

## Association between self-reported sleep duration and dietary quality in European adolescents

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### Abstract

Evidence has grown supporting the role for short sleep duration as an independent risk factor for weight gain and obesity. The purpose of the present study was to examine the relationship between sleep duration and dietary quality in European adolescents. The sample consisted of 1522 adolescents (aged 12·5–17·5 years) participating in the European multi-centre cross-sectional ‘Healthy Lifestyle in Europe by Nutrition in Adolescence’ study. Sleep duration was estimated by a self-reported questionnaire. Dietary intake was assessed by two 24 h

**Abbreviations:** DQI, Diet Quality Index; DQI-AM, Diet Quality Index for Adolescents with Meal index; FBDG, food-based dietary guidelines; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence.

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recalls. The Diet Quality Index for Adolescents with Meal index (DQI-AM) was used to calculate overall dietary quality, considering the components dietary equilibrium, dietary diversity, dietary quality and a meal index. An average sleep duration of  $\geq 9$  h was classified as optimal, between 8 and 9 h as borderline insufficient and  $< 8$  h as insufficient. Sleep duration and the DQI-AM score were positively associated ( $\beta = 0.027$ ,  $r = 0.130$ ,  $P < 0.001$ ). Adolescents with insufficient (62.05 (SD 14.18)) and borderline insufficient sleep (64.25 (SD 12.87)) scored lower on the DQI-AM than adolescents with an optimal sleep duration (64.57 (SD 12.39)) ( $P < 0.001$ ;  $P = 0.018$ ). The present study demonstrated in European adolescents that short sleep duration was associated with a lower dietary quality. This supports the hypothesis that the health consequences of insufficient sleep may be mediated by the relationship of insufficient sleep to poor dietary quality.

**Key words:** Sleep duration: Obesity: Adolescents: Diet: Diet Quality Index

The increased prevalence in Western nations of overweight and obesity over the past half-century is of great public health concern. The situation is particularly alarming with regard to children and adolescents because of how overweight and obesity 'track' from childhood into adulthood<sup>(1)</sup>. It is typically assumed that obesity results from a positive energy balance attributable to excess energy intake and/or insufficient energy expenditure. However, attempts to prevent or manage obesity based on these traditional risk factors have been generally unsuccessful<sup>(2–5)</sup>.

This increased prevalence of obesity has been paralleled by a reduction in sleep duration<sup>(6)</sup>. Evidence to support this claim is scarce and conflicting. However, a recent systematic review concluded that there have been consistent rapid declines in the sleep duration of children and adolescents<sup>(7)</sup>. Experimental studies have shown that the need for sleep during adolescence (10–17 years) is estimated to be on average 9 h of sleep per night<sup>(8)</sup>. Surveys from the American National Sleep Foundation<sup>(9)</sup> in 2006 indicate that, on average, adolescents get about 7.6 h of sleep on weekdays. Adolescents tend to have less sleep as they get older<sup>(9)</sup>, and there seems to be a prominent difference in sleep duration between weekdays and weekends among schoolchildren<sup>(10)</sup>.

Evidence has grown over the past decade in support of the theory that short sleep duration is a novel and independent risk factor for weight gain and obesity, especially in younger populations<sup>(11,12)</sup>. However, major study design and methodological limitations preclude definitive conclusions<sup>(11,13)</sup>, and the association between sleep duration and obesity in adolescence has been shown to differ by sex<sup>(14–17)</sup>. Potential mechanisms underlying the association between short sleep duration and obesity are still unclear. Based on experimental studies of sleep deprivation, different hypotheses have been formulated linking reduced sleep with obesity.

One of the strongest and most plausible hypotheses by which sleep deprivation might lead to weight gain is by increased or altered dietary intake<sup>(6)</sup>. Experimental and observational studies have shown that short sleep duration can disturb the homeostatic regulation of appetite through altering levels of several hormones including leptin, ghrelin, insulin and cortisol<sup>(18–21)</sup>. Lack of sleep could also lead to weight gain and obesity by increasing the potential time available for eating<sup>(22)</sup>.

To our knowledge, only five observational studies have examined the relationship between sleep duration and nutritional intake in adolescents<sup>(23–27)</sup>, and none of them

examined overall dietary quality using a dietary index. Foods and nutrients are not eaten in isolation and may have complicated interactions; also, nutrient bioavailability and absorption often depend on food preparation and eating patterns<sup>(28)</sup>. Therefore, most recent studies on diet and health attempt to address the multidimensional nature of the human diet<sup>(29)</sup>. Dietary indices are ideal for this purpose as they represent overall dietary quality and often show stronger correlations with the risk of disease than with individual nutrients or foods<sup>(30)</sup>.

The study of Garaulet *et al.*<sup>(25)</sup> found an association between short sleep duration and excess adiposity in European adolescents participating in the 'Healthy Lifestyle in Europe by Nutrition in Adolescence' (HELENA) study. They further elucidated whether physical activity, sedentary behaviours and/or inadequate food habits underlie this association. The relationship between sleep duration and food habits was, however, not exhaustively analysed and only nutritional data received from a FFQ were used, which are less detailed than 24 h recall data. The purpose of the present study was to further explore the association between sleep duration and dietary quality in the same sample of European adolescents. The present study contributes to the current knowledge on the relationship between sleep and dietary quality by using an index of diet quality and considering sex differences.

## Methods

### Study design

The HELENA cross-sectional study was established to broaden insight into the nutritional status and lifestyle of adolescents, and to explore the associations between diet and health. The study aimed to obtain standardised, reliable and comparable data from a random sample of European adolescents on a broad battery of relevant nutrition- and health-related parameters<sup>(31,32)</sup>. Data collection took place from October 2006 until December 2007 in ten different European cities (Vienna, Ghent, Lille, Dortmund, Athens, Heraklion, Pécs, Rome, Zaragoza and Stockholm). A detailed description of the HELENA cross-sectional study sampling and recruitment approaches, standardisation and harmonisation processes, data collection, analysis strategies and quality control activities has been published elsewhere<sup>(33)</sup>. The study was performed following the ethical guidelines of the Declaration of Helsinki, the Good Clinical Practice rules and the legislation about clinical research in human subjects in each of the participating



countries. The protocol was approved by the Human Research Review Committees of the centres involved<sup>(34)</sup>.

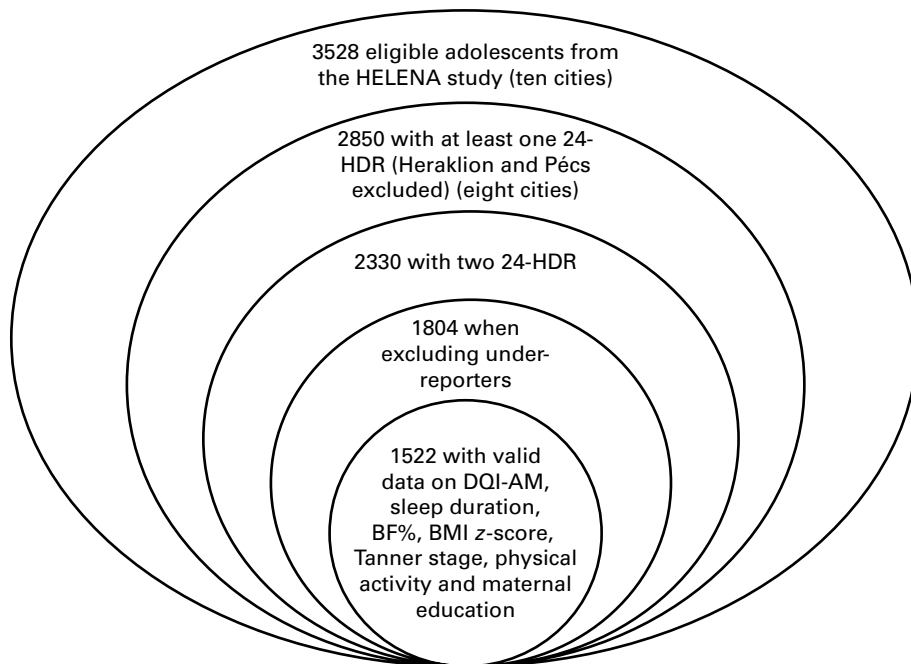
### Subjects

Adolescents, aged 12.5–17.5 years, were recruited from randomly selected schools. After receiving complete information about the aims and methods of the study, all adolescents gave assent to participate in the study and their parents or guardians provided informed written consent. Participants were excluded *a posteriori* from the database if they met one or more of the exclusion criteria: <12.5 or >17.5 years old; missing weight and/or height data; participating simultaneously in another clinical trial; having had an acute infection less than 1 week before the measurement<sup>(33)</sup>. The total eligible HELENA study population consisted of 3528 adolescents (52.3% girls). Participants from Heraklion and Pécs were excluded from the analyses in the present study as no nutrient intake information could be calculated for these cities due to logistical problems. Therefore, eight HELENA centres were included in the study. In the present study, only adolescents who provided two non-consecutive 24 h recalls were included in the analyses, resulting in 2330 subjects. Furthermore, under-reporters were excluded from all analyses, resulting in a sample of 1804 adolescents. BMR was calculated from age-specific FAO/WHO/United Nations University equations<sup>(35)</sup>. Under-reporting was considered when the ratio of energy intake:estimated BMR was <0.96, as proposed by Black<sup>(36)</sup>. For the purpose of the present study, only adolescents with valid data on sleep duration, Diet Quality Index for Adolescents with Meal index (DQI-AM), body fat percentage, Tanner stage, physical activity and maternal educational level were included in

the analyses, resulting in 1522 (53.4% girls) valid cases (see Fig. 1). Characteristics of the included group of adolescents were compared with those of the excluded group of adolescents (data not shown). The included group had a longer sleep duration (8.13 *v.* 7.97 h/night, *P*=0.001), a lower BMI *z*-score (0.25 *v.* 0.68, *P*<0.001), a lower body fat percentage (21.86 *v.* 24.97%, *P*<0.001) and a higher DQI-AM score (63.67 *v.* 60.34, *P*<0.001) than the excluded group. The included adolescents had a higher percentage of mothers with a higher secondary education or higher education/higher degree (69.4 *v.* 61.3%, *P*<0.001) than the excluded group, and adolescents were less frequently categorised in a higher Tanner stage (stage 4 or 5, 67.8 *v.* 75.0%, *P*<0.001). No differences in age, sex and physical activity were observed.

### Dietary intake and diet quality

Following recommendations of the 'European Food Consumption Survey Method' project, two non-consecutive 24 h recalls were completed by the adolescents<sup>(37)</sup>. The dietary intake assessment was performed by a computer-based tool for self-reported 24 h recalls, the HELENA Dietary Intake Assessment Tool, based on a previous version developed for Flemish adolescents, called Young Adolescents' Nutrition Assessment on Computer<sup>(38)</sup>. This tool has been proven to provide a valid measurement of food consumption compared with an interview by a dietitian<sup>(39)</sup>. Food intake refers to the day before the administration of the recall and is divided into six meal occasions. For each occasion, the user is invited to select all the consumed food items and beverages from a standardised food list. Information on quantities is gathered by the use of household measurements or pictures



**Fig. 1.** Flow chart illustrating the exclusion procedure for the study population of adolescents included in the present study. HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence; 24-HDR, 24 h dietary recall; DQI-AM, Diet Quality Index for Adolescents with Meal index; BF%, body fat percentage.

of portion sizes. The adolescents completed the programme autonomously in a computer classroom where fieldworkers could give assistance if necessary<sup>(39)</sup>. The two 24 h recalls comprised weekdays and weekend days, but not necessarily a weekday and weekend day for each individual. Because all 24 h recalls took place during the week (in the classroom), no information was available on the dietary intake of Fridays and Saturdays.

To measure diet quality, the DQI-AM was used. This is an adapted version of a previously validated DQI<sup>(40)</sup>, which was developed for assessing the compliance of preschool children with the Flemish food-based dietary guidelines (FBDG)<sup>(41)</sup>. Unpublished analyses of data collected on adolescents showed that the Diet Quality Index for Adolescents scores were positively associated with nutrient-dense food items (e.g. fruits and vegetables) and inversely associated with energy-dense and low-nutritious food. The Diet Quality Index for Adolescents was also positively related to the intake of water, fibre and most minerals and vitamins and had a positive association with vitamin D, vitamin B<sub>12</sub> and *n*-3 fatty acid serum levels. These results indicate a good validity of the Diet Quality Index for Adolescents in adolescents<sup>(42)</sup>.

The intake of foods (provided by the 24 h recalls) was divided into nine recommended food groups and two non-recommended food groups based on the Flemish FBDG<sup>(41)</sup>: (1) water; (2) bread and cereal; (3) grains and potatoes; (4) fruits; (5) vegetables; (6) milk products; (7) cheese; (8) meat, fish, eggs and substitutes; (9) fat and oils; (10) low-nutrient, energy-dense foods (e.g. chocolate); (11) low-nutrient, energy-dense drinks (e.g. carbonated soft drinks). For each of these food groups, a range of recommended daily intakes specifically for adolescents is provided by the Flemish FBDG. These ranges were based upon the nutrient recommendations of the Belgian Health Council<sup>(43)</sup> and the WHO<sup>(44)</sup>, combined with data on habitual dietary intake in the Belgian population. Because the Flemish FBDG are very similar to dietary guidelines in other countries and to the Countrywide Integrated Non-Communicable Disease Intervention pyramid (from the Countrywide Integrated Non-Communicable Disease Intervention programme) developed by the WHO<sup>(45)</sup>, the index is applicable for a European population.

The DQI-AM consists of four pillars based on the principles of a healthy diet as provided in the Flemish FBDG<sup>(41)</sup>: dietary quality; dietary diversity; dietary equilibrium (adequacy and moderation); a meal index. The dietary quality indicates whether an individual makes optimal food quality choices within each food group. In the Flemish FBDG, foods are categorised into a 'preference group' (e.g. fresh fruit, fish), a 'moderation group' (e.g. white bread, minced meat) and a 'rest group' including low-nutrient, energy-dense foods (e.g. soft drinks, sweet snacks). To calculate the dietary quality score, the daily portion size of foods from the preference group was multiplied by a factor '1', foods categorised as moderate with a factor '0' and those in the rest group with a factor '-1'. These values were summed and divided by the total sum of food quantities eaten per d and multiplied by 100. Dietary diversity expresses the degree of variation in the diet and indicates whether a participant consumes at least

one serving of food per d from each of the nine recommended food groups. The dietary diversity score was computed by dividing the number of food groups from which on average at least one serving was consumed by nine (the total number of the recommended food groups). Dietary equilibrium indicates to what extent the consumed portion sizes of the different food groups correspond with the recommended daily intakes. It results from the difference between the adequacy score (the percentage of the minimum recommended intake for each of the main food groups) and the dietary excess score (expressing the percentage of intake exceeding the upper level of recommendation). Finally, the meal index reflects the frequency of consumption of meals (which should include at least three main courses, as breakfast, lunch or dinner). The three components, dietary diversity, dietary equilibrium and the meal index, can range between 0 and 100%, while the dietary quality component can range between -100 and 100%. To compute the overall DQI-AM, the score is the mean of the four pillars and ranges from -25 to 100%, with higher scores indicating a higher diet quality. More detailed information on the technical aspects has been provided elsewhere<sup>(40)</sup>.

#### Anthropometric data

The protocol used to collect anthropometric data has been described previously<sup>(46)</sup>. Measurements were done while participants were barefoot and in underwear. Weight was measured to the nearest 0.1 kg using electronic scales (Type SECA 861 MWS Ltd, Scalesmart). Height was measured to the nearest 0.1 cm with the head aligned in the Frankfort plane using a telescopic height-measuring instrument (Type SECA 225). BMI was calculated as body weight in kg divided by the square of height in m. In addition, BMI was adjusted for age and sex to give a BMI *z*-score using the British 1990 Growth Reference Data from the Child Growth Foundation<sup>(47)</sup>. A set of skinfold thicknesses were measured three (consecutive) times on the left side of the body, with a Holtain caliper (to the nearest 0.2 mm). Body fat percentage was calculated from the triceps and subscapular skinfolds using the Slaughter formulae<sup>(48)</sup>, which appears to be the most suitable for use in adolescents<sup>(49)</sup>. Pubertal status (stages I–V) was assessed by a medical doctor according to the scale developed by Tanner & Whitehouse<sup>(50)</sup>, based on breast development and pubic hair status in females and genital and pubic hair development in males.

#### Sleep duration

Habitual sleep duration was estimated using a self-reported questionnaire. The question 'How many hours (and minutes) do you usually sleep during weekdays and during weekend days?' was asked. The average sleep duration was calculated as:

$$\text{Average sleep duration} = ((\text{hours weekdays} \times 5) + (\text{hours weekend days} \times 2))/7.$$

Sleep on weekdays and weekend days were not analysed separately because there was no information on dietary



intake on days with a 'weekend' night (Fridays or Saturdays). Sleep duration during the week (8.11 (SD 1.10) h) was significantly shorter than during the weekend (8.18 (SD 1.34) h) ( $P < 0.001$ ). The difference was, however, very small (0.07 h or 4 min). Weekday and weekend day sleep durations were positively associated ( $r = 0.846$ ,  $P < 0.001$ ).

In addition to analysing sleep duration as a continuous variable, sleep duration was stratified into three categories: insufficient sleep duration (<8 h of sleep per night), borderline insufficient sleep duration (between 8 and 9 h of sleep per night) and optimal sleep duration ( $\geq 9$  h of sleep per night), according to the definition of the American National Sleep Foundation<sup>(9)</sup>.

### Socio-economic status and physical activity

A self-reported questionnaire was used to collect data on living conditions, family structure, employment status, occupation and education level of both parents<sup>(51)</sup>. Maternal education level (lower education, higher secondary education and university education) was chosen as a potential confounding factor for the habitual diet quality of the adolescents.

A measure of physical activity was obtained by the International Physical Activity Questionnaire for Adolescents. The validity of this questionnaire has been published previously<sup>(52)</sup>. Reported activities were classified into low, moderate and vigorous activity according to the guidelines for data processing and analyses of the International Physical Activity Questionnaire (<http://www.ipaq.ki.se>). Total time spent on moderate and vigorous activity was summed and truncated in order to avoid overestimations<sup>(53)</sup>.

### Statistical analyses

Analyses were performed using SPSS software (PASW Statistics 18.0). A  $P$  value  $< 0.05$  was considered as significant. The normality of continuous variables was tested using the Kolmogorov–Smirnov test and by visually checking histograms. Variables that were not normally distributed were either log-transformed or square root-transformed. Means and standard deviations or proportions of the adolescents' characteristics were calculated, and differences in these characteristics between the three sleep duration categories were examined using a one-way ANOVA for continuous variables and a  $\chi^2$  test for categorical variables. An independent  $t$  test was used to compare the characteristics between the included and excluded adolescents. To compare the average sleep duration during weekdays and weekend days, a paired  $t$  test was used. A multilevel linear regression analysis (mixed model) with city of origin and school as cluster units was used to examine the relationship between sleep duration (independent variable) and diet quality (dependent variable). Partial Pearson's correlation coefficients were calculated to determine the associations between sleep duration and diet quality. A mixed-model ANCOVA was used to compare diet quality between the groups of adolescents with the different sleep durations (insufficient, borderline insufficient and optimal sleep duration). Analyses were adjusted for

relevant confounding factors (sex, Tanner stage, maternal educational level, body fat percentage and physical activity). Analyses were not stratified for sex because no sex interactions were found for diet quality in the regression model.

### Results

In total, 1522 adolescents were included in the present study (812 girls). Table 1 gives a description of the study population, stratified by sleep duration category. The mean age of the total study sample was 14.7 years. Of the adolescents, 92% were categorised into a Tanner stage 3 or higher and the largest proportion of mothers had a higher education or university degree. For several characteristics, a statistically significant difference was found between the sleep duration categories. Adolescents with insufficient sleep or borderline insufficient sleep were significantly older ( $P < 0.001$ ) and were more frequently categorised into a higher Tanner stage (stage 4 or 5,  $P < 0.001$ ) than adolescents with an optimal sleep duration. Adolescents with insufficient sleep had a significantly higher BMI  $z$ -score and body fat percentage than their peers with an optimal sleep duration. Adolescents with (borderline) insufficient sleep also spent less time in moderate-to-vigorous physical activity and had a lower mean average sleep duration than adolescents with an optimal sleep duration ( $P < 0.001$ ).

The multilevel analysis (Table 2) showed a significant negative association between the average sleep duration and the DQI-AM score ( $\beta = 0.027$ ,  $r = 0.130$ ,  $P < 0.001$ ). No significant associations were found between the average sleep duration and the four subscores of the DQI-AM.

Differences in diet quality in adolescents with an insufficient sleep duration (<8 h), a borderline insufficient sleep duration (between 8 and 9 h) and an optimal sleep duration ( $\geq 9$  h), after adjusting for sex, Tanner stage, body fat percentage, maternal education and physical activity, are presented in Table 3. Adolescents with an insufficient sleep duration (62.05 (SD 14.18)) or a borderline insufficient sleep duration (64.25 (SD 12.87)) scored lower on the DQI-AM than those with an optimal sleep duration (64.57 (SD 12.39)) ( $P < 0.001$ ;  $P = 0.018$ ). No significant differences were found in the scores of the four components of the DQI-AM between the three sleep duration categories. Adolescents with a borderline insufficient sleep duration scored lower on the meal index component than adolescents with an optimal sleep duration; however, this was only borderline significant ( $P = 0.062$ ).

### Discussion

Most observational studies investigating the relationship between sleep duration and dietary intake have analysed the intake of individual nutrients and energy intake. The present study used a Diet Quality Index, which is a valuable tool to assess overall dietary quality or adherence to dietary guidelines. The study investigated the relationship between sleep duration and the DQI-AM. Sleep duration was positively related to the DQI-AM score. This association could also be observed when using sleep duration categories: adolescents with an optimal

**Table 1.** Characteristics of the study population, stratified by sleep duration (Mean values and standard deviations; number of participants and percentages)

	Sleep duration categories								P†
	Total sample (n 1522)		Insufficient (< 8 h/night, n 464)		Borderline insufficient (8–9 h/night, n 612)		Optimal (≥ 9 h/night, n 446)		
	n	%	n	%	n	%	n	%	
Age (years)									
Mean	14.71		15.16*		14.75*		14.18		< 0.001‡
SD	1.23		1.18		1.21		1.10		
Sex									
Male	710	46.6	205	44.2	293	47.9	212	47.5	0.439
Female	812	53.4	259	55.8	319	52.1	234	52.5	
Tanner stage									
Stage 1	6	0.4	0	0	2	0.3	4	0.9	< 0.001‡
Stage 2	117	7.7	19	4.1	44	7.2	54	12.1	
Stage 3	368	24.2	91	19.6	155	25.3	122	27.4	
Stage 4	639	42.0	233	50.2	229	37.4	177	39.7	
Stage 5	392	25.8	121	26.1	182	29.7	89	20.0	
Maternal education									
Lower education	105	6.9	38	8.2	38	6.2	29	6.5	0.223
Lower secondary education	360	23.7	101	21.8	139	22.7	120	26.9	
Higher secondary education	489	32.1	161	34.7	189	30.9	139	31.2	
Higher education or university degree	568	37.3	164	35.3	246	40.2	158	35.4	
BMI (z-score)									
Mean	0.25		0.34*		0.25		0.17		0.042‡
SD	1.05		0.96		1.08		1.11		
Body fat (%)									
Mean	21.86		22.33*		21.96		21.22		0.039‡
SD	8.62		7.97		8.90		8.84		
MVPA (min/week)									
Mean	700.79		626.64*		706.21*		770.47		< 0.001‡
SD	557.56		535.26		575.34		547.12		
Sleep duration (h/night)									
Mean	8.13		6.86*		8.14*		9.43		< 0.001‡
SD	1.13		0.62		0.22		0.72		

MVPA, moderate-to-vigorous physical activity.

\* Mean value was significantly different from that of the optimal sleep duration category ( $P < 0.05$ ; pairwise comparisons: adjustment for multiple comparisons with least significant difference).

† P value of one-way ANOVA for continuous variables and  $\chi^2$  test for categorical variables.

‡ P values were significant ( $P < 0.05$ ).

sleep duration had a better DQI-AM score than those with an insufficient or borderline sleep duration. However, the clinical significance of these differences in DQI scores should be further investigated in future research studies.

**Table 2.** Multilevel analysis, with cities and schools as cluster units, examining the associations between the average sleep duration (independent variable) and the Diet Quality Index for Adolescents with Meal index (DQI-AM) scores (dependent variable)

( $\beta$  Coefficients and 95% confidence intervals)

	$\beta$	r	95% CI	P*
DQI-AM	0.027	0.130	0.018, 0.037	< 0.001†
Dietary quality	1.488	0.037	-0.357, 3.334	0.114
Dietary diversity	-0.191	-0.007	-0.917, 0.535	0.606
Dietary equilibrium	0.046	0.009	-0.500, 0.590	0.869
Meal index	0.422	0.028	-0.301, 1.145	0.252

$\beta$ , Estimate (unstandardised regression coefficient); r, partial Pearson's correlation coefficient.

\* P value adjusted for sex, Tanner stage, maternal educational level, body fat percentage and moderate-to-vigorous physical activity.

† P value was significant ( $P < 0.05$ ).

In line with the results of the present study, the observational study of Hitze *et al.*<sup>(26)</sup> found in children and adolescents (6–20 years) that sleep duration was determined by a higher nutritional quality score, but only in girls. A higher nutritional score was characterised by high consumptions of healthy items (whole-meal products, milk products, fruits, vegetables and potatoes, and fish) and low consumptions of risk-related items (white bread, meat products, soft drinks, fast food and sweets). Fast food (girls) and soft drinks (boys) were more often consumed by 'short' sleepers, whereas for sweets, the opposite was true (girls)<sup>(26)</sup>. The study of Garaulet *et al.*<sup>(25)</sup> in the same European sample found that the proportion of adolescents who had an adequate frequency of eating fruit, vegetables, fish, skimmed milk, breakfast cereals or crisps was lower for those who on average slept less than 8 h. They also found an inverse correlation between the average sleep duration per d and the frequency of eating foods such as pizza, hamburgers, pasta dishes and pasta snack products<sup>(25)</sup>. These findings already suggested a lower dietary quality in adolescents with

**Table 3.** Multilevel ANCOVA of dietary quality (Diet Quality Index for Adolescents with Meal index; DQI-AM) according to sleep duration (with cities and schools as cluster units) (Mean values and standard deviations)

	Sleep duration								
	Insufficient (<8 h/night, n 464)			Borderline insufficient (8–9 h/night, n 612)			Optimal (≥9 h/night, n 446)		
	Mean	SD	P*	Mean	SD	P*	Mean	SD	
DQI-AM	62.05	14.18	<0.001†	64.25	12.87	0.018†	64.57	12.39	
Dietary quality	40.26	35.05	0.236	43.19	34.61	0.950	42.14	37.95	
Dietary diversity	74.42	14.42	0.118	74.05	14.97	0.202	72.92	14.07	
Dietary equilibrium	40.58	10.47	0.885	41.34	10.08	0.171	40.20	10.60	
Meal index	91.67	14.28	0.399	90.65	13.86	0.062	92.17	13.30	

\* P value adjusted for sex, Tanner stage, maternal educational level, body fat percentage and moderate-to-vigorous physical activity (pairwise comparisons: adjustment for multiple comparisons with least significant difference).

† P value v. optimal sleep duration (≥9 h/night): P<0.05.

a short sleep duration. In the cross-sectional study of Weiss *et al.*<sup>(24)</sup> in adolescents, shorter sleep duration was also associated with an increased risk of daily consuming 1987 kJ (475 kcal) or more from snacks (unadjusted analyses).

Several hypotheses can account for the observed relationship between sleep duration and an altered dietary quality in the present study. Experimental and observational studies have shown that short sleep duration is associated with a disturbance of satiety hormones, i.e. decreased leptin levels and increased ghrelin levels, which can lead to an increase in hunger and appetite<sup>(18–21,27)</sup>. The experimental study of Spiegel *et al.*<sup>(18)</sup>, in which sleep was restricted under laboratory conditions, observed an increase in appetite for energy-dense foods with a high carbohydrate content including sweets (such as cake, candy, cookies, ice cream and pastry), salty snacks (such as chips, salty nuts, pickles and olives) and starchy foods (such as bread, pasta, cereal and potatoes). Appetite for fruits, vegetables and high-protein foods was less affected. This could explain a lower diet quality when sleep is restricted. Another explanation could be that sleeping short hours in an obesity-promoting environment, where food is highly palatable and readily available, may facilitate the excessive consumption of unhealthy foods, especially if most of this time is spent in sedentary activities where snacking simultaneously is common, such as watching television or spending time on the computer<sup>(6,22)</sup>. In the experimental study of Nedeltcheva *et al.*<sup>(54)</sup>, sleep restriction in adults, with an *ad libitum* access to palatable food, resulted in increased consumption of energy from snacks, with a higher carbohydrate content, particularly during the period from 19.00 to 07.00 hours. Tiredness may also affect dietary habits. People who are tired may seek fast-release, high-energy foods to compensate for perceived low energy levels<sup>(55)</sup>. Inadequate sleep has been shown to be associated with feeling tired, stressed and pessimistic<sup>(56)</sup>, emotional states that could lessen one's resolve to follow dietary regimens<sup>(57)</sup>. Furthermore, sleep deprivation has been found to hamper attention and impulse control and can delay gratification, thus leading to increased hedonistic eating<sup>(6,58)</sup>. A recent study found that restricted sleep resulted in changes in neuronal activity when exposed to food stimuli,

which affected brain regions that have been associated with motivation and desire. This might indicate an increased propensity to seek food in individuals who are not getting enough sleep<sup>(59)</sup>. The study of Landis *et al.*<sup>(23)</sup> found that daytime sleep (which was associated with decreased nocturnal sleep) was positively associated with food cravings (cravings for carbohydrate–starch and high-fat foods).

### Strengths and limitations

The major strength of the present study is the large sample of adolescents from eight cities across Europe and the highly standardised procedures used. To our knowledge, this is the first study to investigate the association between sleep and dietary quality in adolescents, using a Diet Quality Index. Nevertheless, the present study has also some limitations. First, the cross-sectional design of the study prevents us from finding a causal direction between sleep duration and dietary quality. It could be possible that dietary intake influenced sleep duration, which was recently demonstrated in young children by Diethelm *et al.*<sup>(60)</sup>. Second, data on physical activity, sleeping behaviours and dietary intake were derived from self-reported questionnaires and are thus subjective in nature. A possible reporting bias in these parameters could lead to an overestimate of the correlations. Health-conscious adolescents may be pleased to report healthy food habits and long hours of sleeping, while 'rebel' adolescents might be pleased to show that they go to bed late in the evening and never eat their fruit and vegetables. Nevertheless, all the aforementioned questionnaires have been pilot tested and validated<sup>(39,52,61)</sup>. Moreover, previous studies found an agreement between self-reported sleep duration and sleep duration measured by actigraphy<sup>(62–64)</sup>. Another limitation of the study is the fact that the 24 h recall data did not include any information about the adolescents' diet on Fridays and Saturdays since the 24 h recalls were all completed during school days (about the dietary intake of the previous day). Sleep duration on these 'weekend' nights was included in the average sleep duration. However, the difference between sleep duration on weekdays and weekend days was, although statistically

significant, very small. Another possible limitation is that the DQI-AM used in the present study was based on the Flemish dietary guidelines. However, these guidelines were considered appropriate to apply on a European population because only minor differences were found in comparison with the other European dietary guidelines. A difference in sleep duration between different countries could not be made because the adolescents from one city were not representative for that country. Finally, the study observed significant differences in several variables between the included and excluded adolescents, including sleep duration, body composition and DQI-AM scores. This selection bias might slightly have affected the observed sleep duration and the DQI-AM, but unlikely have led to a spurious correlation between sleep duration and dietary quality.

### Conclusion

The present study demonstrated that, in European adolescents, reported short sleep duration is associated with a lower quality of the reported diet. These findings support the hypothesis of an altered dietary quality in the presence of sleep restriction, possibly leading to obesity and other diet-associated health problems. Further research, with objective measurements and prospective or experimental study designs, is needed to better define the relationship between sleep restriction, diet and health.

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