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# Sleep characteristics and adolescent physical activity-related injuries in sports clubs, leisure time and schools

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Received 17 April 2023

Accepted 8 October 2023

## ABSTRACT

**Objective** Sleep has been identified as an important factor in relation to physical activity-related injury (PARI) in adolescents. The study aimed to explore associations between sleep duration, sleep problems and PARI among Slovak adolescents in three different settings: sports clubs, leisure time and schools.

**Methods** We analysed data from the cross-sectional Health Behaviour in School-aged Children study conducted in 2022 on a representative sample of 10 163 Slovak adolescents aged from 10.5 to 18.3 (mean age 13.4 (SD=1.5); 50.9% boys). Data were collected through self-administered online questionnaires completed by respondents in schools during the classes. Multiple logistic regression models were used to assess associations between sleep duration during schooldays and weekends, sleep problems and PARI in sports clubs, leisure time and schools.

**Results** Adolescents with normal sleep duration during schooldays and those who reported no problems with falling asleep, waking up at night and day sleepiness had a higher chance of not being injured during PA in sports clubs, leisure time and schools compared with adolescents with short sleep duration and sleep problems. Sufficient sleep duration during the weekend increased the probability of not having PARI in leisure time and schools, with the strongest association between long sleep duration and PARI in leisure time.

**Conclusion** Good sleep quality and sufficient sleep duration were found to play a protective role in relation to PARI in adolescents. The findings suggest implementing sleep interventions in PARI prevention programmes, which must be considered a key component of adolescent PA promotion.

## INTRODUCTION

Optimal sleep and regular physical activity (PA) promote physical and mental health, adequate functioning and well-being of adolescents.<sup>1–3</sup> However, despite the health benefits of PA, participation in PA might increase the risk of injuries.<sup>4,5</sup> PA-related injury (PARI) resulting from PA in sports clubs, physical education in schools or leisure time is the most common cause of non-fatal unintentional injuries in adolescents.<sup>6–8</sup> The overall incidence of PARI among adolescents varies between 18% and 65%, with higher rates in boys, sports team members and younger adolescents.<sup>5,7,9–11</sup> In addition, PARI can have negative consequences on adolescent health and well-being and cause financial and economic

## WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Physical activity-related injury (PARI) is adolescents' most common cause of non-fatal unintentional injuries, with sleep playing an important role in its aetiology.

## WHAT THIS STUDY ADDS

⇒ Most previous studies have focused on the link between sleep and adolescents' PARIs in sports clubs. The study explores the protective roles of sleep duration and sleep quality in relation to PARIs in three settings: sports clubs, leisure time and schools. Moreover, this is the first study of its kind in Central and Eastern Europe in a representative sample of adolescents.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The study brings valuable information for trainers, teachers, caregivers and policy-makers about the importance of optimal sleep duration and good sleep quality in the prevention of adolescent PARI in sports clubs, leisure time and schools.

costs related to treating injuries, and losing productivity in terms of both short impact on parents' work and long impact on future adolescents' employability.<sup>7,12</sup>

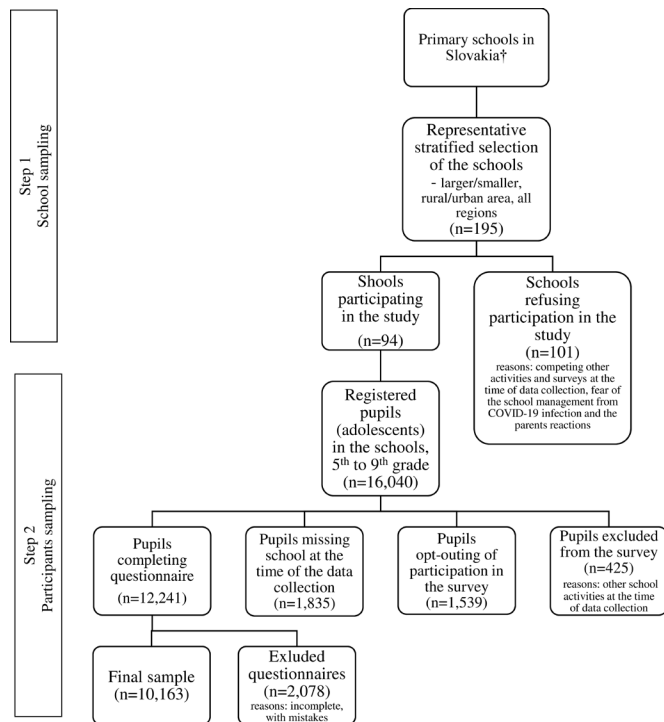
PA takes place in various settings characterised by specific physical and social contexts that are likely to influence the amount and type of PA. Therefore, understanding their influence on PA can help to optimise interventions in those settings.<sup>13</sup> In this study, we focused on PARI in three settings: sports clubs (organised PA in clubs), leisure time (PA performed during free time, not in sports clubs) and schools (physical education, sports activities organised by school).

The aetiology of PARI is multifactorial, involving both intrinsic (eg, age, gender, injury history, perceived stress and other psychological variables) and extrinsic risk factors (eg, environment, sports equipment, sports rules)<sup>14</sup>, with sleep playing an important role. Adolescents with insufficient sleep duration and sleep problems are more likely to experience PARI.<sup>8,15,16</sup> Regarding optimal sleep duration, most of the studies refer to the sleep duration recommendations of the National Sleep Foundation<sup>17</sup> or the American Academy of Sleep Medicine.<sup>18</sup> Evidence shows that 30%–50% of



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**To cite:** Kosticova M, Kopcakova J, Vaskova M, et al. *Inj Prev* Epub ahead of print: [please include Day Month Year]. doi:10.1136/ip-2023-044936



**Figure 1** Flow chart of the study design sampling. † The primary education system (called elementary school/primary school corresponding to primary education) in Slovakia is formally divided into two 'stages'. First primary education stage—6–10 years (1st–4th grades). Second primary education stage—age 10–15 (5th–9th grades), this 'stage' can be spent either in a 9-year primary school or in an 8-year gymnasium and this is the focus of HBSC study. However, also older adolescents can attend the second stage of primary education for various reasons (disabilities, learning difficulties) and they were also included in our study. HBSC, Health Behaviour in School-aged Children.

adolescents sleep less than recommended,<sup>19, 20</sup> and the prevalence of sleep problems ranges from 10% to 30%,<sup>20–22</sup> increasing to 50% during the COVID-19 pandemic.<sup>23, 24</sup>

Even though sleep plays an important role in relation to adolescent PARI, the evidence is scarce, and further research on this topic is recommended.<sup>15</sup> Most of the studies have focused on the link between sleep and injuries in sports clubs, and there is limited evidence on the role of sleep in relation to PARI in other settings. Moreover, the role of sleep problems in relation to PARI is also an under-researched topic. Therefore, the study aimed to explore associations between sleep duration, various sleep problems and PARI in a representative sample of Slovak adolescents in three settings: sports clubs, leisure time and schools. We hypothesised that sufficient sleep duration and good sleep quality (no sleep problems) decreased the probability of adolescents' PARI in each setting.

## METHODS

### Study design, setting and participants

We used data from the Health Behaviour in School-aged Children (HBSC) study conducted in 2022 in Slovakia. HBSC study is a WHO collaborative, cross-national study conducted every 4 years. The study used a two-step sampling to obtain a representative sample. Figure 1 presents the flow chart of the study sampling design. In the first step, 195 larger and smaller primary schools located in rural and urban areas from all regions in Slovakia were asked to participate. These were randomly selected

from a list of all eligible schools in Slovakia obtained from the Slovak Institute of Information and Prognosis for Education. The school response rate (RR) was 45%. In the second step, we obtained data from 10 163 adolescents (RR=63%) from the 5th to 9th grades of primary schools in Slovakia, aged 10.5–18.3 years old (mean age 13.4; 50.9% boys). Data were collected through self-administered online questionnaires completed by pupils at school during the classes, in the presence of researchers or research assistants. Based on the HBSC international protocol, the items in the questionnaire were divided into three modules: mandatory (mandatory for all countries participating in the HBSC study), optional (optional to choose by country) and national specific (designed by country). In the Slovak version of the HBSC questionnaire 2022, questions on sleep duration were chosen from the optional module, and questions on sleep problems and PARI were designed as national specific questions.

### Participants and public involvement

The focus group interviews with adolescents and stakeholders (paediatricians, policy-makers, researchers, public health experts, teachers, trainers) were conducted to identify the research questions and design the questions and items in the HBSC questionnaire. Then, cognitive interviews with adolescents were conducted to explore the understanding and the clarity of the questions in the questionnaire. Finally, the pilot study including 235 adolescents from 5 schools was performed to design the final version of the questionnaire. The findings of the Slovak HBSC study 2021/2022 were summarised in the national report presented to the public and stakeholders at the press conference in September 2023, published on the website and distributed to the schools participating in the study.

### Measures

Sleep duration during schooldays and weekends was calculated by estimating the time between bedtime and wake-up time. Bedtime was measured with the items: 'At what time do you usually go to bed, when you are going to school the morning after/during the weekend?' Wake-up time was measured with the items: 'At what time do you usually get up, when you are going to school/during the weekend?'. Hourly cut-offs for short and long sleep duration for different age groups of adolescents were set up based on the recommendations for research in paediatric sleep<sup>25</sup> and are presented in table 1. Sleep duration between the hourly cut-offs for short and long sleep was coded as 'normal'.

Sleep problems were measured by four items assessing the occurrence of four sleep problems: problems with falling asleep in the evening, waking up at night, waking up in the morning and feeling rested and day sleepiness. The response categories indicating how frequently during the last month the problems had occurred were: 'never', 'less than once a week', 'once or two times per week' and 'three and more times per week'. Responses for specific sleep problems were dichotomised into two categories: adolescents with no problem ('never' and 'less than once a week') versus adolescents with a problem at least once per week versus ('once or two times per week' and 'three and more times per week').

PARIs were measured with three questions assessing the occurrence of injuries during PAs in sports clubs, leisure time and school, which were adopted from the Finnish National Physical Activity Behaviour Study for Children and Adolescents study.<sup>7, 26</sup> The questions were back translated into English and consequently back translated into Slovak and piloted before the main data collection. The formulation of the questions was as

**Table 1** Recommended hourly cut-offs for short and long sleep in adolescents<sup>25</sup>

Age (years)	Cut-off for short sleep (hour)	Cut-off for long sleep (hour)
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

follows: ‘During the past year, have you had an injury while you have participated in sports clubs activities?’, ‘During the past year, have you had an injury while you have participated in leisure-time physical activity (not in a sports club)?’ and ‘During the past year, have you had an injury while you have participated in physical education at school or in supervised academic sports?’. The response categories were ‘no’, ‘once’, ‘twice’ and ‘three times and more’. Responses for injuries in each specific setting were dichotomised into two categories—adolescents with no injury and adolescents with injury (‘once’, ‘two times’ and ‘three and more times’). No definition of injury was provided in the questionnaire. The question about sports club injuries was only asked from the respondents who had reported participating in sports club activities in an earlier question (45.3%). Questions regarding leisure-time PA and school-based PA injuries were asked from all respondents.

## Statistical analysis

First, we described the main sample characteristics using frequency tables. Second, we used univariate binary logistic regression analysis to assess the crude associations of each of the four sleep problems (model 1) with PARI in three different settings (sports club, leisure time and school). Then, we added sleep duration during the schooldays and weekends in the model (model 2) and explored the association with injuries and the modification of the adjusted associations of sleep problems with injuries. Finally, we adjusted regression models for the effect of gender (model 3) and age (model 4).

Statistical analyses were performed using the statistical software package IBM SPSS V.23 (IBM, Released 2015. IBM SPSS Statistics for Windows, V.23.0., IBM).

## RESULTS

### Baseline characteristics

Table 2 shows the basic descriptive statistics of the studied variables for the whole sample, stratified by gender.

PARI was reported by 55.1% of adolescents who attended sports clubs. More than 40% of adolescents reported being injured during PA in their leisure time, and almost 30% in school. Boys had a significantly higher chance of being injured in sports clubs and school than girls during PA. The most common sleep problems were problems with waking up in the morning and feeling rested and day sleepiness, which occurred at least once a week in more than 50% of adolescents. Sleep problems were more common in girls. Short sleep duration was identified in 39.7% of adolescents during schooldays and only in 14.6% of adolescents on weekends.

**Table 2** Descriptive statistics of studied variables stratified by gender (Slovakia, 2022, N=10 163, mean age 13.4 years)

Characteristics		Whole sample	Boys	Girls	Pearson $\chi^2$ value	P value
		n (%)	n (%)	n (%)		
PARI						
Sports clubs	With injury	2316 (55.1)	1412 (60.4)	904 (48.4)	59.874	<0.0001
	No injury	1888 (44.9)	926 (39.6)	962 (51.6)		
Leisure time	With injury	3971 (42.9)	2169 (46.7)	1802 (39.1)	53.714	<0.0001
	No injury	5285 (57.1)	2480 (53.3)	2805 (60.9)		
School	With injury	2521 (27.9)	1290 (28.5)	1231 (27.4)	1.489	0.222
	No injury	6500 (72.1)	3233 (71.5)	3267 (72.6)		
Sleep problems						
Problem with falling asleep	At least once a week	3145 (31.6)	1222 (24.2)	1923 (39.2)	259.237	<0.0001
	No problem	6799 (68.4)	3822 (75.8)	2977 (60.8)		
Waking up at night	At least once a week	2486 (25.2)	963 (19.3)	1523 (31.3)	189.811	<0.0001
	No problem	7377 (74.8)	4036 (80.7)	3341 (68.7)		
Problem with waking up in the morning and feeling rested	At least once a week	5030 (51.1)	2142 (42.9)	2888 (59.5)	271.394	<0.0001
	No problem	4815 (48.9)	2850 (57.1)	1965 (40.5)		
Day sleepiness	At least once a week	5019 (50.9)	2035 (40.7)	2984 (61.3)	417.922	<0.0001
	No problem	4840 (49.1)	2959 (59.3)	1881 (38.7)		
Sleep duration*						
Schooldays	Short	3936 (39.7)	1876 (37.2)	2060 (42.2)	26.031	<0.0001
	Normal	5957 (60)	3143 (62.4)	2814 (57.6)		
	Long	31 (0.3)	19 (0.4)	12 (0.2)		
Weekends	Short	1347 (14.6)	781 (16.5)	566 (12.6)	52.488	<0.0001
	Normal	5851 (63.4)	3035 (64.1)	2816 (62.8)		
	Long	2026 (22)	921 (19.4)	1105 (24.6)		

\*Sleep duration was calculated using the cut-offs for short and long sleep duration from Sawyer *et al.*<sup>25</sup>

PARI, physical activity-related injury.

**Table 3** The associations of sleep problems and sleep duration with PARI in sports clubs and the moderation by age and gender based on multiple logistic regression (Slovakia, 2022, mean age 13.4 years)

Independent variables	PARI in sports clubs (no injuries†)				
	Crude effect OR (95% CI)	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)	Model 4 OR (95% CI)
Sleep problems					
Sleep problems more than once a week	Ref.	Ref.	Ref.	Ref.	Ref.
Problems with falling asleep (less than once a week)	1.37 (1.20 to 1.58)***	1.25 (1.07 to 1.46)**	1.23 (1.05 to 1.44)*	1.32 (1.12 to 1.55)***	1.32 (1.12 to 1.55)***
Waking up at night (less than once a week)	1.58 (1.36 to 1.83)***	1.42 (1.21 to 1.68)***	1.40 (1.19 to 1.66)***	1.45 (1.23 to 1.72)***	1.45 (1.23 to 1.72)***
Problem with waking up in the morning and feeling rested (less than once a week)	1.18 (1.05 to 1.34)**	0.93 (0.80 to 1.08)	0.91 (0.79 to 1.06)	0.95 (0.82 to 1.10)	0.95 (0.82 to 1.11)
Day sleepiness (less than once a week)	1.31 (1.16 to 1.48)***	1.20 (1.03 to 1.39)*	1.17 (1.00 to 1.36)*	1.28 (1.10 to 1.50)***	1.31 (1.12 to 1.53)***
Sleep duration‡, school days					
short	Ref.	--	Ref.	Ref.	Ref.
normal	1.44 (1.26 to 1.63)***	--	1.35 (1.17 to 1.55)***	1.37 (1.19 to 1.58)***	1.37 (1.19 to 1.58)***
long	0.96 (0.31 to 2.94)	--	0.79 (0.23 to 2.72)	0.87 (0.25 to 3.02)	0.86 (0.24 to 2.99)
Sleep duration, weekends					
Short	Ref.	--	Ref.	Ref.	Ref.
Normal	1.32 (1.09 to 1.59)**	--	1.13 (0.93 to 1.38)	1.04 (0.85 to 1.27)	1.03 (0.84 to 1.27)
Long	1.22 (0.98 to 1.53)	--	1.09 (0.87 to 1.38)	1.00 (0.79 to 1.26)	0.98 (0.77 to 1.24)
Gender (girls vs boys)	1.62 (1.43 to 1.83)***	--	--	1.89 (1.65 to 2.17)***	1.91 (1.66 to 2.20)***
Age (continuous)	0.99 (0.95 to 1.03)	--	--	--	1.03 (0.98 to 1.08)

Models 1–4: Univariate binary logistic regression analysis was used to assess the crude associations of each of the four sleep problems (model 1) with PARI. Then, we added sleep duration during the schooldays and weekends in the model (model 2) and explored the association with PARI and the modification of the adjusted associations of sleep problems with PARI. Finally, we adjusted regression models for the effect of gender (model 3) and age (model 4).  
\*p<0.05, \*\*p<0.01, \*\*\*p<0.001.  
†No injury was used as the dependent variable. The table presents the associations between sufficient sleep duration (normal and long sleep) good sleep quality (no sleep problems) and the likelihood of not having PARI (no injury).  
‡Sleep duration was calculated using the cut-offs for short and long sleep duration from Sawyer *et al.*<sup>25</sup>  
PARI, physical activity-related injury.

Tables 3–5 present the associations from multiple logistic regression models of sleep problems and sleep duration with PARI in three different settings: sports clubs, leisure time and schools. We explored the protective roles of sufficient sleep duration (normal and long sleep during school days and weekends) and good sleep quality (no sleep problems) in relation to PARI, with ‘no injury’ being a dependent variable.

### Associations between sleep duration, sleep problems and PARI in sports clubs

Table 3 presents the associations of sleep problems and sleep duration with PARI in sports clubs. The results of model 1 show that not having problems with waking up at night (OR 1.42, 95% CI 1.21 to 1.68), falling asleep (OR 1.25, 95% CI 1.07 to 1.46) and day sleepiness (OR 1.20, 95% CI 1.03 to 1.39) increased the probability of not having injuries. In the next step, we added sleep duration to the model (model 2), and even though specific sleep problems remain significant, the presented ORs decreased slightly, suggesting potential modification. We also found sleep duration during school days to be significantly associated with PARI in sports clubs, with normal sleep duration increasing the probability of not having injuries (OR 1.35, 95% CI 1.17 to 1.55). No significant association was found between sleep duration during weekends and PARI in sports clubs. After adding gender to the model (model 3), the ORs for sleep problems and sleep duration during school days increased slightly,

suggesting potential mediation. We also found that girls have almost two times higher chance of not being injured than boys (OR 1.89, 95% CI 1.65 to 2.17). Finally, we added age in the model (model 4) without affecting the above-mentioned associations or the probability of PARI in sports clubs.

### Associations between sleep duration, sleep problems and PARI in leisure time

Table 4 presents the associations of sleep problems and sleep duration with PARI in leisure time. Model 1 shows that not having difficulties with falling asleep (OR 1.25, 95% CI 1.13 to 1.39) and waking up at night (OR 1.39, 95% CI 1.25 to 1.54) significantly increased the probability of not having injuries in leisure time. In the next step, we added sleep duration in the model (model 2) with no significant interactions with sleep problems. We also found that normal sleep duration during school days (OR 1.18, 95% CI 1.08 to 1.30) and normal (OR 1.36, 95% CI 1.20 to 1.56) and long sleep duration during the weekend increase the probability of not having injuries, with the strongest association for a long sleep during the weekends (OR 1.60, 95% CI 1.37 to 1.86). After adding gender to the model (model 3), the ORs for specific sleep problems and sleep duration during school days increased slightly, with day sleepiness becoming significantly associated with injuries. We also found that girls had a higher chance of not being injured than boys during their leisure time PAs (OR 1.53, 95% CI 1.40 to 1.68).

**Table 4** The associations of sleep problems and sleep duration with PARI in leisure time and the moderation by age and gender based on multiple logistic regression (Slovakia, 2022, mean age 13.4 years)

Independent variables	PARIs in leisure time (no injuries)†				
	Crude effect	Model 1	Model 2	Model 3	Model 4
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sleep problems					
Sleep problems more than once a week	Ref.	Ref.	Ref.	Ref.	Ref.
Problems with falling asleep (less than once a week)	1.44 (1.32 to 1.57)***	1.25 (1.13 to 1.39)***	1.22 (1.10 to 1.36)***	1.27 (1.14 to 1.41)***	1.27 (1.14 to 1.41)***
Waking up at night (less than once a week)	1.54 (1.40 to 1.69)***	1.39 (1.25 to 1.54)***	1.36 (1.22 to 1.51)***	1.41 (1.27 to 1.57)***	1.40 (1.26 to 1.56)***
Problem with waking up in the morning and feeling rested (less than once a week)	1.19 (1.09 to 1.29)***	1.01 (0.91 to 1.12)	1.01 (0.91 to 1.12)	1.04 (0.94 to 1.15)	1.07 (0.97 to 1.18)
Day sleepiness (less than once a week)	1.26 (1.16 to 1.37)***	1.08 (0.97 to 1.19)	1.06 (0.95 to 1.17)	1.13 (1.01 to 1.25)*	1.21 (1.09 to 1.34)***
Sleep duration‡, school days					
Short	Ref.	--	Ref.	Ref.	Ref.
Normal	1.33 (1.22 to 1.45)***	--	1.18 (1.08 to 1.30)***	1.20 (1.10 to 1.32)***	1.22 (1.11 to 1.34)***
Long	1.13 (0.51 to 2.50)	--	1.02 (0.43 to 2.41)	1.14 (0.48 to 2.70)	1.08 (0.45 to 2.56)
Sleep duration, weekends					
Short	Ref.	--	Ref.	Ref.	Ref.
Normal	1.51 (1.34 to 1.71)***	--	1.36 (1.20 to 1.56)***	1.31 (1.14 to 1.49)***	1.26 (1.11 to 1.44)***
Long	1.68 (1.45 to 1.94)***	--	1.60 (1.37 to 1.86)***	1.50 (1.29 to 1.75)***	1.37 (1.17 to 1.60)***
Gender (girls vs boys)	1.36 (1.25 to 1.48)***	--	--	1.53 (1.40 to 1.68)***	1.60 (1.45 to 1.75)***
Age (continuous)	1.11 (1.07 to 1.14)***	--	--	--	1.14 (1.11 to 1.18)***

Models 1–4: Univariate binary logistic regression analysis was used to assess the crude associations of each of the four sleep problems (model 1) with PARI. Then, we added sleep duration during the schooldays and weekends in the model (model 2) and explored the association with PARI and the modification of the adjusted associations of sleep problems with PARI. Finally, we adjusted regression models for the effect of gender (model 3) and age (model 4).  
 \*p<0.05, \*\*\*p<0.001.  
 †No injury was used as the dependent variable. The table presents the associations between sufficient sleep duration (normal and long sleep) good sleep quality (no sleep problems) and the likelihood of not having PARI (no injury).  
 ‡Sleep duration was calculated using the cut-offs for short and long sleep duration from Sawyer *et al.*<sup>25</sup>  
 PARI, physical activity-related injury.

**Table 5** The associations of sleep problems and sleep duration with PARI in schools and the moderation by age and gender based on multiple logistic regression (Slovakia, 2022, mean age 13.4 years)

Independent variables	PARI in schools (no injuries)†				
	Crude effect	Model 1	Model 2	Model 3	Model 4
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sleep problems					
Sleep problems more than once a week	Ref.	Ref.	Ref.	Ref.	Ref.
Problems with falling asleep (less than once a week)	1.42 (1.29 to 1.56)***	1.18 (1.06 to 1.33)**	1.17 (1.04 to 1.31)**	1.19 (1.06 to 1.33)**	1.18 (1.06 to 1.33)**
Waking up at night (less than once a week)	1.61 (1.45 to 1.78)***	1.38 (1.23 to 1.55)***	1.36 (1.21 to 1.53)***	1.38 (1.23 to 1.56)*	1.37 (1.22 to 1.54)***
Problem with waking up in the morning and feeling rested (less than once a week)	1.32 (1.21 to 1.45)***	1.07 (0.95 to 1.20)	1.07 (0.95 to 1.19)	1.08 (0.96 to 1.21)	1.12 (1.00 to 1.25)
Day sleepiness (less than once a week)	1.41 (1.29 to 1.55)***	1.23 (1.10 to 1.38)***	1.21 (1.08 to 1.36)***	1.25 (1.11 to 1.40)***	1.35 (1.20 to 1.52)***
Sleep duration‡, school days					
Short	Ref.	--	Ref.	Ref.	Ref.
Normal	1.32 (1.20 to 1.45)***	--	1.15 (1.04 to 1.28)**	1.16 (1.05 to 1.29)**	1.17 (1.05 to 1.30)**
Long	0.49 (0.22 to 1.12)	--	0.45 (0.18 to 1.10)	0.47 (0.19 to 1.15)	0.45 (0.18 to 1.10)
Sleep duration, weekends					
Short	Ref.	--	Ref.	Ref.	Ref.
Normal	1.34 (1.17 to 1.53)***	--	1.21 (1.05 to 1.40)**	1.18 (1.03 to 1.37)*	1.14 (0.99 to 1.32)
Long	1.29 (1.10 to 1.52)**	--	1.24 (1.05 to 1.47)*	1.21 (1.02 to 1.43)*	1.10 (0.92 to 1.30)
Gender (girls vs boys)	1.06 (0.97 to 1.16)	--	--	1.23 (1.11 to 1.36)***	1.28 (1.15 to 1.42)***
Age (continuous)	1.11 (1.07 to 1.14)***	--	--	--	1.15 (1.11 to 1.19)***

Models 1–4: Univariate binary logistic regression analysis was used to assess the crude associations of each of the four sleep problems (model 1) with PARI. Then, we added sleep duration during the schooldays and weekends in the model (model 2) and explored the association with PARI and the modification of the adjusted associations of sleep problems with PARI. Finally, we adjusted regression models for the effect of gender (model 3) and age (model 4).  
 \*p<0.05, \*\*p<0.01, \*\*\*p<0.001.  
 †No injury was used as the dependent variable. The table presents the associations between sufficient sleep duration (normal and long sleep) good sleep quality (no sleep problems) and the likelihood of not having PARI (no injury).  
 ‡Sleep duration was calculated using the cut-offs for short and long sleep duration from Sawyer *et al.*<sup>25</sup>  
 PARI, physical activity-related injury.

Finally, we added age in the model (model 4) with a significant increase in ORs for day sleepiness and no significant interactions with other sleep problems and sleep duration. We found that older adolescents had a higher probability of not having injury during PA in leisure time than younger adolescents (OR 1.14, 95% CI 1.11 to 1.18).

### Associations between sleep duration, sleep problems and PARI in schools

Table 5 presents the associations of sleep problems and sleep duration with PARI in schools. The results of model 1 show that not having problems with waking up at night (OR 1.38, 95% CI 1.23 to 1.55), day sleepiness (OR 1.23, 95% CI 1.10 to 1.38) and problems with falling asleep in the evening (OR 1.18, 95% CI 1.06 to 1.33) increased the probability of not having the PARI in schools. After adding sleep duration to the model (model 2), the specific sleep problems remained significant, with a slight decrease in odds suggesting potential interactions. We also found that normal sleep duration during the school days (OR 1.15, 95% CI 1.04 to 1.28) and normal (OR 1.21, 95% CI 1.05 to 1.40) and long sleep duration (OR 1.18, 95% CI 1.05 to 1.47) during the weekend increased the probability of not having injuries in school. After adding gender to the model (model 3), we found a slight increase in ORs for sleep problems and sleep duration during the school days suggesting potential mediation. We also found that girls had a higher chance of not being injured than boys during PA in schools (OR 1.23, 95% CI 1.11 to 1.36). Finally, we added age to the model (model 4), with normal and long sleep duration during weekends no longer being significantly associated with a lower probability of PARI in school. We found that older adolescents had a higher probability of not having injuries during PA in schools (OR 1.15, 95% CI 1.11 to 1.19).

### DISCUSSION

The results of the study showed that a significant number of Slovak adolescents were injured in sports clubs (55.1%), leisure-time PA (42.9%) and school related PA (27.9%) and that those injuries were related to sleep duration and sleep problems. The findings suggested that sufficient sleep duration and good sleep quality played protective roles in relation to PARI by increasing the likelihood of not being injured during PA in adolescence. We found that adolescents with normal sleep duration during schooldays and without problems with falling asleep, waking up at night, and day sleepiness had a higher probability of not having PARI in all three settings. The strongest association was found for the problems with night awakening. The protective role of sufficient sleep duration during the weekend was confirmed only in relation to PARI in leisure time and schools, with the strongest association between long sleep duration and not having PARI in leisure time. No significant association was found between the problems with morning awakening, morning tiredness and PARI. The results showed that gender and age moderated these associations, with girls and older adolescents having a higher probability of not having injuries than boys and younger adolescents. Age was not significantly associated with PARI in sports clubs.

The high prevalence of PARI in younger adolescents, boys and sport club members was confirmed by several studies.<sup>5 7 9 10 27 28</sup> Growth spurt, maturity-associated variation, immature musculoskeletal system, and decreased coordination and balance are among the risk factors that may play an important role in the high prevalence of acute and overuse sports injuries in adolescents.<sup>29</sup>

The gender differences could be explained by the fact that boys are more engaged in PA than girls, prefer to be involved in competitive sports activities, behave riskier and are exposed to higher training loads.<sup>5 9 10</sup> However, only a few studies explored the relationship between PARI and adolescent sleep characteristics. Moreover, most studies focused on the relationship between sleep duration and injuries in sports clubs, and only a few on sleep problems and PARI in other settings.

### Relationship between sleep and PARI in sports clubs

Our study showed that sleeping the recommended number of hours during the weekdays increased the probability of not having injuries in sports clubs by more than 30%. These results are in line with the results of other studies. For example, a study from Sweden found that sleeping more than 8 hours during weekdays reduced the odds of injury in 16–19 years old elite athletes by more than 60%.<sup>30</sup> The evidence from other studies showed that lack of sleep, high training load and intensity, high stress levels due to frequent competitions and early sport specialisation were associated with increased risk of injuries in elite athletes.<sup>14 31–33</sup> The underlying mechanism is complex, with several possible pathways explaining this association. High physical and mental demands and lack of time for rest and recovery increase the risk of overload and stress with negative impacts on the musculoskeletal system, mood, alertness, concentration and performance resulting in a higher risk of injuries in sports team members.<sup>14 32</sup> Moreover, the stress, anxiety and social changes after an injury could impair sleep and cause sleep problems.<sup>33</sup> We found that adolescents not having sleep problems such as night awakening, difficulty falling asleep and day sleepiness had a 20%–40% greater chance of not having injuries in sports clubs. Girls were almost two times higher odds of not being injured than boys. We assume this relationship could be bidirectional, with injuries increasing the probability of various sleep problems.

### Relationship between sleep and PARI in leisure time and schools

Several studies explored the prevalence of PARI in schools and leisure time, confirming our results of a higher prevalence of PARI in leisure time than in schools and boys having a higher probability of being injured than girls.<sup>7 11 27 34</sup> There is evidence that both active and inactive adolescents are at a higher risk of having PARI in schools. Whereas inactive adolescents are at risk because of unfamiliarity with exercises and low fitness, active students are because of greater exposure to PA and renewal of old leisure time injuries.<sup>11</sup> Only a few studies examined the role of sleep in relation to injuries in leisure time or school, even less to PARI. In line with our findings, the evidence showed that adolescents with sleep problems and short sleep duration had a higher risk of injuries in school and out-of-school settings.<sup>35 36</sup> We found that adolescents with sufficient sleep duration during the school days and weekends and those not having problems with falling asleep, waking up at night and day sleepiness had increased odds of not being injured during PA in both leisure time and school. Several pathways have been discussed to explain the role of poor sleep in relation to PARI. One possible pathway could be the adverse effects of sleep loss and sleep problems on adolescents' mood, behaviour and cognitive functions such as concentration, attention, memory consolidation, psychomotor vigilance, coordination, and thus sports performance.<sup>15 37–39</sup> Another pathway is related to the potentially detrimental effect of poor sleep on muscular endurance and biochemical muscular recovery after minor injuries, which could lead to injury accumulation

over time.<sup>8 15 39 40</sup> Moreover, both injuries and sleep problems could be related to the same risk factors, such as emotional and behavioural problems or other psychological variables.<sup>22 30</sup>

### Strengths and limitations

The study's strengths include a large representative sample, the use of a valid HBSC questionnaire and empirically based sleep recommendations. The results can be generalised to the Slovak adolescent population and compared with those from other countries participating in the HBSC study. Several study limitations need to be mentioned. First, the cross-sectional design does not allow to establish causal relationships. We are uncertain whether insufficient sleep duration and sleep problems are determinants or outcomes of PARI. Second, the school RR of 45% was low. This might be explained by the time of data collection (April–June 2022) when the school reopened after the COVID-19 pandemic. Third, we used subjective measures of sleep characteristics, which could bias the calculation of sleep duration and prevalence of sleep problems. Nevertheless, this is common in questionnaire studies that cover a broad range of topics and a large sample of participants, such as the HBSC study. Fourth, the sleep duration was calculated as a difference between wake-up time and bedtime, which is the time spent in bed and not the time spent asleep. This could underestimate the number of adolescents with short sleep duration. Fifth, the injuries were self-reported, and data were collected retrospectively, which might cause recall bias. To minimise this recall bias, the time for reporting injuries was limited within the past 12 months. Finally, no definition of injury in the questionnaire might misclassify some respondents and bias the results. To minimise such bias, trained administrators were available in person during data collection in the schools to answer and explain any doubts of the participants regarding the injuries.

We suggest that more studies are needed about the role of various sleep characteristics in relation to PARI in leisure time and schools. Further research should also examine other factors influencing the relationship between insufficient sleep duration and quality and adolescent PARI.

### CONCLUSION

Our findings about the high prevalence of PARI among adolescents align with previous research results. The study provides additional information about the role of sleep quantity and quality in relation to adolescent PARI in three different settings. We found that normal sleep duration during school days and good sleep quality decreased the probability of adolescent PARI in sports clubs, leisure time and school. Sufficient sleep duration during the weekend is essential for reducing the risk of PARI in leisure time and schools. Moreover, being a boy, a sports club member, and a younger adolescent were identified as risk factors in relation to PARI in sleep-deprived adolescents. The results highlight the need for injury prevention as a critical component of PA promotion in adolescents, with healthy sleep promotion being an inevitable part of prevention strategies.

**Contributors** Conceptualization and planning, M.K., P.B. and J.K.; methodology J.K. and P.K.; statistical analysis P.K., data collection M.K., J.K., M.V. and T.K.S. and P.B.; writing – original draft preparation, M.K. and P.B.; writing – review and editing, J.K., M.V., T.K.S., guarantor, M.K.

**Funding** This research was funded by the Slovak Research and Development Agency under contract no. APVV-18-0070 and 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 co-funded by the research grant 622594-EPP-1-2020-1-SK-SPO-SCP from the Education,

Audiovisual and Culture Executive Agency (EACEA) ERASMUS+Sports Collaborative Partnerships Program.

**Competing interests** None declared.

**Patient and public involvement** Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

**Patient consent for publication** Not applicable.

**Ethics approval** This study involves human participants and was approved by the Ethics Committee of the Medical Faculty at P.J. Safarik University in Kosice (13N/2021). Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available on reasonable request. All data relevant to the study are included in the article or uploaded as online supplemental information.

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