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PEDIATRIC ORIGINAL ARTICLE

Short sleep duration is associated with increased obesity markers in European adolescents: effect of physical activity and dietary habits. The HELENA study

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Background: Adequate sleep is a critical factor for adolescent's health and health-related behaviors.
Objective: (a) to describe sleep duration in European adolescents from nine countries, (b) to assess the association of short sleep duration with excess adiposity and (c) to elucidate if physical activity (PA), sedentary behaviors and/or inadequate food habits underlie this association.
Design: A sample of 3311 adolescents (1748 girls) aged 12.5–17.49 years from 10 European cities in Austria, Belgium, France, Germany, Greece, Hungary, Italy, Spain and Sweden was assessed in the Healthy Lifestyle in Europe by Nutrition in Adolescence Study between 2006 and 2008. We measured anthropometric data, sleep duration, PA (accelerometers and questionnaire), television watching and food habits (Food Frequency Questionnaire).
Results: Average duration of daily sleep was 8 h. Shorter sleepers showed higher values of BMI, body fat, waist and hip circumferences and fat mass index ($P < 0.05$), particularly in females. Adolescents who slept <8 h per day were more sedentary, as assessed by accelerometry, and spent more time watching TV ($P < 0.05$). The proportion of adolescents who eat adequate amounts of fruits, vegetables and fish was lower in shorter sleepers than in adolescents who slept $\geqslant 8$ h per day, and so was the probability of having adequate food habits ($P < 0.05$). Correlation analysis indicated that short sleep is associated with higher obesity parameters.
Conclusions: In European adolescents, short sleep duration is associated with higher adiposity markers, particularly in female adolescents. This association seems to be related to both sides of the energy balance equation due to a combination of increased food intake and more sedentary habits.

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Introduction

The prevalence of chronic partial sleep deprivation has increased dramatically in the past half century, in parallel with the rising epidemics of overweight and obesity.[1] A growing number of North Americans reported reduced sleep time.[2] In 1969, sleep duration used to be between 8.0–8.9 h per night while in 1995 it dropped to 7 h.[3] Nowadays, $\geqslant$30% of adults report sleeping <6 h per night.[4] Slightly lower data are found in Europe, although differences in methodology makes the comparison among countries difficult.[5,6]

Adequate sleep is a critical factor for adolescent's health and health-related behaviors.[7] In adolescents, sleep influences physical and emotional well-being (brain maturation,

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For HELENA study group see Appendix.
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biological and psychological changes in puberty).[8,9] Laboratory studies have shown that 'sleep need', defined as the amount of sleep achieved when given 10 h of nocturnal bedtime, does not change substantially across adolescence (10–17 years) and is about 9 h per night.[10]

Cross-sectional studies have consistently observed an association between short sleep duration and increased adiposity in children and adolescents.[11,12] Moreover, there is evidence for a long-term impact of childhood sleeping problems on the later development of obesity.[13] Several studies developed in different European countries such as France, Germany or Portugal[11] have also demonstrated the interrelationship between sleep habits and weight gain in children and adolescents.

Several investigations have tested the hypothesis that the human sleep curtailment could promote excessive energy intake.[14] It is thought that this relationship may be mediated via changes in the levels of some of the neuropeptides involved in the regulation of appetite.[4,15–17] More precisely, it seems that recurrent bedtime restriction in the setting of *ad libitum* access to palatable food is accompanied by an increased consumption of excess calories from snacks without a statistically significant change in the intake of energy from meals.[14] Other studies have focused on the other side of the energy balance, that is, energy expenditure, specifically on the role that daily physical activity (PA) might have in the relationship between obesity and sleep duration.[14]

An important question raised by these reports is whether short sleep duration contributes directly to the mechanisms of unhealthy weight gain or reflects the presence of other relevant risk factors and pathways of reverse causation.[12] To our knowledge, none of the sleep studies incorporated both food and PA data in order to analyze their possible implication in the obesity development.

The purpose of the current study was (a) to describe sleep duration in European adolescents from nine countries, (b) to assess the association of short sleep duration with excess adiposity and (c) to elucidate if PA, sedentary behaviors and/or inadequate food habits underlie this association.

Subjects and methods

Study design

The HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study (http://www.helenastudy.com) is a multicenter study on lifestyle and nutrition in adolescents from 10 European cities: Athens (inland city) and Heraklion (Mediterranean island city) in Greece, Dortmund in Germany, Ghent in Belgium, Lille in France, Pécs in Hungary, Rome in Italy, Stockholm in Sweden, Vienna in Austria and Zaragoza in Spain.[18] Data collection took place between October 2006 and December 2007.

Detailed descriptions of the HELENA sampling and recruitment approaches, standardization and harmonization processes, data collection, analysis strategies, quality control activities and inclusion criteria were published elsewhere.[19] The study was approved by the Research Ethics Committees of each city involved. Written informed consent was obtained from the parents of the adolescents and the adolescents themselves.[20]

Study sample

Ten European cities of $\geqslant$100 000 inhabitants located in separated geographical points in Europe were selected for the study. The geographical distribution was not random and not represented by the strata, but it was decided according to the following criteria: representation of territorial units (countries) of Europe according to geographical location (N/S/E/W), cultural reference and socioeconomic situation; and selection of a territorial unit (city) in the country, which is representative of the average level of demography, cultural, social and economic markers. The age range considered valid for the HELENA Study was 12.5–17.49 years. The inclusion criteria were the following: not participating simultaneously in another clinical trial and be free of any acute infection occurring <1 week before the study.

A total of 3311 adolescents, 1563 boys and 1748 girls, were considered in the current study. To make maximum use of the data, all valid data on sleep ($n=3311$), PA by questionnaire ($n=2848$) and by accelerometry ($n=2161$) and food habit tests ($n=3069$) were included in this report. Consequently, sample sizes vary for the different variables.

Anthropometric data and body fat composition

Weight was measured in underwear and without shoes with an electronic scale (Type SECA 861, MWS Ltd, Scalesmart, Leicester, UK) to the nearest 0.1 kg, and height was measured barefoot in the Frankfort horizontal plane with a telescopic height measuring instrument (Type SECA 225, MWS Ltd, Scalesmart) to the nearest 0.1 cm. Body mass index was calculated as body weight in kg divided by the square of height in meters. A set of skinfold thicknesses (biceps, triceps, subscapular, suprailiac and thigh) were measured three consecutive times on the left side of the body, with a Holtain caliper (J & N Preston Holtain Ltd Crymych, Dyfed, Wales, UK) (to the nearest 0.2 mm). Circumferences (waist, hip and upper thigh) were also measured with a non-elastic tape (Seca 200, MWS Ltd, Scalesmart) to the nearest 0.1 cm.[21] A sum of skinfolds and a fat mass index, defined as body fat (Bioelectrical impedance analysis (*BIA*))/height^2, were further calculated. For BIA measurements, a classical tetrapolar technique was used by means of BIA 101 AKERN SRL. Fat mass was then calculated using the software Bodygram V. 1.31 (Akern S.r.l. Bioresearch, Napoli, Italy) that use the equations previously published by Sun *et al.*[22] Identification of sexual maturation (stages I–V) was assessed by a medical doctor through direct observation, according to Tanner and Whitehouse.[23]

Sleep hours determination

Habitual sleep time was estimated by a questionnaire. 'During week days: How many hours (and minutes) do you usually sleep?'; and 'During weekend days: How many hours (and minutes) do you usually sleep?' A total weekly sleep score was calculated as: ((min Weekdays $\times 5$) + (min Weekend days $\times 2$))/7.

The reliability of both sleep and television viewing time was studied in 183 adolescents (13–18 years). They completed a questionnaire two times, 1 week apart. This subsample did not participate in HELENA Study, yet it did not differ in age, ethnicity or socioeconomic status from the final HELENA Study sample. Questions used to estimate sleep time were reliable. Cohen's weighted Kappa showed an almost perfect agreement (0.81 and 0.96, during weekdays and weekend days, respectively).

We defined insufficient sleep as sleeping <8 h per night, according to the definition of the National Sleep Foundation for adolescent population.[24]

Dietary intake

Food intake was assessed by means of a food frequency questionnaire that was used in the HBSC Study.[25] The food frequency questionnaire consisted of 15 items, which were considered as dependent variables: fruits, vegetables, sweets (candies or chocolates), coke or other soft drinks that contain sugar, diet coke or diet soft drinks, low-fat/semi-skimmed milk, whole-fat milk, cheese, other milk products (like yoghurt, chocolate milk, pudding and quark), cereals (like cornflakes, muesli and choco pops), white bread, brown bread, crisps, chips and fish. Participants were asked to indicate the frequency of eating these foods by ticking one of the following seven responses: (1) never; (2) rarely, less than once a week; (3) once a week; (4) 2–4 times a week; (5) 5–6 times a week; (6) once a day, every day; and (7) more than once a day, every day. Afterwards, response options were recoded into dichotomous outcome variables.

PA and sedentary behaviors

PA and sedentary behaviors were assessed by both objective methods (accelerometry) and self-reported method.

(1) The actigraph accelerometer model GT1M (Actigraph MTI, Manufacturing Technology Inc., Pensacola, FL, USA) was used to assess PA and sedentary time. This small uni-axial accelerometer measures accelerations (g) from 0.05 to $2.1g$ in the vertical axis. Its acceleration is filtered, which discriminates human movements from vibrations. The data are stored at a sampling rate of 10 samples per second and summed over a selected time interval or epoch. The accelerometers were initialized as described by the manufacturer. For the present study, data were saved in 15 s intervals (epochs). Each adolescent was monitored for 7 consecutive days. The adolescents wore the accelerometers on the lower back, secured with an elastic belt, underneath clothing and only during the waking hours.

After the testing period, the accelerometers were collected by the researcher and data were uploaded onto a computer. The rough data of all participants were analyzed centrally to ensure standardization. Data with periods of zero values of $\geqslant 20$ min were excluded from the analysis. A recording of $\geqslant 20\,000$ counts per minute (c.p.m.) was seen as a potential malfunction of the accelerometer and was also excluded from the analyses. Data were considered as valid if the adolescents had accelerometer counts for at least 3 days with at least 8 h of recording time per day. Data were analyzed for minutes per day spent in sedentary activities, moderate and vigorous intensity PA. Sedentary time was defined as minutes spent inactive based on cutoff point of 100 c.p.m. The time engaged at moderate PA (3–6 metabolic equivalents) was calculated based on cutoff points of 2000–3999 c.p.m. The lower cutoff of 2000 c.p.m. is equivalent to walking at 4 km h^{-1}.[26] The time spent in vigorous PA (>6 metabolic equivalents) was calculated based on a cutoff of $\geqslant 4000$ c.p.m. Those cutoff points are similar to those used in previous studies.[27,28] The time engaged in at least moderate PA (moderate to vigorous physical activity (MVPA) $\geqslant 2000$ c.p.m.) was also calculated.

(2) We additionally assessed PA by means of a questionnaire. We used the IPAQ-A (International Physical Activity Questionnaire for Adolescents), an adapted version of the IPAQ, to assess PA over the last 7 days.[29] Questions about PA at work had been replaced by questions about PA at school (that is, physical education, walking, moderate and vigorous PA at school). Furthermore, the module about activities in the household domain had been shortened. Only one question (versus three in the original IPAQ) about PA in the garden or at home remained. Also, the order of PA intensities was changed, to avoid overreporting.[30] The time spent at walking was asked before the time spent at vigorous and moderate intensity (versus vigorous, moderate and walking in the original IPAQ). The questionnaire was translated into French, Flemish, German, Greek, Hungarian, Italian, Spanish and Swedish, and backtranslated into English following the instructions given in the IPAQ manual (http://www.ipaq.ki.se/ipaq.htm).

For each of the four domains (school, transport, housework and leisure time), total METs (metabolic equivalents) per minute were computed for walking, moderate and vigorous PA based on the guidelines for data processing and analyses of the IPAQ (http://www.ipaq.ki.se/ipaq.htm). Total activity was computed as the sum of the activities at different intensities. The data were cleaned and truncated based on previous research.[31]

Adolescents reported for both a typical weekday and weekend day the number of hours watching TV. They had to select one of the following categories: (1) none, (2) $<\frac{1}{2}$ h, (3) between $\frac{1}{2}$–1 h, (4) between 1–2 h, (5) between 2–3 h, (6) between 3–4 h, (7) $\geqslant 4$ h. For further analyses, data were classified as $\leqslant 2$ or >2 h per day.

Cohen's weighted Kappa reliability coefficients for TV using quadratic weights were 0.71 and 0.68 during weekdays and weekend days, respectively. The strength of agreement for the Kappa values can be interpreted as: 0–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.00, almost perfect.[32]

Statistical analysis

Those variables that were not normally distributed were log transformed. We performed analysis of covariance to analyze differences between short sleepers (<8 h) and adequate sleepers (>8 h). We adjusted all analyses for sex, Tanner stages and center. Tanner stages were chosen instead of age, because 'sleep need' does not change substantially across adolescence (10–17 years). Moreover, in the relationship between sleep duration and body composition parameters, sexual maturation is critical because it is related to hormonal pathways nurturing adipose tissue and has a key role in the underlying physiological mechanisms.[31] We also tested the statistical homogeneity of the effects by sex in the corresponding regression model with interaction terms. No sex interactions were found for PA and food intake variables, so males and females were analyzed together for these variables. However, sex interacted for anthropometric and body composition, so data were represented and analyzed in both sexes separately.

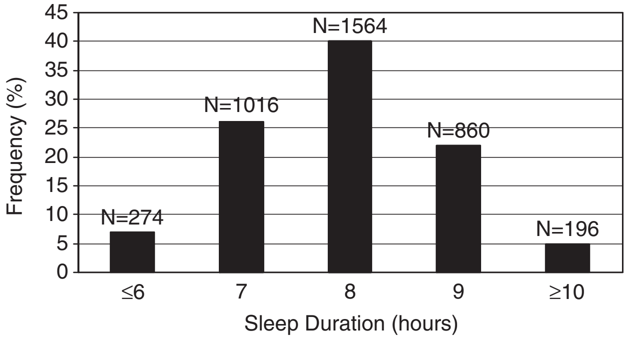

Figure 1 Distribution of sleep hours per day in the European adolescents (frequency).

We fitted logistic regression models to estimate the odds ratio (OR) and 95% CI of meeting food recommendations for fruit, vegetables and fish according to self-reported sleep. Partial correlations were used to analyze association between sleep duration and body composition parameters. All the analyses conducted were adjusted by a weighing factor to balance the sample according to the theoretical estimation of the HELENA sample concerning age and sex distribution in order to ensure true representation of each of the stratified groups.

We used routine regression diagnostic procedures to ensure the appropriateness of the models. Statistical analyses were done using SPSS 15.0 software (SPSS, IBM, Madrid, Spain). A two-tailed *P*-value of <0.05 was considered as statistically significant.

Results

Figure 1 represents the distribution of self-reported daily sleep duration in the population studied. Average duration of daily sleep was around 8 h in both sexes.

The most frequent sleep duration was 8 h (40% of the population). The average hours of sleep a day varied depending on the Tanner stages. Data ranged from 9.1 ± 1.1 h in Tanner1 to 7.9 ± 1.1 h in Tanner5 ($P < 0.0001$).

When data were dichotomized in short (<8 h) or adequate sleepers (⩾8 h), shorter sleepers showed significantly higher values of BMI, body fat, waist and hip circumferences and fat mass index (Table 1). Moreover, after dividing the population in different groups according to their BMI (low, optimal, overweight and obese), significant differences were found in sleep durations towards a longer sleep among low-BMI adolescents ($P = 0.002$).

In order to explain this relationship between obesity parameters and sleep duration in the present population, PA and dietary habits were further studied. Males and

Table 1 Anthropometric characteristics in European adolescents depending on sleep time: short sleepers (<8 h) and normal sleepers

	Male					*Female*					*All*				
	Sleep				P-*value*	*Sleep*				P-*value*	*Sleep*				P-*value*
	<8 h n = *488*		*⩾8 h* n = *1075*			*<8 h* n = *598*		*⩾8 h* n = *1150*			*<8 h* N = *1086*		*⩾8 h* N = *2225*		
	Mean	*s.e.*	*Mean*	*s.e.*		*Mean*	*s.e.*	*Mean*	*s.e.*		*Mean*	*s.e.*	*Mean*	*s.e.*	
BMI	21.73	0.18	21.07	0.23	**0.03**	21.43	0.14	21.02	0.10	**0.0320**	21.71	3.52	21.17	3.70	<**0.0001**
Skinfolds (suma) (mm)	44.00	1.20	43.94	0.77	0.964	57.82	0.96	57.57	0.67	0.836	51.15	0.766	51.24	0.518	0.922
Body fat (%)	14.89	0.43	14.51	0.28	0.455	25.98	7.03	24.10	7.83	<**0.0001**	20.96	8.80	19.74	8.87	<**0.0001**
Fat mass index	3.45	0.11	3.33	0.07	0.371	5.60	0.11	5.25	0.07	**0.010**	4.58	0.07	4.35	0.054	**0.020**
Waist circumference (cm)	75.50	9.13	73.83	9.58	**0.001**	70.57	7.55	69.96	7.95	0.121	72.78	8.65	71.83	8.98	**0.004**
Hip circumference (cm)	92.03	8.48	89.97	9.07	<**0.0001**	93.62	7.30	92.44	8.24	**0.004**	92.90	7.89	91.24	8.74	<**0.0001**

Abbreviation: BMI, body mass index. Fat mass index = body fat (BIA)/height^2. Statistical Analysis ANCOVA. *P*-values after adjusting for Tanner stages and country. Bold face indicates statistical significance ($P < 0.05$).

Table 2 Physical activity in European adolescents depending on sleep time: short sleepers (<8 h) and normal sleepers

	<8 h		*⩾8 h*		P-*value*[a]	P-*value*[b]
	Mean	*s.e.*	*Mean*	*s.e.*		
Physical activity/sedentary time (accelerometry)	*N* = 658		*N* = 1503			
Moderate physical activity (min per day)	39	0.6	40	0.4	0.443	0.720
Vigorous physical activity (min per day)	20	0.5	19	0.4	0.058	0.139
Moderate—vigorous physical activity (min per day)	59	0.9	58	0.6	0.079	0.530
Average intensity (counts per minute)	438	6.2	437	4.1	0.902	0.801
Sedentary time (min per day)	553	3.5	538	2.0	**<0.0001**	**<0.0001**
Physical activity/TV viewing (self-reported)	*N* = 917		*N* = 1931			
METmin for walking	1803	67	1693	43	0.156	0.244
METmin for moderate activity	2123	74	2407	52	**0.001**	**0.010**
METmin for vigorous activity	1715	82	1896	53	0.056	0.419
Total METmin	5640	173	5993	113	0.080	0.261
TV viewing >2 h per day, *N* (%)	395	36.5	680	30.7	**0.001**[c]	

Abbreviation: MET, metabolic equivalents. [a]ANCOVA after adjusting for gender, Tanner stages and country. [b]ANCOVA after adjusting for gender, Tanner stages, country and body mass index. [c]Statistical analysis: χ^2-test. Bold face indicates statistical significance ($P<0.05$).

females were analyzed together because no sex interactions were found for PA and food intake variables.

Table 2 represents differences in PA and sedentary time, as assessed by accelerometer and questionnaires, between short sleepers and adequate sleepers. Data indicate that those adolescents, who slept <8 h per day, were more sedentary as assessed by accelerometry and spent more time watching TV during weekdays, and these differences were maintained even after adjusting for BMI. No consistent associations were observed between sleep duration and PA variables.

Food habits could also be implicated in these results. Table 3 shows that from the total adolescents questioned about their food habits ($n=3069$), the proportion of adolescents who eat adequate amounts of fruit, vegetables, fish, skim milk, breakfast cereal or crisps was lower among those who slept fewer hours. Likewise, regression analysis indicated that shorter sleepers had a lower probability of having adequate food habits than adolescents who slept ⩾8h per day: fruits, OR 0.72, 95% CI: 0.55–0.93 ($P=0.012$); vegetables, OR 0.74, 95% CI: 0.59–0.92 ($P=0.006$); and fish, OR 0.74, 95% CI: 0.61–0.90 ($P=0.002$). Inverse correlations were also found between the average sleep duration per day and the frequency of eating fast food such as pizza ($r=-0.046$, $P=0.016$), hamburgers ($r=-0.04$, $P=0.015$), pasta dishes ($r=-0.051$, $P=0.008$) and pasta snack products ($r=-0.058$, $P=0.003$).

Table 3 Proportion of European adolescents fulfilling the food intake recommendations depending on sleep time: short sleepers (<8 h) and normal sleepers

Food consumption (%)	N	*Sleep*				P-*value*
		<8 h		*⩾8 h*		
		N	*(%)*	N	*(%)*	
Fruit	342	104	(19.9)	238	(25.8)	**0.007**
Vegetables	525	161	(25.7)	366	(32.0)	**0.003**
Fish	1053	343	(54.3)	710	(61.8)	**0.001**
Sweets	366	127	(20.1)	239	(20.8)	0.389
Soft drinks	299	103	(16.5)	196	(17.1)	0.791
Light soft drinks	118	37	(5.9)	81	(7.0)	0.199
Whole milk	265	99	(15.8)	166	(14.5)	0.225
Skim milk	523	162	(25.8)	361	(31.6)	**0.006**
Cheese	376	123	(19.7)	253	(22.2)	0.115
Breakfast cereals	392	119	(19.0)	273	(23.8)	**0.011**
White bread	265	97	(15.5)	168	(14.7)	0.346
Brown bread	349	115	(18.4)	234	(20.7)	0.136
French fries	385	130	(20.7)	255	(22.4)	0.218
Crisps	438	131	(20.8)	307	(26.9)	**0.002**

Statistical analysis: χ^2-test. Bold face indicates statistical significance ($P<0.05$).

Table 4 shows the associations between sleep hours and obesity parameters. Short sleep is associated with higher obesity parameters and vice versa. Total BMI and waist and hip circumferences were inversely related to sleep duration in both sexes, while percentage of body fat was correlated with sleep duration only in females. Age was implicated in these results, indeed when data were adjusted by age, significant associations were only present in females ($P<0.05$). It is noteworthy that when associations between obesity parameters and sleep hours were adjusted to PA variables (low-intensity PA assessed by accelerometer) most of these associations disappeared, while the significance was maintained after adjusting for food habits (fruit, vegetables and fish) (Table 4).

Discussion

In the present study using a relatively large sample of European adolescents, we have observed an inverse association between sleep duration and obesity parameters. This association could be due to slight differences in total energy

Table 4 Correlations between sleep hours and body composition parameters in European adolescents

	Number of sleep hours											
	Males				*Females*				*Total population*			
	r	P	P*	P**	r	P	P*	P**	R	P	P*	P**
BMI	−0.055	**0.041**	0.256	**0.041**	−0.089	**0.0001**	**0.042**	**0.0001**	−0.070	**0.0001**	0.314	**0.0001**
Sum of skinfolds	0.039	0.155	0.430	0.799	−0.031	0.227	0.807	**0.043**	0.005	0.801	0.616	0.098
BIA body fat (%)	0.029	0.285	0.436	0.285	−0.121	**0.0001**	**0.001**	**0.0001**	−0.045	**0.0150**	0.401	**0.0150**
BIA fat mass index	0.020	0.456	0.905	0.493	−0.095	**0.0001**	**0.018**	**0.004**	−0.38	**0.038**	0.252	**0.008**
Waist circumference	−0.052	**0.042**	0.245	**0.042**	−0.071	**0.0001**	**0.107**	**0.0001**	−0.061	**0.0010**	0.461	**0.0010**
Hip circumference	−0.097	**0.0001**	0.007	**0.001**	−0.132	**0.0001**	**0.0001**	**0.001**	−0.114	**0.0001**	**0.0001**	**0.0001**

Abbreviation: BMI, Body mass index. *P* after adjusting for Tanner stages, center and gender (in the total population). **P* after adjusting for Tanner stages, center and gender (in the total population) and for inactivity (accelerometer). ***P* after adjusting for Tanner stages, center and gender (in the total population) and for food intake variables (all variables significantly related to sleep duration, Table 3). Fat mass index = body fat (BIA)/height^2. Statistical analysis: partial correlation. Bold face indicates statistical significance ($P<0.05$).

expenditure (more minutes watching television and more minutes spent inactive) and to worse food habits as reported (less vegetables, fruits and fish consumption). In our study, sleep duration was lower to that obtained in Spanish adolescents in a similar study performed by our group (8.35 h)[33] and much lower to that reported by Belgium and German adolescents (9.4 h).[34,35] However, our results were higher than data obtained in Asian countries such as China,[36] India[37] and South Africa[38] (ranging from 7.1 to 7.8 h).

The association between sleep hours and obesity has been previously described in epidemiological studies performed in children and adolescents from different regions including Asian, European and American countries.[39–41] Moreover, a similar relationship between shorter sleep and increased body weight has been previously found among children.[39] In general, findings in children and adolescents were more consistent than those among adults, which were more mixed and less reliable than the pediatric literature.[11]

Different causes could explain the association between reduced sleep duration and obesity observed in the current population. Van Cauter and Knutson, in an interesting review,[4] postulated that both a lower energy expenditure and an excess of energy intake could be implicated in this interaction. Indeed, studies in adults have shown associations between inadequate sleep and alterations in leptin and/or ghrelin, which may affect hunger and appetite, increasing the risk of overeating and consequently weight gain.[4] Moreover, short sleep duration could lead to obesity by increasing the time available to eat, and has also been suggested to decrease energy expenditure by increasing fatigue as well as changes in thermoregulation.[4] In an attempt to describe the possible mechanisms in the present study, we further studied PA, sedentary behaviors and dietary habits (Figure 2).

Our results from the accelerometers showed that the time spent in sedentary behaviors was significantly higher among shorter sleepers than in those adolescents who slept at least 8 h per day. Accelerometer is currently the objective method of choice to assess PA and sedentary time in a free-living environment.[42,43] These results remained significant after adjusting for total BMI, suggesting that the association between inactivity and sleep duration was independent of obesity.

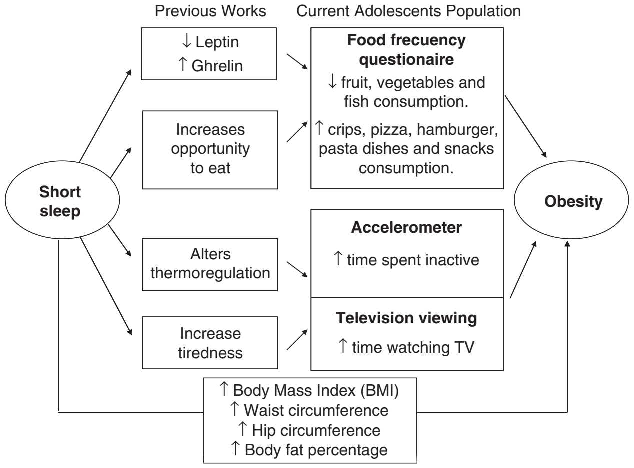

Figure 2 Potential mechanisms by which sleep deprivation may predispose to obesity including current adolescent's data. Adapted from Patel and Hu.[11]

Chronic partial sleep deprivation clearly leads to feelings of fatigue. Tiredness may lead to reduction in PA. One study found that about 40% of short-sleeper adolescents reported waking up tired.[44] In fact, cross-sectional studies in children and adolescents have found short sleep durations to be associated with reduced participation in organized sports.[45] By our results, we have to claim that the relationship between sleep and sedentary habits are clear (Figure 2). However, previous studies are contradictory, particularly for PA. Longitudinal studies performed in women have found little relation between sleep duration and reported PA.[46] Moreover, in an interventional study performed in volunteers who completed two 14-day stays in a sleep laboratory, one of 5.5-h and the other with 8.5-h bedtimes, the opposing effects of daily PA and extended wakefulness were not statistically significant.[14]

Television watching could also partially explain these associations. We observed that short sleepers reported more time watching TV. The number of hours spent in TV viewing has been associated with overweight in multiple studies.[47] A recent report from the United Kingdom suggests that most television viewing is carried out at or near bedtime[48] and therefore, may reduce sleep time.[49]

As suggested, food intake could also be a key player in these results (Figure 2). In the present population, shorter sleepers had a lower probability of having adequate food habits than adolescents who slept $\geqslant 8$ h per day. In the same line, the proportion of students who eat adequate amounts of fruits, vegetables, fish, skim milk, breakfast cereals or crisps was lower among those who slept fewer hours. Besides, frequency of eating junk food such as crisps, pizza, hamburgers and pasta snack products was higher among short sleepers. Interestingly, previous works have found that bedtime curtailment is accompanied by an increased consumption of snacks.[14] When we sleep less, we simply have more time and/or more opportunities to eat.[17] Recurrent bedtime restriction can modify the amount, composition and distribution of human food intake, and sleeping short hours in an obesity-promoting environment may facilitate the excessive consumption of energy from snacks but not meals.[14] This situation could be happening in the current study.

Disruption of the circadian clock could be also implicated in our findings. Abnormal sleep–wake patterns likely alter intracellular circadian clocks. We have recently reported that differences in total energy intake and the frequency of short-time sleepers were both associated with different *CLOCK* gene variants,[50–52] and similarly to the current study, we have described in adults that sleep reduction, alterations of eating behaviors and evening preference with low-PA, that characterized *CLOCK* 3111C carriers could be affecting obesity and weight loss.[53] From this point of view, obesity could be considered as a chronobiological illness, in which a failure of external synchronizers (shortened sleep) of the central internal clock gives to a failure in the circadian system (chronodisruption), which is accompanied by several behavioral changes which increase weight gain.[54] Interestingly, in the current study, the significant association between sleep duration and adiposity was only present in females. Sexual dimorphism has been shown in chronobiology. Morningness–eveningness preference is the individual difference that most clearly explains the variations in the rhythmic expression of biological and behavioral patterns.[55] Marked differences in circadian typology between men and women have been shown with preference of morningness being more common in women.[55] Therefore, from our results showing a higher impact of shorten sleep and adiposity in females, we could hypothesize that shorten sleep could be more deleterious in women than in men, particularly during adolescence in which changes of adipose tissue are marked.

Although cross-sectional studies cannot address the causal relationship between sleep duration and obesity, in the current population the relationship between both variables was still significant when data were adjusted to food intake, whereas it was diminished after adjusting for PA. These results suggest that sedentary habits may be more important than energy intake, in the relationships between short sleep duration and obesity. However, food intake information was only based on a food frequency questionnaire, which is an important limitation.

Strength of this study is the relatively large sample of adolescents recruited from 10 different cities in Europe. It may be noted that this is the first study performed in an adolescent population including objectively measured PA (by accelerometry) and food intake, in an attempt to interpret factors associated to short sleep duration and its connection to obesity. However, our study also has important limitations. We used subjective self-reporting of sleeping hours to determine adequate or inadequate sleep time. Although good agreement has been found in previous studies between self-reported sleep durations, as opposed through actigraphic monitoring,[56,57] the validity of a single question is still to be determined. In addition, further physiologic studies in both human and animal models are needed to better define the pathways by which sleep curtailment might impact weight regulation. In particular, it would be of interest to follow up this adolescent population in terms of obesity in adulthood and the evolution of sleeping habits after the age of 20 years.

In conclusion, we have observed in European adolescents that short sleep duration is associated with higher obesity markers, particularly in female adolescents. This association seems to be related to both sides of the energy balance equation due to a combination of increased food intake and more sedentary habits. Further intervention studies should investigate whether sleep curtailment affects the energy balance or not.

Conflict of interest

The authors declare no conflict of interest.

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