 0.3	13.9 ± 0.3	0.903
Tanner stage (I-V) (%)	0/8/34/48/10	0/10/32/44/14	0/5/36/54/5	
Anthropometry				
Height (cm)	163.0 ± 7.9	164.6 ± 8.6	161.2 ± 6.8	**<0.001**
Weight (kg)	54.1 ± 9.2	54.5 ± 9.6	53.7 ± 8.8	0.486
BMI (kg/m^2)	20.3 ± 2.7	20.0 ± 2.5	20.6 ± 2.9	0.059
Physical activity (min/day)				
Light	174.8 ± 55.8	173.7 ± 58.8	175.9 ± 52.6	0.748
Moderate	76.7 ± 25.4	81.7 ± 24.7	71.4 ± 25.2	**<0.001**
Vigorous	12.5 ± 8.4	15.5 ± 7.7	9.2 ± 7.8	**<0.001**
Moderate and vigorous	89.2 ± 30.3	97.2 ± 28.8	80.5 ± 29.6	**<0.001**
Adherence to the Mediterranean diet				
Overall score (0-12)	7.0 ± 2.2	7.3 ± 2.1	6.6 ± 2.2	**0.010**
Categories (%)				0.115
Poor (0-3)	14 (5.2)	5 (3.6)	9 (7.0)	
Average (4-7)	139 (51.7)	67 (47.9)	72 (55.8)	
Good (8-12)	116 (43.1)	68 (48.6)	48 (37.2)	
Sleep patterns				
Sleep quality score (0-21)	4.8 ± 2.8	4.2 ± 2.7	5.5 ± 2.7	**<0.001**
Good sleep quality (%)	174 (64.7)	104 (74.3)	70 (54.3)	**<0.001**
Sleep duration (hours)	8.0 ± 0.9	7.8 ± 1.0	8.1 ± 0.8	**0.005**
Sleep duration ≥ 8 hours (%)	135 (50.2)	66 (47.1)	69 (53.5)	0.326
Academic grades (0-10)				
Maths	6.8 ± 1.6	7.0 ± 1.6	6.7 ± 1.6	0.196
Language	6.8 ± 1.5	6.6 ± 1.5	6.9 ± 1.5	0.168
Core subjects	6.8 ± 1.4	6.8 ± 1.5	6.8 ± 1.4	0.991
GPA	7.1 ± 1.3	7.1 ± 1.3	7.2 ± 1.3	0.420
Academic abilities				
Verbal ability (0-50)	18.7 ± 5.3	19.1 ± 5.9	18.2 ± 4.6	0.127
Numerical ability (0-30)	13.4 ± 4.8	14.8 ± 4.6	11.9 ± 4.5	**<0.001**
Reasoning ability (0-30)	16.5 ± 5.8	16.1 ± 5.6	16.9 ± 6.0	0.239
Overall score (0-110)	48.6 ± 12.6	50.0 ± 12.8	47.0 ± 12.2	**0.049**

Data are presented as means ± SDs or frequencies (percentages). Sex differences were examined by the t-test or chi-square test.

Statistically significant values are in bold.

BMI: body mass index; GPA: grade point average; Good sleep quality was measured by a Pittsburg sleep quality index of ≤ 5. Core subjects indicates the mean of maths and language. Overall score indicates the sum of the three abilities scores: verbal, numerical and reasoning.

Table 2. Partial correlation coefficients between adherence to the Mediterranean diet score, sleep patterns and academic performance indicators controlling for sex, pubertal stage, body mass index and moderate and vigorous physical activity (n=269).

		Academic grades				Academic abilities			
	Adherence to the Mediterranean diet	Maths	Language	Core subjects	GPA	Verbal	Numerical	Reasoning	Overall score
Adherence to the Mediterranean diet	-	0.115	0.122*	0.121*	0.121*	0.130*	0.063	-0.024	0.067
Sleep quality	0.120*	0.205***	0.169**	0.168**	0.182**	0.023	0.096	0.063	0.074
Sleep duration	-0.059	-0.038	-0.058	-0.072	-0.074	-0.194**	-0.022	-0.008	-0.094

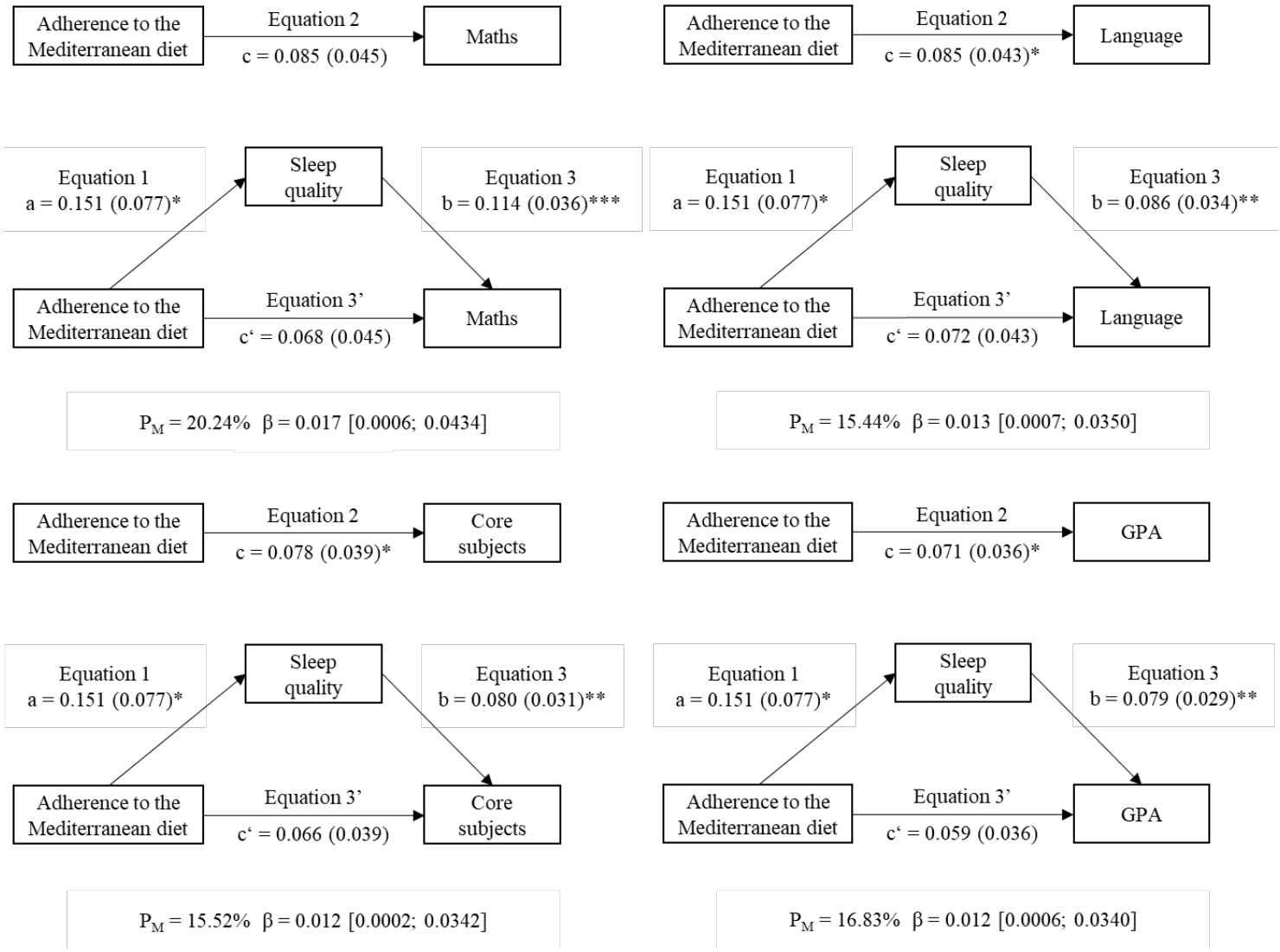
Core subjects indicates the mean of maths and language; GPA: grade point average; Overall score indicates the sum of the three abilities scores: verbal, numerical and reasoning. p-value = ***$p \leq 0.001$, **$p < 0.01$ and *$p < 0.05$.

Table 3. Multiple regression models showing the association between adherence to the Mediterranean diet and academic performance in adolescents (n = 269).

	Model 1			Model 2			Model 3		
	B	β	p	B	β	p	B	β	p
Academic grades									
Maths	0.085	0.116	0.062	0.084	0.114	0.067	0.068	0.092	0.132
Language	0.085	0.121	**0.048**	0.082	0.118	0.055	0.072	0.102	0.094
Core subjects	0.078	0.121	**0.049**	0.075	0.117	0.058	0.066	0.102	0.096
GPA	0.071	0.121	**0.049**	0.069	0.117	0.058	0.059	0.101	0.100
Academic abilities									
Verbal	0.319	0.131	**0.035**	0.293	0.120	**0.049**	0.317	0.130	**0.038**
Numerical	0.131	0.060	0.311	0.129	0.059	0.321	0.109	0.050	0.404
Reasoning	-0.065	-0.024	0.699	-0.066	-0.025	0.693	-0.086	-0.032	0.608
Overall score	0.386	0.067	0.280	0.355	0.061	0.319	0.340	0.059	0.345

Model 1: controlled for sex, pubertal stage, body mass index, and moderate and vigorous physical activity. Model 2: controlled for model 1 plus sleep duration. Model 3: controlled for model 1 plus sleep quality. Core subjects indicates the mean of maths and language; GPA: Grade Point Average. Overall score indicates the sum of the three abilities scores: verbal, numerical and reasoning. Statistically significant values are highlighted in bold. β, standardised coefficient.

Fig. 1. Sleep quality mediation models of the relationship between adherence to the Mediterranean diet and academic grades, controlling for sex, pubertal stage body mass index, and moderate and vigorous physical activity.



Results showed as regression coefficients (standard error). β = indirect effect; LLCI and ULCI = lower and upper levels for 95% confidence interval of the indirect effect between adherence to the Mediterranean diet and academic grades. Core subjects indicates the mean of maths and language. GPA: grade point average. p-value = ***p≤0.001, **p<0.01 and *p<0.05.