Received: 4 June 2024 | Revised: 25 November 2024 | Accepted: 28 November 2024

DOI: 10.1111/apa.17537

ACTA PÆDIATRICA NURTURING THE CHILD WILEY

ORIGINAL ARTICLE

Sleep profiles and their associations with adiposity and cardiorespiratory fitness among adolescents

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Funding information
European Union, Grant/Award Number: CZ.02.01.01/00/22_008/0004583; Palacký University Olomouc, Grant/Award Number: IGA_FTK_2023_001; APVV, Grant/Award Number: APVV-22-0078 and APVV-18-0070; Czech Science Foundation, Grant/Award Number: 22-02392S; VEGA, Grant/Award Number: 1/0179/21

Abstract

Aim: This study aimed to identify sleep profiles in a representative sample of Slovak adolescents and investigate their associations with adiposity indicators and cardiorespiratory fitness.

Methods: Data from the 2022 Health Behaviour in School-aged Children (HBSC) study conducted in Slovakia were analysed. Survey questions on sleep duration and problems from the entire HBSC sample ($n = 8906$) were used to identify sleep profiles. Associations with adiposity indicators and cardiorespiratory fitness were investigated in a subsample of 924 adolescents (average age 13.3 ± 1.48; 56.2% boys) who completed the HBSC survey, bioimpedance analysis, and 20-metre shuttle run test.

Results: Three sleep profiles were identified—optimal sleepers, optimal sleepers with sporadic sleep problems and poor sleepers. Crude models showed that poor sleepers had significantly higher body fat percentage and fat mass index, along with lower cardiorespiratory fitness, compared to optimal sleepers. After adjustment, only the association between sleep profiles and cardiorespiratory fitness remained significant.

Conclusion: The observed associations between sleep profiles and cardiorespiratory fitness may help better target future intervention resources towards adolescents with low cardiorespiratory fitness levels.

KEYWORDS
20-metre shuttle run test, bioimpedance analysis, body composition, sleep duration, sleep problems

1 | INTRODUCTION

Optimal sleep quantity and quality are essential for the health and well-being of adolescents.[1,2] However, 30–50% of adolescents sleep less than recommended,[3,4] and up to 30% report sleep problems.[4,5] The prevalence of sleep problems further increased to 50% during the COVID-19 pandemic.[6] Lack of sleep and the occurrence of sleep problems are associated with adverse cardiometabolic outcomes such as hypertension, insulin resistance, and excess adiposity,[7,8] as well as increased risks of emotional, cognitive, and behavioural issues in adolescents.[9,10]

Short sleep duration is strongly associated with an increased risk of excess adiposity in children and adolescents.[11–14] Poor sleep

Abbreviations: CI, Confidence interval; CRF, Cardiorespiratory fitness; HBSC, Health Behaviour in School-Aged Children study; SES, Socioeconomic status.

quality is reportedly linked to excessive adiposity, independent of sleep duration,[15,16] as well as lower physical activity levels and increased sedentary time.[17] Moreover, reduced sleep duration and poor sleep quality in adolescents are associated with decreased cardiorespiratory fitness (CRF).[18,19]

The above-mentioned associations, along with evidence linking excess adiposity and reduced CRF in adolescence to an increased risk of cardiometabolic diseases later in life,[20,21] underscore the importance of sleep patterns. They are a key lifestyle behaviour for improving weight status and CRF in adolescents.[22,23] Based on the Conceptual Framework of Adolescent Health, this modifiable behavioural factor involves complex interactions with biological and social determinants related to early childhood development.[24] Adolescents with low socioeconomic status are at a higher risk of excess adiposity and have lower CRF levels than their peers.[25,26]

Sleep needs, the combination of various sleep problems, and their impact on adolescent health may differ among individuals.[1,27] A person-centred approach allows these differences to be considered. It provides more insight than a variable-centred approach when investigating the lifestyle practices, habits, and behaviours of specific populations.[28–30] This approach helps identify a small set of underlying subgroups characterised by multiple dimensions. This, in turn, could facilitate the targeting of future intervention resources to these specific subgroups.[31] Sleep can also be used to assess the association between combined sleep duration and quality with adiposity. This is important because sleep duration cannot serve as a proxy for sleep quality. Studies examining sleep-adiposity associations should consider both sleep quality and sleep duration to obtain an accurate estimate.[16] Additionally, a person-centred approach can help assess the association between sleep behaviour and CRF.[32]

Therefore, this study aimed to identify sleep profiles in a representative sample of Slovak adolescents and investigate their associations with adiposity indicators and CRF. Moreover, the possible interactions with sex, socioeconomic status, maternal employment status, sweet consumption, and physical activity within these associations were also explored.

2 | METHODS

We used data from a Health Behaviour in School-aged Children (HBSC) study conducted in Slovakia in 2022. A three-step sampling was performed to obtain a representative sample. First, 195 larger and smaller elementary schools from rural and urban areas were randomly selected from a list of all eligible schools in Slovakia, provided by the Slovak Institute of Information and Prognosis for Education, and invited to participate. Ultimately, 94 schools agreed to participate (response rate: 48%). Second, data were collected from 9697 adolescents in grades 5 to 9 of elementary schools in Slovakia using the HBSC survey (mean age 13.4 ± 1.3; 50.9% boys). Lastly, 1225 surveyed adolescents, representing approximately 13% of the total number of participating schools, participated in body composition and CRF measurements. After excluding those with missing data, the final sample consisted of 924 adolescents (average age 13.3 ± 1.48; 56.2% boys).

This study was approved by the Ethics Committee of the Medical Faculty of Pavol Jozef Šafárik University, Košice (13/N2021). Parents were informed of the study via the school administration and could opt out if they disagreed with their child's participation.

Children were informed about the study in advance by their teachers and again during data collection by the HBSC administrator, who explained the option to refuse participation. Participation was entirely voluntary and anonymous, with no explicit incentives offered.

Key Notes

- Optimal sleep is important for maintaining healthy weight and adequate cardiorespiratory fitness (CRF) in adolescents.
- Our findings indicated that poor sleepers with insufficient sleep duration and poor sleep quality were more likely to have reduced CRF, but no associations were found between sleep patterns and adiposity.
- Interventions to improve CRF in adolescents should prioritise sleep behaviours, although further research is needed to clarify the relationship between sleep and adiposity.

3 | MEASURES

Sleep duration during school days and weekends was calculated by estimating the time between bedtime and wake-up time. Bedtime was measured by asking participants what time they usually went to bed on school nights and weekends. Wake-up time was measured by asking participants what time they awoke on school days and weekends. Hourly cut-offs for short and long sleep duration for different age groups of adolescents were established based on recommendations for paediatric sleep research[33] and are presented in Table 1. Sleep duration between the hourly cut-offs for short and long sleep was classified as 'normal'.

Sleep problems were measured using four items assessing the occurrence of four sleep problems: problems falling asleep in the evening, waking up at night, problems waking up in the morning and feeling rested, and daytime sleepiness. The response categories indicating how frequently problems occurred during the last month were never, less than once a week, once or twice per week, and three or more times per week.

CRF was assessed by the number of laps in the 20-metre shuttle run test, a progressive aerobic exercise test that involves continuous running between two lines 20 m apart, timed to audio signals. The test has moderate criterion validity against gas-analysed peak VO_2

TABLE 1 Recommended hourly cut-offs for short and long sleep in adolescents.[33]

Age (years)	Cut-off for short sleep (hr)	Cut-off for long sleep (hr)
10	≤8.5	≥11
11	≤8	≥11
12	≤8	≥10.5
13	≤8	≥10
14	≤7.5	≥10
15	≤7	≥10
16–18	≤7	≥10

(mL/kg/min), high to very high test–retest reliability, and is meaningfully associated with various health indicators among children and adolescents.[34] Most of the testing was conducted in the morning, with a small number of tests conducted between 12 am and 1 pm.

Various *adiposity indicators* were measured and calculated. Body weight (in kg), body mass index (BMI), percentage of body fat (%), and visceral adipose tissue (VAT) were measured simultaneously during the bioimpedance analysis of body composition. The fat mass index (FMI) was calculated from the measured data. We used the InBody 230 device (Biospace Co., Ltd., Seoul, South Korea), which is considered reasonably accurate for prevalence studies in adolescents.[35] The participants were instructed to wear training clothes, or at a minimum, a T-shirt and pants or a skirt. Before the bioelectrical impedance analysis, body height (cm) was measured using a SECA 213 portable stadiometer (Seca GmbH & Co. KG.). The adolescents assumed an active upright posture and stood barefoot with their backs facing the stadiometer and their heads facing downwards in the Frankfurt horizontal plane. The measurement was performed during inhalation to the nearest 0.1 mm. The starting weight was set to −0.3 kg to account for the fact that participants were weighed while wearing more than just underwear. The calculated WHO BMI z-scores were used for further analyses.[36]

To evaluate the possible distorting effects of other factors on the analysed associations among sleep profiles, adiposity, and CRF, we used the following *confounding factors*. Socioeconomic status (SES) was estimated using the Family Affluence Scale (FAS), which consists of six items: number of family cars, bathrooms, computers in a household, ownership of dishwashers, having a personal bedroom and the number of foreign holidays taken over the past 12 months. Responses to the items were calculated as an aggregated FAS index ranging from 0 to 13.[37] In addition to the FAS, we used items on maternal employment status. Its validity has been demonstrated in several studies, showing high agreement between children's and parents' responses.[38] The HBSC item regarding the frequency of consuming sweet items, such as candies or chocolates, during the week was used in the analyses. The item, developed by Prochaska et al.[39] for clinical practice with adolescents and adapted for the HBSC study, was used to assess moderate-to-vigorous physical activity (MVPA). The frequency of at least 60 min of MVPA per day over the past 7 days was used to evaluate its possible confounding effect on the associations between sleep profiles, adiposity, and CRF.

4 | ANALYSES

All analyses were conducted using R software version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria) and LatentGold software version 6.0.0 (Statistical Innovations, Arlington, USA). The level of significance was set at $p < 0.05$.

4.1 | Sleep profiles

Latent class analysis (LCA), a form of mixture modelling, was conducted to identify distinct subgroups (profiles) characterised by similar response patterns.[40] Individuals from the entire HBSC sample with complete data on sleep duration and problems, totalling 8906, were utilised to identify the sleep profiles. Data on sleep duration and problems were used to fit latent class models using the LatentGold software (Statistical Innovations, Arlington, USA). The fit of the models was evaluated with the Akaike information criterion (AIC) and Bayesian information criterion (BIC), which indicate the balance between model fit and simplicity. Lower values indicate a better-fitting model. When the BIC and AIC continue to decrease, it is recommended to use a scree plot to identify an elbow point, which occurs after a rapid drop followed by a sequential stabilisation of the values.[41] Additionally, entropy was employed as a measure of the certainty level associated with the classification of each identified profile. Furthermore, the identified profiles, their meaningfulness, and sizes were evaluated.[40] The average latent class posterior probability (Table S1) was assessed in the final solution to verify the proposed cut-off of 0.80 for acceptable diagonal probabilities.[40] Descriptive statistics for each profile were computed as weighted means, standard deviations (SD), or weighted proportions. The posterior probability of classifying a specific profile was used as the weight for each observation.

4.2 | Associations between sleep profiles, adiposity, and cardiorespiratory fitness

We used a bias-adjusted three-step approach (Bolck-Croon-Hagenaars method) to relate the identified sleep profiles to the distal outcomes, correcting for misclassification errors. This method involves estimating a weighted linear regression using the weights obtained from the inverse of the misclassification probability matrix.[42] Five separate models were built, one for each adiposity indicator (dependent variable) and one with CRF as the dependent variable. Because of violations of the linear model assumptions, the FMI, VAT, and 20-m shuttle run test results were transformed using the natural logarithm before analysis. Sleep profiles were used as independent variables in all models. The models were adjusted for age, sex, socioeconomic status, sweet consumption, maternal employment status, and physical activity when analysing adiposity indicators. For CRF, the models were adjusted for age, sex, SES, BMI *z*-score, and physical activity. All models, except those with BMI *z*-score, included an interaction between age and sex owing to their significance.

4.3 | Sensitivity analysis

To assess the robustness and generalisability of our findings, we compared selected variables between the subsample and the entire HBSC sample (without the subsample). Differences in age, sex, maternal employment status, SES, and distribution of the identified profiles were verified using the chi-square test for categorical variables and Welch's two-sample t-test for continuous variables (age and SES).

5 | RESULTS

5.1 | Description of the entire HBSC dataset

The entire HBSC dataset (Table 2) comprised 8906 individuals (51.1% boys and 48.9% girls), with a mean age was 13.45 ± 1.48 years. Less than half of the participants reported no problems falling asleep (41.2%) or waking at night (47.5%). Less than one-third of the individuals never felt tired after waking up (27.2%), and fewer than one-third felt sleepy during the day (23.1%). Overall, 59.6% had normal sleep duration during weekdays, and 63.8% had normal sleep duration at weekends. The mothers of 87.5% of the children were employed, and the average SES score was 7.76 ± 2.44 points.

5.2 | Sleep profiles

Table 2 shows the profiles identified from the variables that reflect sleep duration and frequency of sleep problems. To determine the optimal number of profiles, models with one- to five-profile solutions were created. Although the highest drop in the information criteria (Table 3) was observed between one- and two-profile solutions, the three-profile solution was selected as the best option. It provided the optimal balance between model fit, simplicity, profile size, and interpretability.

Based on the profile response probabilities (Table 2), the sleep profiles were labelled as optimal sleepers (profile 1, 20.7%), optimal sleepers with sporadic sleep problems (profile 2, 56.3%), and poor sleepers (profile 3, 22.9%). Optimal sleepers exhibited the best sleep patterns, characterised by the highest probability of having normal sleep duration during school days and at weekends, and the lowest probability of experiencing sleep problems. Thus, this sleep profile was used as the reference category for comparison. Compared to the reference category, optimal sleepers with sporadic sleep problems had normal sleep duration during school days and at weekends. However, they had a noticeably higher probability of experiencing issues with waking up in the morning, feeling rested (80.8 vs. 21.9%), and daytime sleepiness (85.8 vs. 27.3%). Poor sleepers were characterised by an elevated probability of having all four sleep problems compared to the remaining sleep profiles. Furthermore, poor sleepers had a noticeably lower probability of normal sleep duration during school days. The probability of normal sleep duration at weekends was similar among all sleep profiles. The sleep profiles also differed in the proportion of covariates. Optimal sleepers were younger (13.0 years; $p < 000.1$) and had a lower proportion of girls (29.7%; $p < 0.001$) compared to other profiles. In contrast, poor sleepers were older (13.6 years) and the highest proportion of girls (62.6%).

5.3 | Sensitivity analysis

We collected sleep profile data for 8906 participants and data on adiposity and CRF for 924. Sensitivity analysis revealed that, compared to the entire HBSC dataset (without the subsample), this analytic subsample consisted of younger individuals (13.5 vs. 13.3 years; $p = 0.003$) and more boys (50.6 vs. 56.2%; $p = 0.001$). The entire HBSC dataset had a lower mean SES (7.80 vs. 7.46; $p < 0.001$), with no difference in the proportion of employed mothers (89.0 vs. 87.3%; $p = 0.123$) compared to the subsample. The distribution of the identified sleep profiles also differed ($p = 0.002$), especially the proportions of optimal and poor sleepers (17.9 vs. 22.4% and 22.1 vs. 18.8%, respectively). The descriptive characteristics of the analytical subsamples used to investigate the associations between sleep profiles are presented in Table 4.

5.4 | Associations between sleep profiles, adiposity, and cardiorespiratory fitness

The results of the latent class step-3 analysis are summarised in Table 5. The crude models showed that poor sleepers had a significantly higher percentage of body fat ($B = 3.31$, 95% CI: 1.14, 5.48, $p = 0.003$) and FMI ($B = 0.22$, 95% CI: 0.07, 0.36, $p = 0.004$) and a lower CRF ($B = -0.26$, 95% CI: −0.39, −0.12, $p < 0.001$) than those of optimal sleepers. The associations between sleep profiles, adiposity indicators, and CRF weakened after adjusting the crude models for confounders and the interaction between age and sex. After adjustments, only the associations between sleep profiles and CRF remained significant ($B = -0.17$, 95% CI: −0.30, −0.05, $p = 0.005$).

6 | DISCUSSION

This study aimed to identify sleep profiles in adolescents and investigate their association with adiposity indicators and CRF. Based on the data on sleep duration and frequency of sleep

TABLE 2 Characteristics of the identified sleep profiles.

	Overall	Profile 1 (20.8%)	Profile 2 (56.3%)	Profile 3 (22.9%)
	%	%	%	%
Falling asleep				
Never	41.2	85.1	38.6	8.0
Less than once a week	27.1	13.6	34.8	20.2
1–2 times per week	16.2	1.2	17.0	27.7
3+ times per week	15.6	0.1	9.7	44.2
Waking up at night				
Never	47.5	81.9	46.4	18.9
Less than once a week	27.3	15.8	31.7	27.0
1–2 times per week	14.2	2.0	14.2	25.3
3+ times per week	11.0	0.3	7.7	28.7
Problem waking up				
Never	27.2	78.1	19.2	0.5
Less than once a week	21.0	18.7	28.8	3.8
1–2 times per week	20.5	2.9	27.9	18.3
3+ times per week	31.4	0.4	24.1	77.4
Sleepiness during the day				
Never	23.1	72.7	14.2	0.1
Less than once a week	25.3	24.1	35.0	2.5
1–2 times per week	22.8	3.0	32.1	17.6
3+ times per week	28.9	0.2	18.7	79.8
Sleep duration weekday				
Short	40.2	28.3	36.5	59.8
Normal	59.6	71.2	63.2	40.1
Long	0.3	0.5	0.3	0.1
Sleep duration weekend				
Short	14.5	14.1	13.6	16.8
Normal	63.8	63.8	63.6	64.3
Long	21.7	22.2	22.8	18.9

Note: Profile 1-Optimal sleepers, Profile 2-Optimal sleepers with sporadic sleep problems, Profile 3-Poor sleepers.

TABLE 3 Evaluation information criteria.

	Log-likelihood	BIC	AIC	Entropy	Min. size (%)
1 Profile	−61214	122574	122461	1.00	100
2 Profiles	−58293	116796	116632	0.69	49.2
3 Profiles	−57748	115768	115555	0.66	20.8
4 Profiles	−57603	115543	115281	0.62	10.1
5 Profiles	−57467	115334	115022	0.58	7.2

Note: Min. size-Denotes the size of the smallest profile in a given solution.
Abbreviations: AIC, Akaike information criterion, BIC, Bayesian information criterion.

problems, three sleep profiles were identified: optimal sleepers, optimal sleepers with sporadic sleep problems, and poor sleepers. The crude regression model indicated that adolescents with poor sleeper profiles had significantly increased adiposity and decreased CRF levels compared with adolescents with optimal sleeper profiles. However, after adjusting for confounders, only the association between the sleep profile and CRF remained significant.

Our study is one of the few to adopt a person-centred approach when examining sleep as a multidimensional construct in the population-derived sample.[43] Unlike other studies, we

TABLE 4 Descriptive characteristics of the analytic subsample ($n=924$).

	Mean	SD
Age (years)	13.3	1.48
Socioeconomic status[a]	7.47	2.31
Adiposity indicators		
BMI *z*-score	0.28	1.24
Fat mass percentage (%)	20.4	9.37
Fat mass index (kg/m^2)	4.3	2.76
Visceral adipose tissue (cm^2)	42.5	30.4
20-m shuttle run (number of laps)	37.6	21.9
	n	**%**
Sex		
Girls	405	56.2
Boys	519	43.8
Sweets consumption		
Less than once a day	631	68.3
Every day	293	31.7
Mother employment status		
Yes	822	89.0
No	90	9.7
Don't know	12	1.3
Moderate-to-Vigorous Physical Activity (days 60 minutes per day)	4.42 ± 2.00	

Note: Profile 1—Optimal sleepers, Profile 2—Optimal sleepers with sporadic sleep problems, Profile 3—Poor sleepers.

Abbreviation: BMI—body mass index.

[a]Expressed by the Family Affluence Scale.

identified fewer sleep profiles. Matricciani et al.[43] identified four sleep profiles, namely short sleepers, late to bed, long sleepers, and overall good sleepers, while Magee and Blunden[44] reported six sleep profiles—early larks, larks, intermediate, owls, variable owls, and late owls. Several factors could have contributed to these differences, primarily differences in methodologies used for input sleep variables and statistical analyses. For instance, Matricciani et al.[43] used wrist-worn GENEActiv accelerometers to collect device-based data, from which sleep period, sleep efficiency, sleep midpoint, and day-to-day sleep variability were calculated. Subsequently, they conducted cluster analysis and various other statistical analyses. Conversely, Magge and Blunden[44] conducted structured interviews to collect information on sleep timing—bedtimes, sleep-onset times, and wake times—on weekends and weekdays. They then used latent profile analysis to identify profiles and latent transition analysis to examine the stability and changes in profiles over time. This should be considered when interpreting our results and comparing them to those of other studies. Our results indicate sufficient variability in the selected sleep characteristics, allowing the identification of several distinct subgroups of adolescents within the population. This can be used in designing future intervention resources for specific subgroups,[31] based on the characteristics of each profile, with further research needed.

To the best of our knowledge, our study is the first to examine the associations between the identified sleep profiles, adiposity indicators, and CRF. Our results contribute to the conflicting evidence regarding the association between sleep and excess adiposity. Some studies support strong associations between multiple behavioural factors, including sleep, and the risk of excess adiposity during adolescence, while others show non-significant results.[23,25,26] Our study did not find any direct association between the identified sleep profiles and adiposity indicators. As our approach followed the recommendation to examine both sleep duration and quality for an accurate estimate of their association with adiposity,[16] our results provide new insights into the relationships between sleep and adiposity.

In contrast, our findings support the previously postulated hypothesis that reduced sleep duration and poor sleep quality are associated with decreased CRF in adolescents.[18,19,45] As suggested by Neikrug et al.,[45] the underlying causes of this observation may include less variability in sleep times (improved sleep consistency), a more advanced circadian activity phase (i.e. going to sleep earlier), and greater frontal sleep slow-wave activity in adolescents with higher CRF. Further research should explore whether these assumptions are correct and if interventions that improve CRF also enhance sleep and related brain plasticity.

As mentioned above, adjusting for confounders weakened the association between sleep profiles and adiposity indicators in the crude regression model. Factors such as SES, maternal employment status, sweet consumption, and MVPA had substantial effects on these associations. This corroborates previous findings on the negative association between SES and adiposity in high-income countries and the positive association in medium- to low-income countries.[46] It also supports the link between maternal employment status and child adiposity[47]; sweet consumption and adiposity, especially in adolescent girls[48]; and physical activity and adiposity.[49] Therefore, rather than focusing solely on the aforementioned sleep characteristics, various other factors should be considered when designing future sleep interventions aimed at reducing adiposity changes.

7 | STRENGTHS AND LIMITATIONS

This study had several strengths. This study used a valid HBSC questionnaire in a large representative sample of adolescents, augmented with objectively measured adiposity rather than relying solely on BMI, which is not considered a valid indicator of adiposity in adolescents.[50] Furthermore, the use of LCA allowed the combination of sleep duration and quality to investigate their association with adiposity indicators and CRF. To the best of our knowledge, this is the first study to adopt this design.

This study had numerous limitations. First, the cross-sectional design did not allow the establishment of causal relationships.

TABLE 5 Associations between sleep profiles and adiposity and cardiorespiratory fitness.

	BMI *z*-score		FM%		FMI[a]		VAT[a]		CRF[a]	
	B	95% CI	*B*	95% CI	*B*	95% CI	*B*	95% CI	*B*	95% CI
Crude models										
Optimal sleepers	Reference		Reference		Reference		Reference		Reference	
Optimal sleepers with sporadic sleep problems	−0.17	−0.42, 0.08	0.62	−1.21, 2.45	0.05	−0.07, 0.17	0.03	−0.13, 0.18	−0.08	−0.20, 0.03
Poor sleepers	−0.09	−0.37, 0.19	**3.31**	**1.14, 5.48**	**0.22**	**0.07, 0.36**	0.14	−0.04, 0.32	**−0.26**	**−0.39, −0.12**
Adjusted models[b]										
Optimal sleepers	Reference		Reference		Reference		Reference		Reference	
Optimal sleepers with sporadic sleep problems	−0.07	−0.33, 0.18	0.15	−1.63, 1.93	0.01	−0.12, 0.13	−0.01	−0.18, 0.15	−0.07	−0.17, 0.03
Poor sleepers	0.14	−0.17, 0.44	1.56	−0.65, 3.76	0.08	−0.07, 0.24	0.08	−0.12, 0.28	**−0.17**	**−0.30, 0.05**

Note: Bold values denote significant associations ($p < 0.05$).

Abbreviations: *B*, regression coefficient; BMI, body mass index; CI, confidence interval; CRF, cardiorespiratory fitness; FM%, fat mass percentage; FMI, fat mass index; VAT, visceral adipose tissue.

[a]Variable transformed using natural logarithm.

[b]Models with adiposity indicators (dependent variable) were adjusted for age, sex, socioeconomic status, sweets consumption, mother employment status, and physical activity. Models with cardiorespiratory fitness (dependent variable) were adjusted for age, sex, socioeconomic status, BMI *z*-score, and physical activity. All models (except for the model with BMI *z*-score as a dependent variable) were additionally adjusted for the interaction between sex and age.

Therefore, we cannot conclude whether the identified sleep profiles are determinants or outcomes of CRF. Second, the subsample used for the regression analyses differed from the entire HBSC study sample in some aspects. Therefore, the results cannot be generalised, and differences between the entire HBSC sample and its subsamples must be considered when interpreting the findings. This applies only to the regression analysis, as sleep profiles were identified for the entire HBSC sample. Third, we used subjective measures of sleep characteristics, which could introduce bias in the calculation of sleep duration and the prevalence of sleep problems. Nevertheless, this is common in studies using questionnaires that cover a broad range of topics and large sample sizes, such as the HBSC study. Fourth, sleep duration was calculated as the difference between waking up and bedtime, that is, the time spent in bed and not the time spent asleep. This could have underestimated the number of adolescents with short sleep duration. Fifth, several sleep characteristics, such as sleep consistency and sleep-onset, were missing. Sixth, evidence on the reliability of using the BIA method to assess VFA is still mixed. Therefore, our results for VFA, though non-significant, should be interpreted with caution. Finally, because CRF testing was primarily conducted in the morning, it could have potentially negatively influenced performance in the 20-m shuttle run test.[51]

Additionally, there are three main consequences of incorrectly treating a complex survey design as a simple random sample, as was done in our study. First, standard sample statistics computed from data collected using a complex survey design may lead to biased estimates of the population statistics. Second, the estimates of variation in the sample statistics may be inaccurate, resulting in incorrect confidence intervals and p-values. Finally, ignoring the complex survey design may violate the independence assumption required by standard statistical methods.[52]

8 | CONCLUSIONS

Multiple subgroups can be identified in relation to sleep duration and problems in the adolescent population. Furthermore, associations between these subgroups and CRF suggest that future intervention resources could be better targeted to subgroups with low levels of CRF, such as those with sleep problems and insufficient sleep duration during school days. Further research is required to explore the roles of various factors in the association between sleep and adiposity in adolescents.

AUTHOR CONTRIBUTIONS

Peter Bakalár: Conceptualization; investigation; funding acquisition; writing – original draft; methodology; writing – review and editing; data curation; project administration. **David Janda:** Conceptualization; funding acquisition; writing – original draft; methodology; visualization; writing – review and editing; software; data curation; formal analysis. **Michaela Kostičová:** Conceptualization; investigation; funding acquisition; writing – original draft; writing – review and editing; methodology. **Jaroslava Kopčáková:** Investigation; funding acquisition; writing – original draft; writing – review and editing; data curation. **Peter Kolarčik:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Petr Badura:** Conceptualization;

funding acquisition; writing – original draft; writing – review and editing. **Aleš Gába:** Conceptualization; funding acquisition; writing – original draft; methodology; writing – review and editing; supervision.

FUNDING INFORMATION

This research was funded by the research grant 1/0179/21 of the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences (VEGA) and by the research grants of the Slovak Research and Development Agency under contract nos. APVV–18–0070 and APVV-22-0078. David Janda was supported by the Palacký University Olomouc internal grant (IGA_FTK_2023_001). Aleš Gába and David Janda were supported by Czech Science Foundation (22-02392S). Aleš Gába and Petr Badura were supported by the project 'Research of Excellence on Digital Technologies and Wellbeing CZ.02.01.01/00/22_008/0004583' which is co-financed by the European Union.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets generated and analysed during the current study are not publicly available, although can be requested from the corresponding author.

ETHICS STATEMENT

This study was approved by the Ethics Committee of the Medical Faculty of Pavol Jozef Šafárik University, Košice (13/N2021).

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How to cite this article: Bakalár P, Janda D, Kostičová M, Kopčáková J, Kolarčik P, Badura P, et al. Sleep profiles and their associations with adiposity and cardiorespiratory fitness among adolescents. Acta Paediatr. 2025;114:1152–1160. https://doi.org/10.1111/apa.17537