Sleeping Habits of Adolescents in Relation to Their Physical Activity and Exercise Output: Results from the ELSPAC Study

Máchal, Jan (1*); Zlámal, Filip (2); Andrýsková, Lenka (2); Švancara, Jan (2,3); Pikhart, Hynek (2,4); Bienertová-Vašků, Julie (2)

1) Department of Pathophysiology, Faculty of Medicine, Masaryk University, Brno, Czech Republic

2) Research Centre for Toxic Compounds in the Environment, Faculty of Science, Masaryk University, Brno, Czech Republic

3) Institute of Biostatistics and Analyses, Masaryk University, Brno, Czech Republic

4) Department of Epidemiology & Public Health, University College London, London, United Kingdom

* Corresponding author

Jan Machal, M.D., Ph.D.

Department of Pathophysiology, Faculty of Medicine, Masaryk University

Kamenice 5

62500 Brno, the Czech Republic

Email: jmachal@med.muni.cz

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Abstract

Background: Little is known about the effects of physical activity and fitness on sleep timing parameters in adolescence.

Methods: We investigated the development of sleep timing between age 8 and 15 and its association with physical fitness at age 15 in 787 adolescents (408 males, 379 females). Physical fitness was measured using the physical work capacity (PWC) protocol. Information on sport activity was collected at ages 11 and 15. Finally, the contribution of other covariates (sex, BMI, parental education and occupational skill level) to the association between sleep parameters and physical fitness was evaluated. The correlation of BMI and physical fitness was assessed separately.

Results: Mild correlation of sleep duration at ages 8 and 15 was observed (r=0.08–0.16). Higher sport activity participation and physical fitness were found to be mildly associated with delayed bedtime and reduced sleep duration; the association with bedtime was significant after adjustment for all covariates. Sport activity at age 11 was not associated with sleep timing at age 15. Interestingly, higher BMI was linked to delayed bedtime and higher physical fitness.

Conclusion: Our findings do not support existing hypotheses suggesting the association of low physical activity and fitness with shorter sleep duration and high BMI in a generally non-obese adolescent population without severe sleep restriction.

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Summary – thumbnail sketch

What is already known on this subject

- The physical activity was reported to influence the sleep timing parameters. There are, however, conflicting data about the relation of physical activity, physical fitness and bedtime in adolescents.
- Most studies also link reduced sleep and lower physical fitness to increased body mass index (BMI).
- We assessed sleep timing parameters of 787 15-year old adolescents and their possible modification by sport activity self-reported at age 11 and 15, as well as an association with their physical fitness, measured by bicycle ergometry. To clarify whether the nature of sleep timing is long-term, the information about the sleep timing at age 8 was also collected. The association of BMI and sleep timing parameters and physical fitness were assessed separately.

What this study adds

- We found only a very mild positive correlation between sleep duration at ages 8 and 15. Both the objective measures of physical fitness and self-reported physical activity participation were positively associated with delayed bedtime and reduced sleep duration.
- The positive association of BMI, delayed bedtime and shorter sleep duration was confirmed after adjusting for sex and other potential confounders. Interestingly, BMI was also positively associated with physical fitness in both sexes.
- The "risky cluster" of increased BMI, delayed bedtime and lower physical fitness was not confirmed. However, it must be noted that neither particularly short sleep duration nor obesity were frequently observed in our study.

Introduction

The physical condition of individual human subjects is an important cardiometabolic health factor in different age groups – including adolescents. Bad performance in exercise tests has been associated with various components of the metabolic syndrome in adolescents [1,2] and is steadily worsening in recent decades [3]. This trend is linked to the increasing prevalence of obesity in this age category [4,5].

Other factors contributing to cardiometabolic health also include sleep disturbances [6,7]. Various studies have reported on the complex relationships between sleep, physical activity and exercise outcomes. While prolonged sleep deprivation has been reported to reduce physical exercise outcomes [8,9], physical activity has been found to affect sleep quality and quantity in various age categories [10,11]. Obesity has been found to affect both sleep quality, for example, via obstructive sleep apnoea [12], and exercise performance, while sleep deprivation has been linked to an unhealthy diet [13] and adolescent overweight or obesity [6].

Several sleep timing parameters such as sleep duration, bedtime or social jet lag may play a role in the development of cardiovascular complications in later life. The abovementioned term “social jet lag” refers to the difference between social and biological sleep time. It may be quantified as the difference between mid-sleep points of work/school days and non-work/non-school days [14]. Along with sleep deprivation and delayed bedtime, social jet lag is considered to be a factor contributing to the current obesity epidemic. [14].

To date, only a limited amount of longitudinal information on associations between sport activity, objectively measured physical fitness, socioeconomic status, body mass index (BMI) and sleep timing has been available for the general adolescent population, especially in Central and Eastern Europe.

Aims

Our prospective study aimed to investigate the sleep timing parameters of 15-year old adolescents (sleep duration, social jet lag, bedtime) and their possible modification by self-reported sport activity as well as an association with their physical fitness, measured by bicycle ergometry. To clarify whether the nature of sleep timing is long-term, sleep timing at age 8, its development from age 8 to 15 and potential associations with physical exercise outcomes at age 15 were assessed. Self-reported information on sport activity was also collected at age 11 in order to evaluate the potential long-term effect of physical exercise on sleep timing. Finally, the effect of other variables (BMI, parental education, occupational skill level) on sleep timing parameters was also analysed. The correlation of BMI and physical fitness was assessed separately.

Methods

Study population and data collection

The study population consisted of the participants of the European Longitudinal Study of Pregnancy and Childhood (ELSPAC) in the Czech Republic, a prospective study initiated by the World Health Organization (WHO) Regional Office for Europe in 1985 and designed to include a total of 40,000 children across Europe [15]. The study design and population in the Czech Republic has been described in detail elsewhere [16,17]. In brief, the study population involved all children born in Brno, Czech Republic between March 1991 and June 1992 as well as their parents. Children comprising the cohort were thus born during the transition from communism to a market economy. After signing written informed consent forms, the parents were asked to provide further data using self-reported questionnaires completed by parents, paediatricians, and, from age 11, by the children themselves. A total of 974 children from Brno were followed up until reaching 15 years of age. The research followed the principles of the Declaration of Helsinki.

Variables used in the study

The present study uses data from questionnaires, completed at ages 8, 11 and 15, designed to elicit information on sleep timing, sport activity duration in a typical week (outside school hours, open-ended answer, indicated in hours), anthropometric data (height, weight, BMI, waist circumference, hip circumference), parental education and occupation skill level ranked form 1 to 4 according to the International Standard Classification of Occupations (ISCO)-88 classification [18].

Sleep timing parameters included average bedtime and waking time both on school days and at the weekends, average sleep duration both on school days and at the weekends and social jet lag, defined as the difference between mid-sleep points on school days and at the weekends. For the purpose of descriptive statistics the sleep timing parameter values were expressed as hours:minutes in the 24-hour format. For regression modelling we use these values of these parameters as standard decimal values (eg 6h 30min being 6.5).

While sleep timing parameters and information on socioeconomic background were reported by either the participants or their parents, medical records, including anthropometric parameters, were provided by paediatricians.

Physical fitness measurement

To evaluate physical fitness at the age of 15, bicycle ergometry was used along with the PWC 170 physical work capacity protocol [19]. Two output parameters were evaluated: output at 170 beats per minute (bpm) in watts per kilogram (PWC_{170}) and the fitness grade, defined as

F = 6 - (10*(HR1-HR2)/HR1)), where HR1 corresponds to maximum heart rate and HR2 indicates heart rate after a period of one minute. The protocol included the telemetric measurement of heart rate at several (usually three or four) six-minute-long stages of increasing loads. Output at 170 bpm was estimated using linear regression. Only tests with achieved heart rates of at least 165 bpm were considered valid in accordance with existing studies [20]. The fitness grade sought to measure the normalisation of HR following physical effort. Test results were available for 787 out of 974 participants as the rest either did not participate in bicycle ergometry (n = 162) or did not complete the test (n = 25). While the three groups did not differ in most sleep timing parameters, sex or BMI, a difference in waking time during the weekend was observed: waking time for non-participants was 12 minutes later compared to participants with valid tests (ANOVA + Tukey post hoc test: $p = 0.007$). The bicycle ergometry took place between 9:00 (9 am) and 14:00 (2 pm).

Statistical methods

The correlations of continuous parameters were expressed using Spearman rank order coefficients and corresponding p-values. Univariable and multivariable linear regression models were constructed for sleep timing parameters. Missing values were imputed using Multiple Imputation by Chained Equations [21]. The proportions of imputed data for different factors were ranging from 0% for sex, BMI systolic blood pressure and sport activity at 15 years up to 24.8 % and 25.4% for father's education and father's ISCO skill level. Mother's ISCO skill level was missing for 7.2% of records and mother's education for 4.4%. Fifty imputed datasets were generated as the number of imputed datasets should be equal or greater than the proportion of cases with missing value on at least one study variable. Since bicycle ergometry was performed at the same age in all subjects, just after reaching age of fifteen years, absolute BMI values were used for the analyses; however, in simple correlations, the BMI z-scores were also employed to confirm the results using BMI. Values of $p < 0.05$ were considered to be statistically significant. False discovery rate (FDR)-adjusted p-values according to the Benjamini-Hochberg procedure [22] were subsequently computed to avoid false positive discoveries, the FDR being set at 0.05 similarly to the α-value. The FDR-adjusted p-values were not assessed in the multivariable models (for PWC_{170} and BMI), which served as post hoc analyses of the observations already identified as discoveries. All analyses were performed in R, version 3.2.1.

Results

Sleep timing parameters and their changes during adolescence

The basic characteristics of the studied population are shown in Table 1. All participants' parameters refer to the situation at the age of 15 unless stated otherwise.

Sleep duration at age 8 mildly correlated with sleep duration at age 15, both in the case of weekends ($r = 0.08$, $p = 0.031$) and school days ($r = 0.16$, $p < 0.001$). Sleep duration at age 8 on school days also showed a mild negative correlation with bedtime at age 15 (school days: $r = -0.14$, $p < 0.001$; weekends: $r = -0.09$, $p = 0.026$). Naps were not associated with any other sleep parameter either at age 8 or at age 15.

The sleep timing indicators such as bedtime (Table 2), sleep duration and social jet lag (Table 3) were associated with PWC_{170} and several other factors in univariable model. The associations were generally weaker for waking time (data not shown), with waking time itself being strongly correlated with other sleep timing parameters.

In multivariable models, the physical fitness as defined by PWC_{170} remained a significant predictor of bedtime on school days after adjusting for sex, BMI, systolic blood pressure, sport activity, parental education, parental ISCO skill level, neighbourhood noise, irregular sleep timing and the presence or absence of naps (model A). The effect of PWC_{170} was also significant after adjusting for previously mentioned factors and waking time (model B). This adjustment was employed with respect to establishing whether the potential effects of physical condition on sleep timing were primarily linked to changes in waking time. The effect of PWC_{170} is shown in table 4 and table 5.

PWC_{170} was found to be negatively associated with sleep duration, more strongly at weekends than on school days, and with the delayed bedtime on school/work days. This last association remained significant after correction for both individual and parental factors. This interaction was not modified much when waking time (strongly correlated with bedtime) was added to the model. On the other hand, while sleep duration on school days was not significantly influenced by PWC_{170} in the multivariable model, the effect became significant once waking time was added. This underlines the association of PWC_{170}, corrected for possible confounders, with bedtime and not with waking time. Both PWC_{170} and the fitness grade were also significantly associated with social jet-lag, but not in multivariable models. Interestingly, self-reported information on sport activity was associated with bedtime, sleep duration and social jet-lag only marginally or not at all (measured in hours per week).

BMI, sleep timing parameters and physical fitness

After correcting for sex and other above mentioned factors, participant BMI remained positively associated with bedtime on school days ($p = 0.050$) and weekends ($p = 0.006$) and negatively associated with sleep duration on school days ($p = 0.050$) and weekends ($p = 0.006$), with no significant effect on social jet lag ($p = 0.088$). Interestingly, BMI also correlated positively with PWC_{170} (measured in watts per kilogram, $r = 0.18$, $p < 0.001$; in males only: $r = 0.27$, $p < 0.001$; in females only: $r = 0.27$, $p < 0.001$) and this remained significant after correcting for the same confounding factors ($p < 0.001$). Similar values of positive association with PWC_{170} were obtained when the z-score was used instead of absolute BMI values ($r = 0.24$, $p < 0.001$ for the total sample; $r = 0.27$. $p < 0.001$ in males only; $r = 0.26$, $p < 0.001$ in females only). The BMI z-score > 2, indicating obesity, was present in 1.8 % of the total number of participants.

Discussion

Sleep at age 8 and 15

Sleep duration at age 15 was correlated with values at age 8, both on weekends and on school days; however, the correlation was very mild. In previous prospective studies, sleeping habits were found to be relatively stable in childhood and adolescence [23–25]. While the correlation was not assessed quantitatively in the first two studies, Thorleifsdottir et al. found a high degree of correlation ($r = 0.53$) between sleep duration at ages 5 and 15 in an Icelandic population [25], which was thus much higher than the correlation established by our study. While at the beginning of our study all participants were living in an urban area (Brno), the population sample in the Icelandic study was over 40% rural, and the study established differences in sleep timing between adolescents from urban and rural areas. The presence or absence of shared external factors contributing to markedly different correlation coefficients in both studies cannot be excluded. Sleep duration on school days roughly corresponded to percentile curves established by a longitudinal Swiss study conducted by Iglowstein et al. while sleep duration on weekends was found to be approximately 1.5 hours longer [26]. In our study, sleep duration was not found to change substantially on weekends between ages 8 and 15, though we did observe the shortening of mean sleep duration by 52 minutes on school days ($p < 0.001$). It must be noted, however, that sleeping times at age 8 were reported by parents and values at age 15 years were reported by the participants themselves. According to a previous meta-analysis, self-reported information provided by children and adolescents was confirmed as reliable as the data obtained using an accelerometer, while parents tended to overestimate the child’s sleeping time [27].

Sleep and exercise

It is conceivable that in our study, the timing of sport activity, which usually took place in the afternoon, could have contributed to the phase delay and postponed bedtime. The fact that self-reported information on sport activity and objectively measured physical fitness were similarly correlated with sleep timing supports a possible causal mechanism. Because sport activity at age 11 also showed similar trends, these effects may be long-term in nature; however, a bigger population sample is needed to prove or disprove this assumption. Our findings are contradictory to a recent meta-analysis of 41 studies performed in adolescent populations of comparable age around the world [28] where physical activity was associated with an earlier bedtime; our results can thus be population-specific. It must be noted, for example, that, compared to previous studies [29], average sleep duration was relatively long (8:23 ± 0:49 on school days) and only three participants reported severe sleep restriction (< 6 hours).

The association between physical activity and sleep timing as well as sleep quality remains controversial [30,31]. Most studies conclude that physical activity improves sleep quality in various age categories [10,32]. The effect of physical exercise on sleep timing depends on the timing of the physical activity itself and is influenced by the light timing schedule [31]. Exercise has been found to facilitate the phase delay of melatonin levels [33,34] and core body temperature [35] in young adults when applied at night. On the other hand, Miyazaki et al. also reported a phase advance in melatonin secretion induced by physical exercise together with artificial light, both advancing each day. The combined effect was higher than the effect of advancing artificial light only [34]. In a study by Yamanaka et al., physical exercise was found to facilitate the phase advance of the sleep-wake cycle, while a melatonin peak showed a mild phase delay and core body temperature exhibited no significant changes (both similarly to a resting control group), thereby suggesting internal desynchronization during the experiment.

However, the study focused on a relatively short time period of several days [36]. An additional study reported a phase advance in melatonin onset after early evening exercise at approximately 18:30; the next day, the group showed a large phase delay, so that the total phase delay accumulated over two days was similar to the non-exercising control group [37]. Most of the above mentioned studies were conducted using young adults, i.e. relevance for an adolescent population needs to be confirmed. However, these studies provide evidence of exercise altering circadian timing, which can be responsible for the effects observed in our study.

BMI

The association of the increased BMI and the BMI z-score with better physical fitness in both sexes contradicts the findings of previous studies focusing on adolescents of similar age [38–40]. However, in a recent study by Chastin et al., moderate to vigorous physical activity was not found to correlate with BMI in underweight, normal and overweight adults and was only found to be decreased in an obese group [7]. In young adults with a mean age of 24 years, a non-linear relationship has been proposed for the correlation of BMI and motor-endurance variables, with optimal BMI values mostly around 23 $kg.m^{-2}$ [41]. In our study, mean BMI was 20.2 $kg.m^{-2}$ and BMI distribution was similar to values observed in 2001 by the Czech National Anthropological Survey [42]. The BMI z-score > 2, defining adolescent obesity, was present in only 1.8 % of participants. Obese participants thus did not substantially influence the results of our study. Moreover, lower physical fitness in leaner subjects could have been attributed to lower muscle mass in our study group. Furthermore, the abovementioned studies used methods where the participants' muscles lifted their body weight to test physical fitness, which is not the case with bicycle ergometry.

Methodological aspects of the study

While an important strength of the study is the non-selective approach to the target population (virtually all children born in Brno in the 1991–1992 period were included in the original ELSPAC study), the study suffered a large dropout rate which reduced the initial population of more than 4,500 to 974 by age 15. The dropouts were selective and children from families with higher socioeconomic status and higher parental education levels were more likely to stay in the study. Potential inaccuracies in questionnaire-based data collection constitute a second limitation. Also, no information about the nature and exact timing of the participant's sport activity was collected at either age 11 or 15; this knowledge is potentially valuable with respect to elucidating the precise mechanisms of the exercise–sleep timing association.

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Competing interest

None declared

Contributorship statement

Jan Máchal wrote the manuscript. Filip Zlámal provided the statistical evaluation of the data. Lenka Andrýsková, Petr Švancara, Hynek Pikhart and Julie Bienertová-Vašků were responsible for conducting the ELSPAC study in the Czech Republic. Hynek Pikhart and Julie-Bienertová-Vašků also contributed to the text of the manuscript.

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Table 1. Study subject characteristics by sex of participants (mean ± standard deviation)

Parameter	Total sample (N=787)	Male (N=408)	Female (N=379)
Height [cm]	170.9 ± 8.3	175.3 ± 7.4	166.2 ± 6.5
Weight [kg]	59.0 ± 9.7	62.2 ± 10.5	55.6 ± 7.4
BMI [kg.m^{-2}]	20.2 ± 2.6	20.2 ± 2.7	20.2 ± 2.4
BMI z-score > 2 [%]	1.8 %	2.9 %	0.5 %
Waist circumference [cm]	70.3 ± 6.8	73.6 ± 6.7	66.8 ± 5.0
Hip circumference [cm]	91.4 ± 6.5	90.1 ± 6.8	92.9 ± 5.8
Heart rate at rest [beats per minute]	73 ± 13	71 ± 13	75 ± 13
PWC_{170} [W.kg^{-1}]	150.4 ± 45.7	176.9 ± 41.4	121.9 ± 30.4
Fitness grade*	2.5 ± 0.7	2.8 ± 0.7	2.2 ± 0.5
Sport activity at age 15 [h/week] [median (IQR**)]	8 (5 – 12)	9 (6 – 13)	7 (4 – 10)
Sport activity at age 11 [h/week] [median (IQR**)]	2 (1 – 3)	2 (1 – 3)	2 (1 – 3)
Bedtime (school days) [h:min]	22:16 ± 0:46	22:19 ± 0:50	22:12 ± 0:42
Bedtime (weekends) [h:min]	23:28 ± 1:18	23:30 ± 1:20	23:24 ± 1:15
Waking time (school days) [h:min]	6:39 ± 0:30	6:42 ± 0:30	6:37 ± 0:30
Waking time (weekends) [h:min]	9:12 ± 1:21	9:12 ± 0:24	9:26 ± 0:17
Sleep duration (school days) [h:min]	8:23 ± 0:49	8:22 ± 0:51	8:25 ± 0:48
Sleep duration (weekends) [h:min]	9:52 ± 1:26	9:42 ± 1:29	10:01 ± 1:22
Social jet lag (mid-sleep point difference) [h:min]	+1:56 ± 0:59	+1:51 ± 1:01	+2:01 ± 0:56
Nap presence (school days) [% of total population]	52 (7.0 %)	33 (8.5 %)	19 (5.3 %)
Nap presence (weekends) [% of total population]	63 (8.4 %)	28 (7.2 %)	35 (9.7 %)
Sleep duration at age 8 (school days) [h:min]	9:15 ± 0:42	9:16 ± 0:41	9:14 ± 0:43
Sleep duration at age 8 (weekends) [h:min]	9:40 ± 0:55	9:37 ± 0:53	9:43 ± 0:58
Maternal education (%)			
Elementary	18.5 %	20.3 %	16.5 %
Secondary	47.2 %	44.7 %	50.0 %
Higher	34.3 %	35.0 %	33.5 %
Maternal ISCOskill level (%)***			
1	4.9 %	4.4 %	5.5 %
2	19.3 %	21.0 %	17.4 %
3	32.9 %	33.5 %	32.2 %
4	33.6 %	32.2 %	35.1 %
Paternal education (%)			
Elementary	24.8 %	23.5 %	26.4 %
Secondary	24.1 %	33.5 %	34.8 %
Higher	41.0 %	42.9 %	38.8 %
Paternal ISCO skill level (%)***			
1	1.5 %	1.3 %	1.8 %
2	31.3 %	30.4 %	32.5 %
3	21.6 %	22.5 %	20.3 %
4	41.6 %	40.8 %	42.4 %

F = 6 - (10(HR1-HR2)/HR1))

**IQR: Interquartile Range

***ISCO: International Standard Classification of Occupations

Table 2. Selected factors and their association with bedtime in univariable regression models

	Bedtime (school days)			Bedtime (weekends)		
Factor	b* (95% CI)	p (unadjusted)	p (FDR-adjusted)	b* (95% CI)	p (unadjusted)	P (FDR-adjusted)
Sex (female as reference)	*0.13 (0.01; 0.24)*	*0.027*	*0.054*	0.09 (-0.10; 0.28)	0.36	0.51
BMI	***0.10 (0.04; 0.15)***	***< 0.001***	***0.002***	***0.19 (0.10; 0.29)***	***< 0.001***	***<0.001***
Fitness grade	0.05 (0.00; 0.11)	0.056	0.083	-0.05 (-0.14; 0.04)	0.29	0.51
PWC_{170}	***0.12 (0.07; 0.18)***	***< 0.001***	***<0.001***	0.07 (-0.02; 0.16)	0.14	0.37
Sport activity (age 15)	*0.05 (-0.01; 0.011)*	*0.079*	*0.090*	0.03 (-0.06; 0.13)	0.48	0.55
Sport activity at age 11	*0.06 (0.00; 0.12)*	*0.062*	*0.083*	0.04 (-0.05; 0.14)	0.38	0.51
Sleep duration at age 8 (school days)	***-0.10 (-0.16; -0.04)***	***0.001***	***0.002***	*-0.09 (-0.19; 0.00)*	*0.063*	*0.25*
Sleep duration at age 8 (weekends)	0.00 (-0.06; 0.05)	0.89	0.89	-0.03 (-0.13; 0.07)	0.58	0.58

*b: standardized regression coefficient

BMI, body mass index; FDR, false discovery rate; PWC, physical work capacity.

The linear regression models with FDR-adjusted p-value <0.05 are marked in bold.

Table 3. Selected factors and their association with sleep duration and social jet lag in univariable regression models

	Sleep duration (school days)			Sleep duration (weekends)			Social jet-lag		
Factor	b* (95% CI)	p	p (FDR-adjusted)	b* (95% CI)	p	P (FDR-adjusted)	b* (95% CI)	p	P (FDR-adjusted)
Sex (female as reference)	-0.05 (-0.17; 0.07)	0.41	0.49	***-0.32 (-0.52; -0.09)***	***0.006***	***0.024***	*-0.16 (-0.31; -0.02)*	*0.025*	*0.067*
BMI	*-0.076 (-0.13; -0.01)*	*0.028*	*0.096*	***-0.13 (-0.24; 0.02)***	***0.026***	***0.050***	*0.07 (-0.01; 0.14)*	*0.081*	*0.13*
Fitness grade	-0.01 (-0.7; 0.05)	0.70	*0.70*	*-0.10 (-0.21; 0.01)*	*0.082*	*0.11*	***-0.15 (-0.22; -0.08)***	***< 0.001***	***<0.001***
PWC_{170}	*-0.06(-0.12; 0.00)*	*0.036*	*0.096*	***-0.16 (-0.27; -0.05)***	***0.004***	***0.024***	***-0.10 (-0.17; -0.05)***	***0.005***	***0.02***
Sport activity (age 15)	-0.02 (-0.08; 0.04)	0.43	0.49	***-0.12 (-0.23; -0.01)***	***0.031***	***0.050***	*-0.06 (-0.14; 0.01)*	*0.079*	*0.13*
Sport activity at age 11	0.020 (-0.11; 0.03)	0.22	0.35	-0.01 (-0.12; 0.10)	0.86	0.97	0.00 (-0.08; 0.08)	1.00	1.00
Sleep duration at age 8 (school days)	***0.11 (0.05; 0.18)***	***< 0.001***	***0.003***	0.00 (-0.11; 0.12)	0.97	0.97	-0.05 (-0.12; 0.03)	0.23	0.30
Sleep duration at age 8 (weekends)	0.05 (-0.02; 0.11)	0.16	0.32	***0.15 (0.03; 0.26)***	***0.018***	***0.048***	0.03 (-0.05; 0.11)	0.51	0.59

*b: standardized regression coefficient

Table 4. Effect of PWC_{170} on bedtime in multivariable models

	Bedtime (school days)		Bedtime (weekends)	
Model	b* (95% CI)	p-value	b* (95% CI)	p-value
Model A*	***0.10 (0.03; 0.17)***	***0.008***	0.02 (-0.10; 0.14)	0.74
Model B (Model A + waking time)	***0.08 (0.01; 0.15)***	***0.019***	0.04 (-0.07; 0.15)	0.48

*b: standardized regression coefficient

**Model A: adjustment for sex, BMI, systolic blood pressure, sport activity, parental education, parental ISCO skill level, neighbourhood noise, irregular sleep timing and the presence of naps

Table 5. Effect of PWC_{170} on sleep duration and social jet lag in multivariable models

	Sleep duration (school days)		Sleep duration (weekends)		Social jet-lag	
Model	b* (95% CI)	p-value	b* (95% CI)	p-value	b* (95% CI)	p-value
Model A*	-0.05 (-0.13; 0.03)	0.20	-0.08 (-0.22; 0.06)	0.28	*-0.09 (-0.18; 0.01)*	*0.064*
Model B (Model A + waking time)	***-0.08 (-0.15; -0.01)***	***0.019***	-0.04 (-0.15; 0.07)	0.48	-0.03 (-0.08; 0.02)	0.28

*b: standardized regression coefficient

**Model A: adjustment for sex, BMI, systolic blood pressure, sport activity, parental education, parental ISCO skill level, neighbourhood noise, irregular sleep timing and the presence of naps