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Physical Activity-Sleep Quality Relationships: Insights from Slovak Adolescents by Age and Gender

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Abstract

This study aims to provide insights into how physical activity is associated with sleep patterns in youth populations, in particular, Slovak adolescents, and how gender (boys vs. girls) and age (≤16 vs. ≥18) moderate this relationship, using an extreme-group comparison approach that excludes 17-year-olds to enhance contrast between developmental stages. Using a cross-sectional design, self-reported data were collected from 2504 (100%) high school students (aged 15–19; 45.6% boys, 54.4% girls) using the International Physical Activity Questionnaire-Short Form (IPAQ-SF) and the Pittsburgh Sleep Quality Index (PSQI). Participants aged 17 years were excluded from age-stratified analysis to create clearer separation between early/mid and late adolescence. The primary outcome was global sleep quality (PSQI > 5). Secondary outcomes included sleep duration and PSQI component scores. All other analyses (age- and gender-stratified comparisons and interaction models) were predefined as exploratory and hypothesis-generating to examine potential effect modification. Age-stratified analyses among girls showed that, within the low PA group, good sleep was reported by 37.7% of younger girls (≤16) and 28.6% of older girls (≥18). Among older girls, the proportion reporting good sleep increased to 49.8% in the high PA group (χ^2 = 29.16, $p < 0.001$). No consistent associations between PA and sleep quality were observed among boys; however, significant association was identified among younger boys (≤16 years), which was not observed in older boys. Logistic regression revealed a modest interaction between age and PA level in predicting sleep quality among girls (β = 0.346, $p = 0.049$), suggesting small age-dependent variation in the association. This effect should be interpreted cautiously given its borderline statistical significance. Component-level PSQI analyses showed that girls experienced higher rates of sleep disturbances (χ^2 = 91.40, $p < 0.001$), longer sleep latency (χ^2 = 26.71, $p < 0.001$), and greater daytime dysfunction (χ^2 = 79.90, $p < 0.001$). These findings provide region-specific evidence from Central and Eastern Europe and underscore the need for age- and gender-sensitive public health strategies targeting both physical activity promotion and better sleep outcomes, given their observed associations.

Keywords: adolescents; age and gender differences; physical activity; sleep quality

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1. Introduction

Adolescence represents an important window for establishing behaviors that are strongly associated with lifelong health. During this stage, individuals undergo physiological, psychological, and socio-emotional transformations that directly impact health routines such as physical activity (PA) and sleep [1,2]. Both PA and sleep are widely regarded as key components of adolescent well-being, affecting cognitive function, mood regulation, metabolic processes, and immune responses [3]. The World Health Organization (WHO) recommends that adolescents engage in at least 60 min of moderate-to-vigorous physical activity (MVPA) daily and 8–10 h of quality sleep nightly [4,5].

Alarmingly, adherence to these guidelines is steadily declining. A global study revealed that more than 80% of school-going adolescents fail to meet PA recommendations [5]. Simultaneously, studies indicate increasing sleep deprivation among adolescents, in particular, in urban settings, where academic stress, digital media consumption, and irregular routines have become the norm [6,7]. In Slovakia and the surrounding Central and Eastern European (CEE) regions, cultural and economic transitions have further amplified these trends [8,9].

Over the past decade, research has increasingly emphasized the potentially bidirectional relationships between PA and sleep, primarily demonstrated in longitudinal and experimental studies. Numerous studies, particularly in adult populations, suggest that regular PA is associated with more favorable sleep outcomes such as shorter sleep latency, longer duration, and higher efficiency, while insufficient sleep is associated with reduced physical vitality and motivation for movement [10–12]. However, findings among adolescents remain inconsistent. These inconsistencies may partly reflect insufficient control for key confounding variables. Prior research indicates that factors such as screen use, academic stress, chronotype, mental health, dietary patterns, and family environment are independently associated with both PA and sleep outcomes and may substantially influence observed relationships if not accounted for. For example, some findings indicate that MVPA is significantly associated with better sleep in middle adolescents [13], whereas others did not observe robust associations after adjusting for variables such as screen time and psychological stress [14]. Recent Slovak data also emphasize the role of sleep quality in preventing injuries during PA among adolescents, which points toward complex reciprocal mechanisms [15].

These divergent findings may be explained by methodological differences, including the use of self-reported versus objective data, variability in sample characteristics, or differences in how PA and sleep are measured. Another important factor is the omission of moderating variables such as age and gender, which are known to shape both sleep architecture and PA patterns during adolescence [16]. For this reason, advanced statistical models that include interaction effects, such as gender × PA or age × sleep, are essential to understand these dynamics and form the methodological basis for the current study [15].

Biological sex and age play important roles in shaping both PA patterns and sleep architecture during adolescence. Physiological changes during puberty, such as increased gonadal hormone levels, shifts in melatonin secretion, and circadian phase delay, interact with psychosocial stressors like academic pressure and screen exposure, leading to variability in both PA and sleep outcomes [17,18].

Gender differences in these behaviors are consistent across studies. Girls tend to report lower levels of MVPA and are more likely to experience subjective sleep complaints such as longer sleep latency, reduced satisfaction, and increased daytime sleepiness, compared to boys [19]. These gender gaps appear to widen during mid-to-late adolescence, where hormonal maturation interacts with social expectations and peer dynamics. Older adolescents (aged 18+) may exhibit exaggerated circadian shifts and diminished sleep quality, which often coincide with breakdowns in structured activity schedules as they transition from high schools into higher education or employment [20–22].

Understanding these developmental and sex patterns is not merely academic; it has practical implications for intervention design. Interventions that fail to account for biological sex and age-specific chronobiology may fall short in efficacy [23]. Therefore, stratified analyses and gender-responsive models, like those employed in the present study, are critical for developing tailored public health strategies [18,22].

Despite growing international evidence [5,11–13,19,24–28], there remains a dearth of high-quality, regionally specific data from CEE countries [15,29,30], where adolescent lifestyle patterns are increasingly affected by Westernization, digitalization, and academic pressures. Slovakia represents an under-investigated context, where local socioeconomic and cultural dynamics may shape adolescent behaviors differently than in Western Europe.

Therefore, the present study aims to provide insights into how PA is associated with sleep patterns in youth populations, in particular, Slovak adolescents. Special attention is given to two moderating variables: age (≤16 vs. ≥18) and gender (boys vs. girls). Using stratified analyses and logistic regression models with interaction terms, the study investigates how these factors shape sleep results. By integrating categorical data (e.g., PA) with continuous and ordinal sleep indicators, the research aims to examine associations between PA and sleep, acknowledging that potential bidirectional relationships cannot be determined because of the cross-sectional design. In doing so, it contributes region-specific, developmentally informed evidence that can support more effective and personalized public health interventions for adolescents in Central Europe. However, given the cross-sectional nature of the present study, the analysis is limited to identifying associations, and no conclusions regarding directionality or bidirectional effects can be drawn. To better capture developmental contrasts, the present study applies an extreme-group comparison design (≤16 vs. ≥18 years), intentionally excluding 17-year-olds. This approach reduces overlap between adjacent developmental stages and allows clearer interpretation of age-related differences, although it limits generalizability across the full adolescent age spectrum. To avoid fragmented statistical interpretation, the analyses were structured within predefined hierarchical frameworks distinguishing primary, secondary, and exploratory outcomes, with interaction effects evaluated within regression models rather than relying solely on parallel subgroup testing.

2. Materials and Methods

2.1. Study Design

This research employed a cross-sectional observational study design aimed at analyzing the associations between PA and sleep quality among Slovak adolescents. The study was non-interventional in nature, with no experimental manipulation, relying solely on self-reported data collected at a single time point. As such, the design does not allow for inference of causal or bidirectional relationships between PA and sleep variables.

2.2. Participants and Sampling

The sample consisted of 2504 adolescents from high schools, with 1371 students aged 16 years or younger (≤16; 54.8%) and 1133 students aged 18 years or older (≥18; 45.2%). Although the eligible age range was 15–19 years, the age-stratified analysis was designed to compare two predefined groups: younger adolescents (≤16 years) and older adolescents (≥18 years); therefore, participants aged 17 years were not included in age-group comparisons. This decision was made to implement an extreme-group comparison design, maximizing developmental contrast between early/mid adolescence (≤16 years) and late adolescence (≥18 years). While this approach improves the interpretability of age-related differences, it excludes transitional individuals and should be considered when interpreting the findings. Participants were selected through stratified random sampling procedures to ensure proportional representation across predefined strata. Stratification variables included gender (boys vs. girls), school year (1st–4th), school type (public, private,

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church-run), school specialization (grammar, vocational, conservatory), geographic region (Western vs. Eastern Slovakia), and residential setting (urban vs. rural). Within each stratum, participants were randomly selected using school-level student lists provided by participating institutions. The sampling frame was constructed using an official registry of Slovak high schools obtained through the Ministry of Education and regional school authorities. Schools were first categorized according to region, type, and specialization. Participating schools provided anonymized student enrollment lists, which served as the basis for random selection within each predefined stratum. This stratified approach ensured that the final sample closely reflected the demographic and educational structure of the Slovak adolescent population (Table 1).

Table 1. Socio-demographics of participants (N = 2504; 100%).

Socio-Demographics	Category	≤16 (N = 1371; 54.8%)	≥18 (N = 1133; 45.2%)
Age [years; M ± SD]	Boys	15.8 ± 0.2	18.4 ± 0.3
	Girls	15.6 ± 0.3	18.6 ± 0.2
Gender [N; %]	Boys	621; 45.3%	521; 45.9%
	Girls	750; 54.7%	612; 54.1%
Year [N; %]	1	664; 48.4%	-
	2	707; 51.6%	-
	3	-	559; 49.3%
	4	-	574; 50.7%
School type [N; %]	Public	914; 66.7%	742; 65.5%
	Private	328; 23.9%	265; 23.4%
	Church-run	129; 9.4%	126; 11.1%
School specialization [N; %]	Grammar	698; 50.9%	555; 49.0%
	Vocational	503; 36.7%	440; 38.8%
	Conservatory	170; 12.4%	138; 12.2%
School region [N; %]	Western	721; 52.6%	579; 51.1%
	Eastern	650; 47.4%	554; 48.9%
School residence [N; %]	Urban	973; 71.0%	815; 71.9%
	Rural	398; 29.0%	318; 28.1%

N = Number; % = Percentage; M = Mean; SD = Standard deviation.

In terms of age, boys in the ≤16 group had a mean age of 15.8 years (SD = 0.2), while those in the ≥18 group averaged 18.4 years (SD = 0.3). Girls were younger on average in the younger group (15.6 years, SD = 0.3) and older in the older group (18.6 years, SD = 0.2). Independent-samples *t*-tests confirmed statistically significant differences in age across groups for both boys ($t = -100.41$, $p < 0.001$) and girls ($t = -132.88$, $p < 0.001$), consistent with expected educational progression.

Gender distribution was balanced between groups. Among younger students (≤16), boys comprised 45.3% (N = 621) and girls 54.7% (N = 750). In the older group (≥18), boys represented 45.9% (N = 521) and girls 54.1% (N = 612). A chi-square test showed no significant difference in gender distribution between age groups, $\chi^2(1, N = 2504) = 0.09$, $p = 0.76$.

Regarding educational stage, students in the ≤16 category were enrolled in either the first (48.4%, N = 664) or second (51.6%, N = 707) year of high school. Those in the ≥18 group were in the third (49.3%, N = 559) or fourth (50.7%, N = 574) year. No statistical testing was needed here due to exact year-based grouping.

School type was distributed as follows: in the younger group, 66.7% (N = 914) attended public schools, 23.9% (N = 328) private schools, and 9.4% (N = 129) church-run schools; in the older group, the proportions were 65.5% (N = 742) public, 23.4% (N = 265) private, and 11.1% (N = 126) church-run. A chi-square analysis indicated no statistically significant difference in school type between age groups, χ^2(2, N = 2504) = 1.99, p = 0.37.

Academic (school) specialization was balanced. Grammar schools were the most common (≤16: 50.9%, N = 698; ≤18: 49.0%, N = 555), followed by vocational schools (≤16: 36.7%, N = 503; ≤18: 38.8%, N = 440) and conservatories (≤16: 12.4%, N = 170; ≤18: 12.2%, N = 138). Differences in specialization by age group were not statistically significant, χ^2(2, N = 2504) = 1.24, p = 0.54.

In terms of region, the sample was split between Western Slovakia (≤16: 52.6%, N = 721; ≥18: 51.1%, N = 579) and Eastern Slovakia (≤16: 47.4%, N = 650; ≥18: 48.9%, N = 554). Regional distribution was statistically equivalent between age groups, χ^2(1, N = 2504) = 0.49, p = 0.48.

Residential setting analysis showed that most students lived in urban areas (≤16: 71.0%, N = 973; ≥18: 71.9%, N = 815), while the remainder lived in rural areas (≤16: 29.0%, N = 398; ≥18: 28.1%, N = 318). No significant difference in urban–rural distribution was observed (χ^2(1, N = 2504) = 0.23, p = 0.63).

2.3. Data Collection and Measures

Data collection was conducted over a 6-month period, from January to June 2025, coinciding with the second half of the academic year. This time frame was chosen to reduce the potential influence of seasonal variability on PA and sleep behavior, while ensuring stable school attendance during standard curricular weeks. The study was implemented in Slovak high schools located across two administrative regions, Western and Eastern Slovakia (Table 1), to capture the regional, educational, and socio-demographic diversity of the adolescent population.

The study employed hybrid questionnaire administration methods to accommodate institutional preferences and maximize participation [31]. In schools opting for in-person data collection, students completed paper-based questionnaires during regular Physical Education (PE) classes. The questionnaire was administered under the direct supervision of the research team, and PE teachers were, on purpose, not present during the sessions to reduce potential bias and ensure student privacy. This protocol was particularly important given that a substantial portion of participants were under the age of 18, and the study required written parental or legal guardian consent in accordance with Slovak national ethical standards. In other schools, the questionnaire was distributed online via secure Microsoft Forms (Office 365, Microsoft Corp., Redmond, WA, USA), with individualized access provided through the national EduPage school information system [32]. In both administration formats, participation was entirely anonymous and voluntary. All students received standardized explanations of the study's objectives, confidentiality assurances, and their right to withdraw at any time without consequence. Informed consent was obtained from all participants prior to beginning the survey.

Participants were eligible for inclusion if they were between 15 and 19 years of age, enrolled full-time in Slovak high schools, and provided informed consent in accordance with ethical requirements, either personally if aged 18 or older, or jointly with a parent or legal guardian if younger than 18. Participants were excluded based on predefined criteria, including the following: (1) self-reported diagnosed sleep disorders or medical conditions limiting PA (2) incomplete questionnaires (defined as >10% missing responses on key variables); (3) implausible or inconsistent responses, such as reported sleep duration exceeding 15 h per night or below 3 h, and extreme or non-physiological MET values (>20,000 MET-min/week); (4) logical inconsistencies between related questionnaire items (e.g., reporting zero PA alongside high MET scores). In total, 123 questionnaires were excluded. Of these, 85 (69.1%) were excluded due to participants being aged 17 years, in accordance with the predefined extreme-group comparison design, while the remaining 38 (30.9%) were excluded due to data quality issues, including 22 (17.9%) incomplete questionnaires, 10 (8.1%) implausible values, and 6 (4.9%) logical inconsistencies.

The analytical sample (final) comprised 2504 adolescents, representing 95.3% of the total collected data. This sample size provided adequate statistical power to support the planned analyses. In particular, with N = 2504, the study was sufficiently powered ($\geq$95%) to detect medium effect sizes (Cohen's d = 0.3, OR = 1.5) in between-group comparisons and logistic regression models at a significance level of α = 0.05.

Self-reported data on PA and sleep behavior were collected using two internationally validated instruments: the Pittsburgh Sleep Quality Index (PSQI) and the International Physical Activity Questionnaire-Short Form (IPAQ-SF). Both tools were selected for their strong psychometric properties and suitability for adolescent populations. The Slovak-language versions used in this study were adapted through forward–backward translations and reviewed for cultural and linguistic appropriateness.

Measurement of PA was carried out using the IPAQ-SF, a widely used self-report instrument developed for international population surveillance among individuals aged 15–69 years. The IPAQ-SF includes seven items that capture the frequency (days/week) and duration (minutes/day) of activity performed in the previous seven days across three intensity levels: vigorous-intensity, moderate-intensity, and walking. An additional item records sedentary time during typical weekdays. Responses were converted to Metabolic Equivalent of Task (MET)–minutes per week using established scoring protocols (vigorous activity = 8 METs, moderate activity = 4 METs, walking = 3.3 METs). Total MET–minutes were computed by multiplying the reported minutes and days by the MET value assigned to each activity level. Participants were then categorized into three PA levels, low (below the 33rd percentile), moderate (33rd–66th percentile), and high (above the 66th percentile), based on the tertile distribution of MET scores across the sample. This approach enabled comparison of PA levels across age and gender groups and was used in subsequent statistical analyses [33]. However, it is important to note that these categories represent relative, within-sample comparisons rather than externally standardized or clinically meaningful PA levels. Unlike IPAQ scoring protocols that classify individuals into low, moderate, and high activity based on absolute MET thresholds or alignment with public health recommendations (e.g., WHO guidelines), the present tertile-based classification reflects the distribution of PA within this specific sample. Therefore, the labels "low," "moderate," and "high" PA should be interpreted cautiously, as they do not directly correspond to recommended activity levels or population-wide benchmarks, but rather indicate relative positioning within the study population.

Measurement of sleep quality was carried out using the PSQI, standardized and validated tool for assessing subjective sleep experiences over the past month. The PSQI includes 19 self-rated items organized into seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, sleep medication, and daytime dysfunction. Each component is scored on a scale from 0 to 3, with higher scores indicating greater sleep problems. The component scores are summed to yield a global PSQI score ranging from 0 to 21. In accordance with established guidelines, a cut-off score >5 was used to classify participants as having poor sleep quality, while scores $\leq$5 indicated good sleep quality [34].

2.4. Ethical Considerations

The study was conducted in full accordance with the ethical standards outlined in the Declaration of Helsinki [35]. Ethical approval was obtained from the Ethics Committee of the Artistic and Pedagogical Council of the Faculty of Performing Arts, Academy of Arts in Banská Bystrica (Approval No. 03, FMU-AU/26).

Participation in the study was voluntary, and all participants, as well as their legal guardians (for minors under the age of 18), provided informed consent before taking part. Participants were informed about the purpose of the research, the procedures involved, their right to withdraw at any time without penalty, and the measures in place to ensure confidentiality and anonymity.

2.5. Statistical Analysis

To ensure a coherent analytical strategy and limit risks of data-driven inference, analyses were conducted within predefined hierarchical frameworks. The primary outcome was global sleep quality (PSQI > 5), analyzed in relation to PA levels. Secondary outcomes included sleep duration and PSQI component scores. Exploratory analyses included subgroup comparisons stratified by age and gender, as well as interaction effects (PA $\times$ age), examined using regression models. This structure was applied to distinguish confirmatory from hypothesis-generating analyses and to improve interpretability.

Statistical analyses were conducted using IBM SPSS Statistics (Version 27.0, IBM Corp., Armonk, NY, USA). Analyses were performed in accordance with predefined hierarchical frameworks, prioritizing the primary outcome (global sleep quality), followed by secondary and exploratory analyses.

Descriptive statistics (means $\pm$ standard deviations, frequency, and percentage) were computed for all key data. Group differences in continuous variables (e.g., total PA and sleep duration) were assessed using independent samples *t*-tests as descriptive secondary analyses to characterize the sample.

Associations between categorical variables (PA level and sleep quality) were initially assessed using Pearson's chi-square tests (χ^2) as unadjusted exploratory analyses, intended to inform subsequent regression modeling

To examine predictors of sleep quality, binary logistic regression was applied with sleep quality (0 = good sleep [PSQI $\leq$ 5], 1 = poor sleep [PSQI > 5]) as the dependent variable, with good sleep serving as the reference category. PA level, age group, and the interaction term (PA $\times$ age) were entered as predictors. Age was treated as a categorical variable (0 = $\leq$16 years, 1 = $\geq$18 years), consistent with the predefined stratification used throughout the study. The exclusion of 17-year-olds ensured non-overlapping age categories, minimizing misclassification bias between the adjacent developmental stages. PA level was treated as an ordinal variable (0 = low, 1 = moderate, 2 = high), reflecting increasing levels of PA based on the tertile distribution of MET scores. This ordinal coding approach was chosen to preserve the inherent ranking of PA levels and to test for linear trends across increasing activity categories, while maintaining model parsimony. Additional analysis using dummy-coded PA variables was explored and yielded comparable patterns of results. Separate models were run for boys and girls. No additional covariates were included in the regression models. While preliminary analyses suggested no strong effects of available socio-demographic variables, several potentially important confounders—such as screen time, academic stress, chronotype, mental health, dietary patterns, and family context—were not measured and therefore could not be incorporated into the models. This limitation restricts the ability to isolate independent associations between PA and sleep outcomes. Regression coefficients (β) and corresponding *p*-values were calculated.

Kruskal–Wallis tests (*H*) were used as secondary exploratory analyses to assess differences in sleep duration categories across PA levels when assumptions for parametric analysis were not met.

Component-level analyses of PSQI were considered secondary and exploratory, given multiple comparisons across domains. Statistical tests were two-tailed, with the significance threshold set at $\alpha = 0.05$. Effect sizes were reported where applicable. The sample size was sufficient to detect medium effect sizes with high statistical power.

Given the number of secondary and exploratory analyses performed, results from these tests should be interpreted with caution due to potential inflation of Type I error. No formal correction for multiple comparisons was applied, as these analyses were considered hypothesis-generating; however, emphasis is placed on effect sizes and consistency of patterns rather than isolated *p*-values

3. Results

Results are presented according to the predefined analytical hierarchy. Findings for the primary outcome (global sleep quality) are presented first, followed by secondary outcomes and exploratory subgroup analyses. An analysis of total weekly PA (measured in MET-min/week) showed significant gender differences. Boys (M = 3547.09, SD = 980.76) had higher PA levels than girls overall ($t = 29.61$, $p < 0.001$). Age-specific comparisons revealed no significant difference in PA between younger (≤16 years) and older (≥18 years) boys ($t = 1.07$, $p = 0.287$), with means of 4192.62 ± 938.18 and 3991.85 ± 938.18 MET-min/week, respectively. In contrast, girls showed significant declines in PA with age. Younger girls (≤16) reported an average of 3380.58 ± 664.42 MET-min/week, while older girls (≥18) averaged 2717.49 ± 664.42 ($t = 4.99$, $p < 0.001$) (Table 2).

Table 2. Total METs by gender and age of participants (N = 2504; 100%).

Gender	Age	METs	*t*	*p*	Sign.
Boys [M ± SD]	≤16 ≥18	4192.62 ± 938.18 3991.85 ± 938.18	1.07	0.287	NS
Girls [M ± SD]	≤16 ≥18	3380.58 ± 664.42 2717.49 ± 664.42	4.99	6.7×10^{-7}	***
Gender [M ± SD]	-	3547.09 ± 980.76	29.61	1.0×10^{-192}	***

M = Mean; SD = Standard deviation; Sign. = Significance; NS = Not significant; *** = <0.001.

Among the full sample, 1106 adolescents (44.2%) had good sleep quality (PSQI ≤ 5), while 1398 (55.8%) reported poor sleep (PSQI > 5). No significant differences in sleep quality by age were found within gender groups: for boys, 52.5% of younger and 51.3% of older participants reported good sleep ($\chi^2 = 0.13$, $p = 0.718$); for girls, the rates were 35.5% and 40.4%, respectively ($\chi^2 = 3.23$, $p = 0.072$). However, significant gender differences emerged overall: boys had higher proportions of good sleep than girls ($\chi^2 = 50.65$, $p = 1.0 \times 10^{-12}$) (Table 3).

Table 3. Sleep quality by gender and age of participants (N = 2504; 100%).

Gender	Age	Good Sleep	Sleep Disorder	χ^2	*p*	Sign.
Boys [N; %]	≤16 ≥18	326; 52.5% 267; 51.3%	295; 47.5% 254; 48.7%	0.13	0.718	NS
Girls [N; %]	≤16 ≥18	266; 35.5% 247; 40.4%	484; 64.5% 365; 59.6%	3.23	0.072	NS
Gender [N; %]	-	1106; 44.2%	1398; 55.8%	50.65	1.0×10^{-12}	***

N = Number; % = Percentage; Sign. = Significance; NS = Not significant; *** = <0.001.

Associations between PA level (low, moderate, high) and sleep quality were assessed separately by gender and age using chi-square tests. Among younger boys (≤16), good sleep was reported by 42.8% in the low PA group, 55.2% in the moderate PA group, and 53.6% in the high PA group, indicating statistically significant differences (χ^2 = 13.02, p = 0.023). However, this association was not observed among older boys and was not supported by regression analyses, suggesting that the finding may be age-specific and exploratory in nature. For older boys (≥18), the association between PA and sleep quality was not statistically significant. Among girls, sleep quality differed across PA levels in both age groups. Within the low PA group, 37.7% of younger girls (≤16) and 28.6% of older girls (≥18) reported good sleep. In contrast, among older girls, 49.8% in the high PA group reported good sleep, indicating significant associations (χ^2 = 29.16, p < 0.001) (Table 4).

Table 4. Sleep quality and PA by gender and age of participants (N = 2504; 100%).

Gender	Age	PA	Good Sleep	Sleep Disorder	χ^2	p	Sign.
Boys [N; %]	≤16	Low	89; 42.8%	118; 57.2%	13.02	0.023	*
		Moderate	114; 55.2%	93; 44.8%			
		High	111; 53.6%	96; 46.4%			
	≥18	Low	105; 60.4%	69; 39.6%			
		Moderate	69; 39.4%	105; 60.6%			
		High	94; 54.4%	79; 45.6%			
Girls [N; %]	≤16	Low	94; 37.7%	156; 62.3%	29.16	0.000	***
		Moderate	73; 29.1%	177; 70.9%			
		High	98; 39.1%	152; 60.9%			
	≥18	Low	58; 28.6%	146; 71.4%			
		Moderate	49; 24.1%	134; 65.9%			
		High	102; 49.8%	102; 50.2%			
Gender [N; %]	-	-	1056; 42.2%	1448; 57.8%	21.35	2.3×10^{-5}	***

N = Number; % = Percentage; Sign. = Significance; * = <0.05; *** = <0.001.

Binary logistic regression models were used to examine predictors of poor sleep quality (reference = good sleep), including age group (≤16 vs. ≥18), PA level (ordinal), and the age × PA interaction. For boys, none of the predictors were statistically significant. The intercept was non-significant ($\beta = -0.078$, p = 0.710), as were age ($\beta = -0.086$, p = 0.784), PA level (β = 0.125, p = 0.313), and their interaction (β = 0.009, p = 0.957). Among girls, the interaction between age and PA was statistically significant (β = 0.346, p = 0.049). This corresponds to an odds ratio (*OR*) of approximately 1.41, indicating a modest increase in the odds of good sleep with higher PA among older girls compared to younger girls. However, given the borderline statistical significance, this interaction effect should be interpreted cautiously. Confidence intervals for the interaction term should be reported to further contextualize the precision of this estimate. The intercept was also significant ($\beta = -0.867$, p < 0.001), but the main effects of age ($\beta = -0.237$, p = 0.391) and PA (β = 0.182, p = 0.125) were not (Table 5).

Component-level analysis of the PSQI highlighted several gender and age effects. For subjective sleep quality, boys showed significant age differences (χ^2 = 9.65, p = 0.021), but girls did not. Significant gender difference was present overall (χ^2 = 27.84, p < 0.001), with boys reporting better subjective sleep. For sleep latency, there were no age differences within genders, but a significant overall gender difference was observed (χ^2 = 26.71, p < 0.001), with girls reporting longer latency. Sleep duration did not differ significantly between genders (χ^2 = 5.29, p = 0.151) or within either age group (χ^2 = 6.42, p = 0.092 in boys; χ^2 = 3.31, p = 0.345 in girls). Habitual sleep efficiency was consistently high across groups with no significant differences (χ^2 = 1.62, p = 0.653). For sleep disturbances, girls reported significantly more issues than boys (χ^2 = 91.40, p < 0.001), and a small but significant age effect was observed among girls (χ^2 = 8.32, p = 0.039). Sleep medication use was generally low, but a significant gender difference was found (χ^2 = 12.08, p = 0.007), with more frequent use among girls. Daytime dysfunction was significantly worse in girls than in boys (χ^2 = 79.90, p < 0.001), with no notable age differences within groups (Table 6).

Table 5. Logistic regression results predicting poor sleep quality (reference = good sleep) (N = 2504; 100%).

Gender	Category	β	p	Sign.
Boys	Intercept	−0.078	0.710	NS
	Age (≤16 vs. ≥18)	−0.086	0.784	NS
	PA (0 = Low to 2 = High)	0.125	0.313	NS
	PA × Age (≥18)	0.009	0.957	NS
Girls	Intercept	−0.867	0.000	***
	Age (≤16 vs. ≥18)	−0.237	0.391	NS
	PA (0 = Low to 2 = High)	0.182	0.125	NS
	PA × Age (≥18)	0.346	0.049	*

Sign. = Significance; NS = Not significant; * = <0.05; *** = <0.001.

Table 6. Sleep components by gender and age of participants (N = 2504; 100%).

Subjective Sleep Quality								
Gender	Age	0	1	2	3	χ^2	p	Sign.
Boys [N; %]	≤16	91; 14.7%	375;60.4%	119; 19.1%	36; 5.8%	9.65	0.021	*
	≥18	98; 18.8%	303; 58.2%	106; 20.4%	14; 2.6%			
Girls [N; %]	≤16	80; 10.7%	418; 55.7%	201; 26.8%	51; 6.8%	6.07	0.108	NS
	≥18	83; 13.6%	341; 55.7%	137; 22.4%	51; 8.3%			
Gender [N; %]	-	352; 14.1%	1437; 57.4%	653; 22.5%	152; 6.1%	27.84	0.000	***
Sleep latency								
Gender	Age	Σ0	Σ1–2	Σ3–4	Σ5–6	χ^2	p	Sign.
Boys [N; %]	≤16	157; 25.3%	255; 41.1%	155; 24.9%	54; 8.7%	0.67	0.879	NS
	≥18	140; 26.9%	214; 41.1%	127; 24.4%	40; 7.6%			
Girls [N; %]	≤16	145; 19.3%	283; 37.7%	227; 30.2%	96; 12.8%	1.25	0.741	NS
	≥18	129; 21.1%	236; 38.5%	173; 28.3%	74; 12.1%			
Gender [N; %]	-	581; 23.2%	992; 39.6%	674; 26.9%	257; 10.3%	26.71	0.000	***
Sleep duration								
Gender	Age	<5 h	5–6 h	6–7 h	>7 h	χ^2	p	Sign.
Boys [N; %]	≤16	32; 5.2%	53; 8.5%	232; 37.4%	304; 48.9%	6.42	0.092	NS
	≥18	31; 5.9%	56; 10.8%	217; 41.6%	217; 41.7%			
Girls [N; %]	≤16	49; 6.5%	89; 11.9%	313; 41.7%	299; 39.9%	3.31	0.345	NS
	≥18	40; 6.5%	68; 11.1%	231; 37.7%	274; 44.7%			
Gender [N; %]	-	150; 6.0%	266; 10.6%	992; 39.6%	1096; 43.8%	5.29	0.151	NS

Table 6. *Cont.*

Subjective Sleep Quality								
Habitual sleep efficiency								
Gender	Age	<65%	65–74%	75–84%	>85%	χ^2	*p*	Sign.
Boys [N; %]	≤16	19; 3.1%	22; 3.5%	51; 8.2%	529; 85.2%	4.64	0.200	NS
	≥18	20; 3.8%	13; 2.5%	59; 11.3%	429; 82.4%			
Girls [N; %]	≤16	24; 3.2%	20; 2.6%	67; 8.9%	640; 85.3%	2.48	0.478	NS
	≥18	17; 2.8%	23; 3.8%	47; 7.6%	525; 85.8%			
Gender [N; %]	-	80; 3.2%	78; 3.1%	225; 9.0%	2121; 84.7%	1.62	0.653	NS
Sleep disturbances								
Gender	Age	Σ0	Σ1–9	Σ10–18	Σ19–27	χ^2	*p*	Sign.
Boys [N; %]	≤16	52; 8.4%	472; 76.0%	88; 14.1%	9; 1.5%	2.62	0.454	NS
	≥18	38; 7.3%	403; 77.4%	77; 14.7%	3; 0.6%			
Girls [N; %]	≤16	24; 3.2%	505; 67.3%	194; 25.9%	27; 3.6%	8.32	0.039	*
	≥18	16; 2.6%	412; 67.3%	176; 28.8%	8; 1.3%			
Gender [N; %]	-	135; 5.4%	1803; 72.0%	521; 20.8%	45; 1.8%	91.40	0.000	***
Use of sleep medication								
Gender	Age	0	≤1/week	1–2/week	≥3/week	χ^2	*p*	Sign.
Boys [N; %]	≤16	568; 91.5%	26; 4.2%	9; 1.5%	18; 2.9%	3.61	0.307	NS
	≥18	483; 92.7%	25; 4.8%	6; 1.2%	7; 1.3%			
Girls [N; %]	≤16	667; 88.9%	44; 5.8%	19; 2.5%	21; 2.8%	2.62	0.454	NS
	≥18	529; 86.5%	46; 7.5%	14; 2.3%	23; 3.7%			
Gender [N; %]	-	2251; 89.9%	140; 5.6%	48; 1.9%	65; 2.6%	12.08	0.007	***
Daytime dysfunction								
Gender	Age	Σ0	Σ1–2	Σ3–4	Σ5–6	χ^2	*p*	Sign.
Boys [N; %]	≤16	81; 13.1%	256; 41.2%	220; 35.4%	68; 10.3%	1.00	0.801	NS
	≥18	75; 14.4%	207; 39.7%	191; 36.7%	48; 9.2%			
Girls [N; %]	≤16	43; 5.7%	241; 32.1%	322; 42.9%	145; 19.3%	4.43	0.218	NS
	≥18	43; 7.1%	222; 36.3%	235; 38.4%	111; 18.2%			
Gender [N; %]	-	253; 10.1%	934; 37.3%	962; 38.4%	356; 14.2%	79.90	0.000	***

N = Number; % = Percentage; Sign. = Significance; * = <0.05; *** = <0.001.

Kruskal–Wallis tests examined the relationships between PA level and sleep duration categories. Among adolescents aged ≤ 16, no significant associations were found for either boys (H = 0.11, p = 0.947) or girls (H = 3.55, p = 0.169). However, among adolescents aged ≥18, significant differences in sleep duration were observed. In older boys, 73.5% of those in the high PA group reported sleeping more than seven hours, compared to just 3.3% in the low PA group (H = 12.06, p = 0.002). Among older girls, 53.3% in the high PA group slept more than seven hours, versus 8.1% in the low PA group (H = 14.89, $p < 0.001$), demonstrating clear positive associations between PA and sleep duration in older adolescents (Table 7).

Table 7. Relationships between sleep duration and PA by gender and age of participants (N = 2504; 100%).

Gender	Age	PA	<5 h	5–6 h	6–7 h	>7 h	*H*	*p*	Sign.
Boys [N; %]	≤16	Low	220; 35.5%	62; 10.0%	48; 7.7%	49; 7.9%			
		Moderate	81; 13.1%	137; 22.0%	163; 26.2%	152; 24.4%	0.11	0.947	NS
		High	301; 48.4%	422; 68.0%	410; 66.1%	420; 67.7%			
	≥18	Low	51; 9.7%	65; 12.5%	65; 12.0%	63; 3.3%			
		Moderate	235; 45.2%	158; 30.4%	110; 21.2%	121; 23.2%	12.06	0.002	***
		High	235; 45.1%	297; 57.1%	348; 66.8%	383; 73.5%			
Girls [N; %]	≤16	Low	64; 8.5%	61; 8.1%	74; 9.9%	73; 9.7%			
		Moderate	399; 53.2%	288; 38.4%	271; 36.1%	218; 29.1%	3.55	0.169	NS
		High	287; 38.3%	401; 53.5%	405; 54.0%	459; 61.2%			
	≥18	Low	78; 12.8%	100; 16.4%	85; 13.9%	50 8.1%			
		Moderate	361; 59.0%	311; 50.8%	280; 45.7%	236; 38.6%	14.89	0.000	***
		High	173; 28.2%	201; 32.8%	247; 40.4%	326; 53.3%			
Gender [N; %]	-	-	51.6; 24.7%	52.0; 24.9%	52.1; 24.9%	52.9; 25.5%	1.06	0.302	NS

N = Number; % = Percentage; Sign. = Significance; *** = <0.001.

4. Discussion

This study aimed to provide insights into how PA is associated with sleep patterns in youth populations, in particular, Slovak adolescents, and how gender (boys vs. girls) and age (≤16 vs. ≥18) moderate this relationship. The results confirm complex, multi-layered associations that align with, but also extend, existing global findings. A descriptive pattern was observed among older girls (≥18) who report high levels of PA: a descriptive pattern was observed in which older girls (≥18) reporting higher PA also reported better sleep outcomes on several indicators. However, these observations should be interpreted cautiously, as they are based on subgroup comparisons and not consistently supported across all analyses. This supports previous work showing that adolescent girls, although often at higher risk of sleep problems, may report more favorable sleep outcomes in relation to PA levels than their male peers [25,27,36,37]. These findings are consistent with recent evidence emphasizing the role of circadian regulation and mental health in the PA–sleep relationship. Higher levels of PA have been associated with better sleep outcomes, potentially reflecting physiological and psychological pathways suggested in prior research [38]. This multidimensional mechanism may help explain why some variation in associations was observed in specific subgroups, such as older adolescent girls in the present study. Importantly, the findings should be interpreted in light of the predefined analytical hierarchy, where regression-based interaction models represent the primary inferential evidence, while subgroup comparisons and component-level analyses are exploratory.

In our sample, logistic regression analysis revealed that the interaction between PA level and age was significantly associated with sleep quality for adolescent girls ($\beta = 0.346$, $p = 0.049$), but not for boys. This finding indicates statistically significant but modest interactions between age and PA among girls [39]. Rather than suggesting a clear developmental threshold or critical period, the result may reflect gradual or context-dependent variations in the association between PA and sleep outcomes [13,25].

Sleep quality differences were evident at the descriptive level: while 49.8% of older girls (≥18) in the high PA group reported good sleep, this compares to 28.6% in the low PA group and 24.1% in the moderate PA group. This is consistent with earlier findings showing that adolescent girls who report higher PA levels also report fewer subjective complaints of fatigue and better emotional regulation [40,41]. In contrast, boys showed no clear gradient in PA and sleep associations, and some paradoxical trends emerged, such as older boys (≥18) in the low PA group reporting better sleep than those in the high PA group. While this finding runs counter to most global literature, this pattern cannot be explained within the scope of the present data and should not be attributed to specific mechanisms, as relevant variables such as academic stress, electronic media use, and chronotype were not measured [42].

No consistent relationships between PA and sleep quality were observed among boys. Although a significant association was identified among younger boys (≤16 years) in subgroup analysis, this pattern was not replicated in older boys nor supported by regression models. Late chronotype adolescents, in particular, boys, tend to delay sleep onset and have fragmented sleep, regardless of PA engagement [43,44]. In the present study, subjective sleep quality among boys remained stable across age and PA, suggesting that sleep patterns may be less strongly associated with PA in this group.

Our component-level analysis of the PSQI revealed that girls reported significantly worse outcomes than boys in several domains: sleep latency, sleep disturbances, and daytime dysfunction. These results align with large-scale epidemiological studies, which have shown that adolescent girls are more likely to suffer from delayed sleep onset, poor sleep continuity, and daytime fatigue [20,22,45].

Sleep latency differed by gender. Over 40% of girls aged ≥18 reported needing more than 30 min to fall asleep, compared to 24% of boys in the same category. This echoes findings that emotional dysregulation and mobile phone dependency prolong sleep latency among adolescent girls [26,46]. Daytime dysfunction, measured by subjective alertness and concentration, was significantly worse in girls (χ^2 = 79.90, p < 0.001). These complaints are not merely psychological; research suggests that hormonal shifts during adolescence are associated with both the subjective and objective experience of fatigue [17,47].

The observed gender differences in subjective sleep quality and sleep disturbances align with existing research showing that girls often experience more fragmented sleep and shorter sleep time despite making greater efforts to improve sleep hygiene [48,49]. Poor sleep among physically active adolescent girls has been associated with an increased risk of sports-related injuries and reduced motivation to maintain regular PA, potentially reflecting bidirectional associations, although this cannot be determined here [15].

Available findings offer novel insights from Slovakia, the CEE country with limited representation in adolescent sleep-PA research. Previous CEE-based studies, such as those in Czechia [7,49,50] and Poland [8,51,52], have documented rising trends in adolescent sleep deprivation and declining PA.

Our data show that 55.8% of Slovak adolescents experience poor sleep, higher than the global average (±40%) reported in meta-analyses [11]. The high prevalence may relate to regional challenges such as academic pressure, economic uncertainty, and digitalization, all factors known to reduce both PA and sleep duration [53].

Slovakia's unique educational transitions, from secondary to tertiary schooling, may be contributing factors. This transition period is characterized by lifestyle destabilization, increased screen exposure, and changes in PA scheduling [9]. Our findings of reduced PA and worsening sleep among older adolescents mirror this, in particular, in girls

From a methodological standpoint, our use of self-reported instruments (IPAQ-SF, PSQI) is consistent with global best practices, but still subject to bias. While these tools are validated for adolescent populations [33,34], future research should incorporate actigraphy or wearable technology for more objective sleep tracking [54].

The cross-sectional nature of this study precludes any inference regarding causality or directionality between PA and sleep. Given the cross-sectional design and reliance on self-reported data collected at a single time point, all findings should be interpreted strictly as associations, and no causal or directional inferences can be made. Although prior longitudinal and experimental studies suggest potential bidirectional relationships, the present findings should be interpreted strictly as associative [10,12]. Regression models did not adjust for potential socio-demographic confounders (e.g., school type or region), which may influence both PA and sleep outcomes.

Unmeasured variables such as nutrition, family structure, and mental health deserve attention. Some evidence suggests that adolescents' beliefs about their PA levels may influence sleep quality more than their actual, objectively measured activity [13,36,55]. This indicates that future models should incorporate psychological constructs alongside behavioral data. A methodological limitation of this study is the exclusion of 17-year-old participants from age-stratified analyses. Although this was carried out to enhance contrast between developmental stages using an extreme-group comparison approach, it reduces representativeness across the full adolescent age range (15–19 years). Adolescents aged 17 may exhibit transitional behavioral patterns that are not captured in the present analysis. Future research employing longitudinal or experimental designs (e.g., cross-lagged panel models or intervention studies) is required to clarify the directionality and potential bidirectional dynamics between PA and sleep in adolescents.

5. Conclusions

This study highlights the relationships between PA and sleep quality among Slovak adolescents, emphasizing the critical role of gender (boys vs. girls) and age ($\leq$16 vs. $\geq$18) as moderating variables. More than 50% of adolescents reported poor sleep quality, with girls, in particular, older ones ($\geq$18), being disproportionately affected; however, older girls who reported high levels of PA also reported better sleep outcomes, both globally and in terms of individual sleep components such as sleep duration and daytime functioning. This suggests that higher PA levels are associated with better sleep health in this subgroup. No consistent association between PA and sleep was observed among boys, although a significant relationship was identified in younger boys that was not evident across other analyses. Some findings, such as older boys ($\geq$18) in the low PA group reporting better sleep, highlight the potential influence of unmeasured variables, including psychological stress or chronotype differences. These results suggest that adolescent boys' sleep quality may be less strongly associated with variations in PA and more dependent on other behavioral or biological factors.

Component-level analyses reinforced existing gender differences. Girls consistently reported longer sleep latency, more sleep disturbances, and greater daytime dysfunction. These outcomes support previous literature indicating that adolescent girls face greater vulnerability to sleep problems, despite often engaging in healthier routines. The interaction effects observed in logistic regression modeling (significant only in girls) suggest the developmental window during which PA shows stronger associations with sleep outcomes, in particular, during late adolescence.

Available data suggest the regional implications. Compared to global averages, Slovak adolescents appear to suffer from higher prevalence of poor sleep. Cultural transitions, academic pressures, and increasing digital media exposure in CEE may be intensifying these challenges. In light of this, the study contributes valuable, region-specific evidence to the global conversation on adolescent health.

While the cross-sectional design limits causal inference, the patterns observed align with existing longitudinal and interventional research. Future work should integrate objective measurements (e.g., actigraphy), assess psychological mediators, and include qualitative approaches to better understand motivational drivers behind adolescent PA and sleep behaviors. Tailored interventions that account for age, gender, and socio-cultural context appear essential for addressing the dual public health challenges of physical inactivity and poor sleep among adolescents in CEE. These findings reflect associations only, and no conclusions regarding causal or bidirectional relationships can be drawn due to the cross-sectional design. Future research should include the full adolescent age spectrum, particularly mid-adolescents (e.g., 17-year-olds), to better capture developmental transitions.

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Abbreviations

The following abbreviations arde used in this manuscript:

PA	Physical activity
WHO	World Health Organization
MVPA	Moderate-to-vigorous physical activity
CEE	Central and Eastern Europe

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