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Sleep difficulties as a consistent risk factor for medically treated injuries among adolescents in 46 countries

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Abstract

Adolescent poor sleep is common and has been associated with unintentional injury risks. Yet the comparability of evidence is limited by differences in measures of sleep and injury implemented across studies. We examined the potential cross-national consistency of relationships between poor sleep and unintentional injury using self-reports from 239 816 adolescents (50.8% girls) in 46 countries collected using a common survey procedure. A cross-sectional study was conducted using nationally representative records from the 2017/2018 International Health Behaviour in School-aged Children study. The prevalence of sleep indicators (difficulties in falling asleep, insufficient sleep, social jetlag) and annual medically treated injuries (any, multiple) were described cross-nationally and by gender. Multivariable modified Poisson regression analyses were conducted within and across countries to test the consistency of associations between sleep and injury. 16.3%–48.3% of adolescents reported an indicator of poor sleep and 44.0% sustained any injury. We observed striking cross-national variations in sleep, yet consistent gendered patterns across countries [e.g. sleep difficulties more prevalent among girls vs. insufficient sleep (non-school days) more prevalent among boys]. Country-level models displayed relatively consistent and positive associations. Multi-country (pooled) models demonstrated a consistency of effects, with the strongest association observed between difficulties in falling asleep and multiple injuries (prevalence ratio: 1.58, 95% CI: 1.55–1.61); these effects were especially pronounced in girls. Using standard indicators, this novel cross-national study demonstrated that poor sleep is a consistent risk factor for adolescent injuries. Given the recent epidemic of adolescent sleep problems, sleep hygiene represents a novel target for injury prevention.

Introduction

Unintentional injuries to young people contribute to a substantial global health burden [1]. Contemporary studies continue to identify large variations in adolescent injury rates [2]. Individual- and country-level determinants, such as socioeconomic status and poverty [3], access to healthcare [4], and cultural influences [5] have been identified as plausible explanations. The identification of potentially modifiable injury risk factors, both structural and intermediary [6], that can be targeted in clinical and public health interventions is important in addressing this burden and narrowing inequities [7]. One such adolescent injury determinant, which may be of clinical and social relevance, is the 'sleeping patterns' of young people, including reports of insufficient sleep, social jetlag, and difficulties in falling asleep.

The importance of achieving sufficient and good quality sleep is a well-recognized intermediary determinant of health [8]. Adolescent sleep is unique to that experienced in other developmental stages; a delay in sleep timing occurs during this period due to biological factors (i.e. shifts in circadian rhythms) associated with puberty [9]. Current sleep guidelines recommend 9–11 h of sleep for 5- to 13-year-olds and 8–10 h for 14- to 17-year-olds [10, 11]. However, the percentage of adolescents who are not meeting these recommendations is of concern [12]. A recent cross-national study verified this fact, with 32%–86% of youth meeting recognized sleep guidelines on school days across 24 countries [13]. Social and environmental factors, including socio-demographics, varying school start times, and cultural influences were identified as relevant determinants [13]. Further, an international study of secular trends in adolescents reporting difficulties with falling asleep identified increases in the prevalence from 2002 to 2014 across 33 countries in Europe [14]. Given these trends, identifying the contemporary factors impacting adolescent sleep, and in turn, the negative health consequences stemming from poor sleep hygiene, have become public health priorities [15].

Mechanisms relating sleep and injury risks have been established. Dorrian *et al.* [16] described the psychological consequences of sleep

deprivation, which include behavioural and cognitive deficits (i.e. poor decision-making, inattention, reduced social information processing, and impaired perceptions of social environments) which in turn, may lead to unintentional injuries. Further, a systematic review and meta-analysis that focused on sleep patterns (i.e. duration, sleepiness, medication use) and adolescent unintentional injuries identified a pooled odds ratio (OR) of 1.64 [95% confidence interval (CI): 1.44–1.85] from 10 observational studies that met the inclusion criteria [17]. Similarly, a systematic review of chronic poor sleep and sports injuries identified a pooled OR of 1.58 (95% CI: 1.05–2.37) from three studies [18]. However, two systematic reviews remained inconclusive on associations between sleep (i.e. duration, timing) and injuries/harms to children, with both unable to perform a meta-analysis due to heterogeneity of measures used across available observational studies [8, 19].

Despite recognition of the relationship between adolescent sleep and injuries at regional- and (in some cases) national levels [20, 21], the comparability of this evidence is limited by differences in assessments of sleep [e.g. type of sleep pattern measured (quality vs. quantity), how it was assessed (objectively vs. subjectively), the duration of recall timing ("usual" sleep vs. in a designated time period)] and injuries [e.g. type, severity (medically- vs. self-treated), duration of recall timing] across studies [8, 17, 19]. There is a paucity of cross-national assessments of such relationships that involve standard indicators and robust, representative samples. Identification of particular injury types that are more vulnerable to poor sleep may also be useful in targeting public health initiatives, and in establishing this as a global health priority. Promotion of sleep hygiene to protect against injurious behaviours and risks may indeed provide a novel focus for international health campaigns.

In this international study of some 230 000 children in 46 countries, we had a rare opportunity to examine the consistency of relationships between sleeping behaviours and risks for medically treated injuries. We hypothesized that while cross-national variations in adolescent sleeping patterns would be observed, adolescents who exhibit poor sleep hygiene would consistently experience more medically treated injuries.

Methods

Study design

An international cross-sectional study was conducted using data from the 2017/2018 Health Behaviour in School-aged Children (HBSC) study [22]. The HBSC study is a school-based survey conducted every four years among adolescents aged 11, 13, and 15 years in countries in Europe, Central Asia, and Canada [22]. The study employs a multi-stage sampling approach, with classes or schools used as the primary sampling units. At least 95% of the eligible target population is available for sampling, aiming to produce nationally representative samples [22]. Response rates across countries were, on average, 79.1% (range: 42.0%–99.3%) at the student-level and 70.3% (range: 14.6%–100%) at the school-level. Additional details and access to the 2017/2018 HBSC survey protocol can be found here: https://hbsc.org/publications/survey-protocols/. Measures of 'sleep' were derived from mandatory and optional packages included in study questionnaires used across participating countries. A measure of medically treated injury was available in all 46 countries that participated in 2017/2018. The full sample that was studied involved 239 816 adolescents. We excluded adolescents who did not report their 'age' ($n = 1516$) and who did not respond to our outcome variable of 'any medically treated injury' ($n = 8820$). The final sample size (unweighted) included 229 589 adolescents, representing 95.7% of the original sample (see Supplementary Table S1 for sample sizes of each country involved in this study). Survey weights were incorporated during analyses to ensure the results were representative of the countries. The final weighted sample includes 229 020 adolescents.

Key measures

Sleep

In 46 countries, adolescents were asked how often they experienced 'difficulties in falling asleep' during the previous six months (response options: "rarely or never", "about every month", "about every week", "more than once a week", or "about every day"). This item originates from a larger, eight-item scale, which asked adolescents about the frequency of non-clinical "psychosomatic complaints" (e.g. headaches, dizziness, feeling low). For analyses, this item was dichotomized as "yes" (about every day/more than once a week) or "no" (rarely or never/about every month/about every week), as per precedent [22].

Some countries administered optional packages of items on usual sleep timing (wake and bedtime) on school days (16 countries) and non-school days (12 countries). Responses were available in 30-min intervals. On school days, bedtimes ranged from "no later than 21:00" to "02:00 or later", and wake times ranged from "no later than 05:00" to "08:00 or later". On non-school days, bedtimes ranged from "no later than 21:00" to "04:00 or later", and wake times from "no later than 07:00" to "14:00 or later". From these items, we estimated sleep duration on school and non-school days and then categorized adolescents as having 'insufficient sleep' on school and non-school days (separately) if they did not meet the minimum sleep guideline for their age (9 h for children aged 5–13; 8 h for adolescents aged 14–17) [10]. We calculated 'social jetlag', an indicator of inconsistency in sleep timing and "misalignment" between weekdays and free days [23], via the difference in bedtime on school and non-school days. A difference in bedtime of greater or less than 2 h was categorized as social jetlag. Despite countries using the same survey protocol [22], there were some exceptions at a national-level. Sleep data were not collected among 11-year-olds in the following countries: "difficulties in falling asleep" (North Macedonia), "sleep timing" (Finland and Scotland). In Flemish Belgium, two additional bedtime categories were included in their survey instrument: "20:00" and "20:30" on school and non-school days.

Medically treated injury

Participants were asked whether they had experienced an injury in the past 12 months that required medical treatment from a doctor or nurse [24]. Response options included: "No, I was not injured in the past 12 months", "1 time", "2 times", "3 times", or "4 or more times". For purposes of analyses, we examined injury events in two forms: (1) 'any medically treated injury' ("no" or "yes") and (2) 'multiple medically treated injuries' ("no or 1 time" or "2 or more times").

Potential confounders and effect modifiers

Potential confounders included age (11, 13, or 15 years old), relative family affluence (based on a measure of material assets that categorizes adolescents to low (20%), middle (60%), and high (20%) affluence groups), and the frequency (0–7 days/week) that participants engaged in moderate-to-vigorous physical activity (MVPA) [22]. Through preliminary analyses we evaluated the potential impact of other, literature-informed potential confounders (e.g. alcohol use, cigarette smoking, family support, problematic social media use) on our relationships of interest; however, these factors did not meaningfully contribute to significant changes in the associations, and thus were omitted from further analyses. *A priori*, gender ("boy" or "girl"; gender-diverse options were not available in many countries in 2017/2018) was selected as a potential effect modifier of the association between sleep and injury.

Statistical analysis

Descriptive analyses were conducted to examine the socio-demographic characteristics of the sample, sleeping behaviours,

and their bivariate relationship with any medically treated injury. Comparative tests included the Rao-Scott chi-square test for categorical variables and *t*-tests for continuous variables. Next, multivariable modified Poisson regression analyses were performed to examine associations between sleep indicators (difficulties in falling asleep, insufficient sleep on school and non-school days, social jetlag) and medically treated injuries (any, multiple), while accounting for potential confounders [25]. Models were conducted separately for each country to test their consistency, and then, a pooled multi-country analysis was conducted to examine the strength of associations. As gender acted as a statistically significant effect modifier across some countries, we reported multivariable results overall and stratified by gender. Adjusted prevalence ratios (PRs) and 95% CIs are presented. Survey weights were applied, and clustering was accounted for at the school-level (and country-level, in pooled multi-country analyses). All analyses were conducted on SAS 9.4 (SAS Institute, Cary, NC, 2013).

Ethical considerations

Each participating country obtained ethical clearance for the conduct of the HBSC survey from the relevant institutional ethical review board or equivalent.

Results

Table 1 displays the descriptive characteristics and sleeping behaviours of the final 2017/2018 HBSC study weighted sample ($n = 229\,020$) overall, and by any medically treated injury. There was a similar distribution of boys (49.2%) and girls (50.8%) and those aged 11, 13, and 15 years old, the majority reported "medium" relative family affluence levels, and the average MVPA level was 4.1 (SD: 2.1) days per week. The prevalence of any injury was 44.0%, with 21.5% of adolescents reporting multiple injuries. Insufficient sleep on school days was the most prevalent sleep indicator reported (48.3%), followed by social jetlag (32.3%), difficulties in falling asleep (24.0%), and insufficient sleep on non-school days (13.3%). Bivariate analyses revealed that adolescents who sustained any injury were more likely to identify as boys, be aged 13 years old, report having "medium" relative family affluence, have higher average levels of MVPA, and report any indicator of poor sleep.

The proportions of boys and girls reporting difficulties in falling asleep in 46 countries are shown in Panel A of Fig. 1. Striking variations were observed cross-nationally, with girls universally reporting higher proportions of sleep difficulties in each country. Proportions of boys and girls reporting insufficient sleep on school and non-school days are provided in Supplementary Fig. S1. There were unique gender patterns identified with these indicators. While girls displayed higher proportions of insufficient sleep on school days, boys reported higher levels of insufficient sleep on non-school days.

Multivariable associations between difficulties in falling asleep and multiple medically treated injuries across 46 countries are shown in Panel B of Fig. 1 (gender-stratified associations shown in Supplementary Fig. S2). Each country displayed positive and statistically significant risk associations; Albania had the largest risk estimate (PR: 2.02, 95% CI: 1.57–2.60), whereas Denmark had the smallest effects (PR: 1.29, 1.14–1.47). Country-level associations between difficulties in falling asleep and any injury are provided in Supplementary Fig. S3 (gender-stratified associations shown in Supplementary Fig. S4); consistent and statistically significant associations were observed across each country, except null associations in Greenland and North Macedonia.

A summary of country-level regression analyses between sleep indicators and any and multiple injuries overall, and by gender is shown in Table 2. Generally, positive and statistically significant effects were observed across majorities of countries. The exception was insufficient sleep on non-school days, which slightly varied for any injury (i.e. more null associations than positive across countries). Gender-stratified models revealed similar trends, with slightly more cross-country consistency of associations among girls compared to boys. No negative associations were observed between sleep and injury outcomes across countries. The country-level associations between sleep indicators and injury overall, and by gender, are shown in Supplementary Table S2.

Table 3 displays multi-country (pooled) regression analyses between sleep indicators and injury, overall and by gender. We observed consistent and positive associations across each sleep and

Table 1. Descriptive characteristics of the study sample overall and by any medically treated injury status ($n = 229\,020$)

	Overall sample		Any medically treated injury				*P*
			No		Yes		
Total, % (*n*)	100.0	(229 020)	56.0	(128 263)	44.0	(100 756)	
Gender, % (*n*)							<.0001
Boys	49.2	(112 613)	45.1	(57 896)	54.3	(54 716)	
Girls	50.8	(116 407)	54.9	(70 367)	45.7	(46 040)	
Age, % (*n*)							<.0001
11 years	33.6	(76 926)	33.2	(42 577)	34.1	(34 350)	
13 years	34.3	(78 554)	33.5	(42 981)	35.3	(35 573)	
15 years	32.1	(73 540)	32.3	(42 706)	30.6	(30 834)	
Relative family affluence, % (*n*)							<.0001
Low	19.5	(43 188)	21.0	(25 957)	17.7	(17 231)	
Medium	61.6	(136 178)	62.0	(76 816)	61.1	(59 362)	
High	18.9	(41 715)	17.0	(21 090)	21.2	(20 624)	
MVPA (days/week), mean (SD)[a,b]	4.1	(2.0)	3.9	(0.01)	4.3	(0.01)	<.0001
Difficulties in falling asleep, % (*n*)							<.0001
No	76.0	(169 205)	79.2	(98 325)	71.9	(70 880)	
Yes	24.0	(53 414)	20.8	(25 673)	28.1	(27 652)	
Insufficient sleep on school days (16 countries)[c], % (*n*)							<.0001
No	51.7	(36 199)	54.2	(21 198)	48.5	(15 001)	
Yes	48.3	(33 811)	45.8	(17 905)	51.5	(15 907)	
Insufficient sleep on non-school days (12 countries)[d], % (*n*)							<.0001
No	83.7	(44 424)	85.3	(25 111)	81.8	(19 313)	
Yes	16.3	(8644)	14.7	(4337)	18.2	(4306)	
Social jetlag, % (*n*)							
No	67.7	(36 042)	70.2	(20 759)	64.5	(15 283)	<.0001
Yes	32.3	(17 223)	29.8	(8794)	35.5	(8429)	

Note: All values (*n*) are weighted to ensure national representativeness. Rao-Scott chi-square test and *t*-tests were conducted, with adjustment for school- and country-level clustering. Some frequencies (*n*) do not equal the total or stratified sample amount due to rounding or missing responses for some demographic and sleep items.

a: Mean (SD) of MVPA is based on reports from 45 countries and excludes those from Lithuania as a different assessment of MVPA was employed in their survey instrument.

b: MVPA estimates stratified by any medically treated injury are presented as mean (SE).

c: Sleep patterns on school days available in 16 countries: Belgium (French), Belgium (Flemish), Czech Republic, Denmark, Estonia, Finland, Scotland, Greece, Hungary, Latvia, Moldova, Netherlands, Norway, Poland, Slovakia, and Ukraine.

d: Sleep patterns on non-school days available in 12 of these 16 countries [no data from Belgium (French), Denmark, Netherlands, and Slovakia].

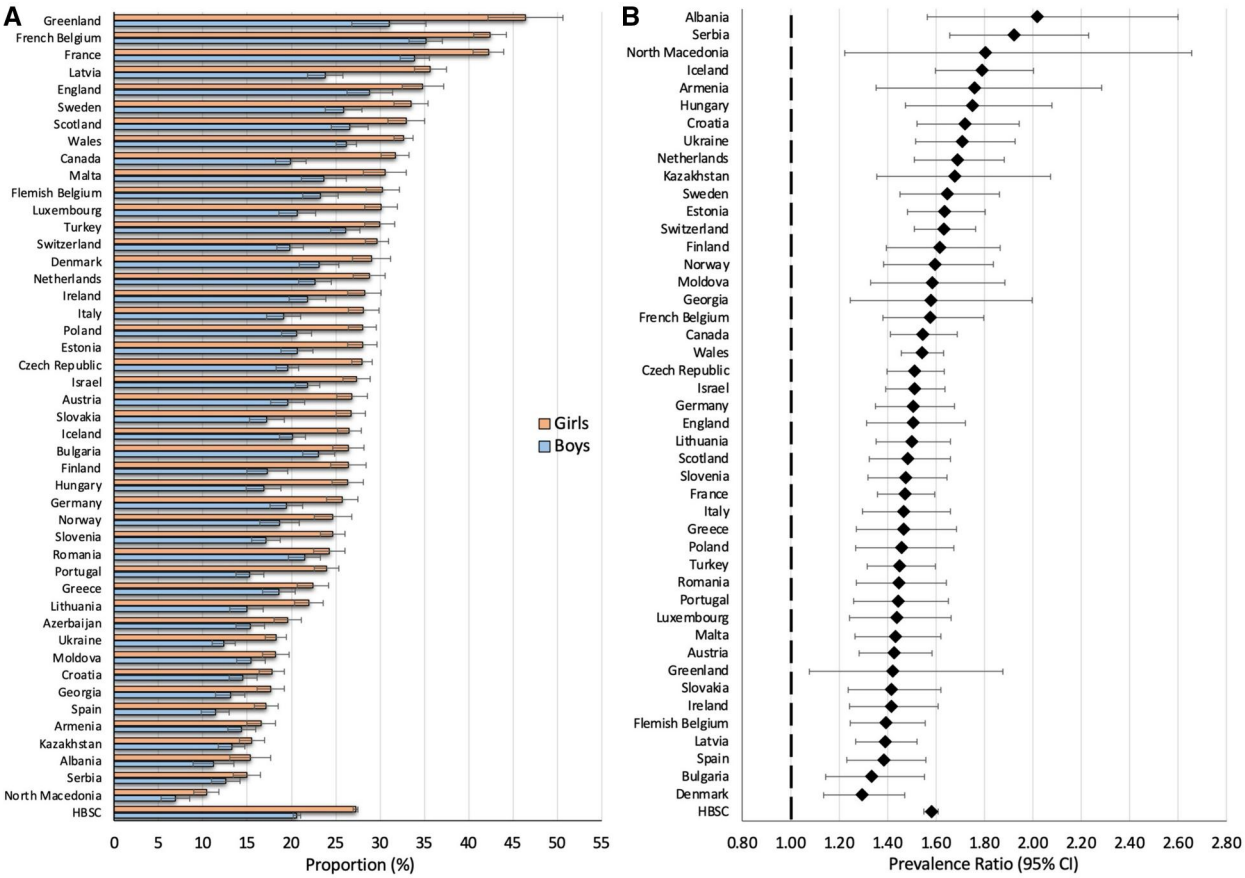

Figure 1. Prevalence (%; 95% CI) of difficulties in falling asleep across countries (Panel A), and its association (PR; 95% CI) with multiple medically treated injuries (Panel B). **Note**: The ordering of countries in the figures are arranged from smallest to largest prevalence (Panel A) and smallest to largest association (Panel B). "HBSC" is the multi-country (pooled) prevalence estimate (Panel A) and association (Panel B). The dotted line on Panel B at the PR value of 1.0 represents a null effect; PRs and/or 95% CI bounds that cross this line are considered statistically non-significant at $P < .05$. For analyses shown in Panel B, models were adjusted for age, gender, relative family affluence, and MVPA. Sample weights were applied to ensure the representativeness of estimates, and all models accounted for school-level clustering. The effect estimate for Azerbaijan (PR: 3.49, 2.69–4.53) was omitted from the figure as it was interpreted as an outlier. "Difficulties in falling asleep" was not asked among 11-year-old participants in North Macedonia.

Table 2. Summary of country-level associations between sleep indicators and medically treated injuries, overall and by gender

		Overall			Boys			Girls		
	No. of countries	Pos.	Neg.	None	Pos.	Neg.	None	Pos.	Neg.	None
Any medically treated injury										
Difficulties in falling asleep	46	44	0	2	34	0	12	44	0	2
Insufficient sleep on school days	16	12	0	4	6	0	10	10	0	6
Insufficient sleep on non-school days	12	5	0	7	2	0	10	6	0	6
Social jetlag	12	9	0	3	3	0	9	10	0	2
Multiple medically treated injuries										
Difficulties in falling asleep	46	46	0	0	42	0	4	45	0	1
Insufficient sleep on school days	16	13	0	3	11	0	5	11	0	5
Insufficient sleep on non-school days	12	8	0	4	6	0	6	6	0	6
Social jetlag	12	9	0	3	7	0	5	10	0	2

Note: Values in cells represent a summation (count) of the country-level associations for each sleep indicator and injury outcome according to their statistical significance and direction. "Pos." indicates a statistically significant and positive association (PR and lower 95% CI above the value of 1.0), "Neg" indicates a statistically significant negative association (PR and upper 95% CI below the value of 1.0), and "None" indicates null association (PR with a 95% CI that includes the value of 1.0).

injury item. Gradients in injury risks were shown, with higher risks displayed for multiple injury, compared to any injury, across sleep indicators. Variations in the strength and magnitude of risks were also observed across sleep indicators and by gender. Adolescents reporting difficulties in falling asleep were at the highest risk of experiencing any injury (PR: 1.28, 1.27–1.30) and multiple injury (PR: 1.58, 1.55–1.61), whereas risk estimates were similar and modest for insufficient sleep (school and non-school days) and social

Table 3. Multi-country (pooled) associations between indicators of sleep and medically treated injuries, overall and by gender

			Any medically treated injury			Multiple medically treated injuries		
	No. of countries	*n*	No. injured	PR	95% CI	No. injured	PR	95% CI
Difficulties in falling asleep (Ref. "No")								
Overall	46	211 741	93 819	1.28	(1.27–1.30)	45 882	1.58	(1.55–1.61)
Boys		103 118	50 503	1.20	(1.18–1.22)	25 686	1.46	(1.42–1.50)
Girls		108 624	43 315	1.36	(1.34–1.38)	20 195	1.72	(1.67–1.76)
Insufficient sleep on school days (Ref. "No")								
Overall	16	66 808	29 502	1.14	(1.12–1.17)	14 072	1.29	(1.25–1.33)
Boys		32 764	15 681	1.12	(1.09–1.14)	7735	1.26	(1.21–1.32)
Girls		34 044	13 820	1.18	(1.14–1.21)	6337	1.32	(1.26–1.39)
Insufficient sleep on non-school days (Ref. "No")								
Overall	12	51 078	22 731	1.11	(1.08–1.14)	10 730	1.23	(1.18–1.29)
Boys		25 012	12 053	1.07	(1.03–1.10)	5902	1.18	(1.12–1.24)
Girls		26 065	10 678	1.17	(1.12–1.21)	4828	1.31	(1.22–1.40)
Social jetlag (Ref. "No")								
Overall	12	51 240	22 809	1.15	(1.13–1.17)	10 769	1.30	(1.24–1.34)
Boys		25 113	12 112	1.11	(1.08–1.14)	5933	1.25	(1.19–1.30)
Girls		26 127	10 698	1.20	(1.16–1.24)	4836	1.36	(1.29–1.44)

Note: Overall models adjusted for age, gender, relative family affluence, and MVPA. Gender-stratified models accounted for age, relative family affluence, and MVPA. Sample weights were applied to ensure national representativeness of countries, and all models accounted for school- and country-level clustering.

jetlag for both injury outcomes. Further, girls displayed excesses in risks for both injury outcomes compared to boys, regardless of the sleep indicator.

Discussion

This cross-national study examined associations between poor sleep patterns and medically treated injuries among adolescents across 46 countries. The core findings of this study include: (1) poor sleep, in the form of difficulties in falling asleep, insufficient sleep, and social jetlag, were reported by 16.3%–48.3% of adolescents, with variations by country and gender; (2) country-stratified analyses revealed positive and mainly consistent associations between sleep indicators and any and multiple injury; (3) pooled (multi-country) analyses demonstrated a consistency of effects between sleep indicators and injuries; and (4) variations in the strength and consistency of these effects were observed by gender, and were especially detrimental to girls.

This international study provides a novel contribution to the growing evidence base concerning the relationship between poor sleep and injuries among adolescents; a research area mainly informed by regional and some national evidence [20, 21]. We affirmed that adolescent poor sleep is common and that striking variations in the prevalence of poor sleep exist cross-nationally [13, 26]. Our use of a common data source (HBSC study), which employs a standardized methodology to measure sleep and injury across countries, supports the validity of these international comparisons [22]. Interpretively, when considering the many documented individual-level social and behavioural factors that impact adolescent sleep (i.e. age and onset of puberty [9], academic and social obligations [27], bedtime social media use [28]), these cross-national variations point to country-specific and culturally relevant factors that could differentially affect adolescent sleep. As per prior evidence, these may include differences in school systems, start times, and the common modes of school transportation (i.e. active vs. motorized) which can impact sleep timing [29], familial attitudes and beliefs toward sleep (i.e. parental set bedtimes, room sharing) [30], as well as potential geographical implications (i.e. latitude and longitude, seasonality) [26]. In this study, we observed mainly consistent gendered patterns in sleep across countries. Girls were more vulnerable to experiencing sleep difficulties and insufficient sleep on school days, whereas boys had higher proportions of insufficient sleep on non-school days, across most countries. The size of these differences, however, varied largely across countries, with some appearing quite small [i.e. a difference of 1.9% in the prevalence of sleep difficulties among boys (25.4%) and girls (27.3%) in Israel]. The magnitude of some gendered patterns may not be clinically important.

Our multivariable analyses revealed that poor sleep indicators are meaningful injury risk factors across most countries. To illustrate, difficulties in falling asleep displayed significant and positive risk associations in 44 out of 46 countries for "any" injury and in each of the 46 countries for "multiple" injury. Notable cross-national variations in the strength and magnitude of these relationships were displayed. For example, significant risk associations for sleep difficulties ranged from 1.14 (1.06–1.23) in Ireland to 1.61 (1.48–1.75) in Iceland for "any" injury, and 1.29 (1.14–1.47) in Denmark to 2.33 (1.58–3.44) in Albania for "multiple" injury. The strength of these pathways varied across sleep and injury indicators and socio-demographically. For sleep, experiencing difficulties in falling asleep was the most consistent and robust injury risk factor across countries, compared to insufficient sleep and social jetlag. From a public health perspective, sleep difficulties may represent one important and plausible target for injury prevention. Such focus may also be highly pertinent, considering the current global evidence indicating that rates of adolescent sleep difficulties are increasing over time [14]. However, as we had limited country-level data on insufficient sleep and social jetlag (i.e. 12–16 countries), additional analyses are warranted to confirm the magnitude of these relationships in other countries.

With respect to injury, we universally identified larger associations for "multiple" injuries compared to "any" injury, regardless of the sleep indicator. This observation aligns with a previous study conducted among adolescents in France, with higher odds of repeated versus single injuries among those reporting sleep difficulties [31]. In terms of socio-demographic patterns, girls displayed more robust and consistent risk associations across countries, compared to boys. Previous literature has reported conflicting results on the role of gender in this pathway. For instance, a population-based study of school-aged children (aged 9–18) in China identified boys who used sleeping pills/medications to have higher odds of unintentional injury, whereas girls who reported snoring (one or multiple nights per week) experienced higher odds of injury [32]. A cross-sectional study of sleep

characteristics (i.e. duration, difficulties) and physical activity-related injuries among adolescents in Slovakia identified lower odds of injury among girls compared to boys [33]. While our findings suggest that girls were more vulnerable to the effects of poor sleep, the analysis of gendered differences in sleep with particular injury outcomes warrants investigation.

Collectively, our country-level findings support our core hypotheses that there is evidence of consistency of this pathway between poor sleep and injury among adolescents which crosses countries and cultures. Our pooled (multi-country) models demonstrated an almost total consistency of effects, with similar gradients observed according to the sleep indicator, injury outcome, and gender. The magnitude of these combined effects (i.e. small-to-moderate) also was similar to the pooled effects (OR range: 1.58–1.64) reported in existent systematic evidence [17, 18]. Furthermore, our study suggests that sleep patterns may indeed act as an important correlate of injury and that these associations remained important at an international-level.

Study findings have implications for future research and prevention. Studies on the underlying mechanisms by which these aetiological relationships occur are warranted, particularly with a focus on specific injury outcomes (i.e. sports injuries, slips/falls) [33] and potentially mediating factors (i.e. cognitive deficits, behavioural factors, risk-taking) [16, 34]. Despite the evidence of cross-national consistency in our aetiological pathways, there were variations in the magnitude of these relationships across countries. Studies should investigate the specific social and contextual correlates and inequalities (i.e. gendered, socioeconomic) related to these pathways. These may assist in the targeting and delivery of equity-focused public health campaigns, or in the evaluation of current programs that may be in place in some countries (e.g. governmental initiatives, community or school-based sleep hygiene campaigns).

The strengths of this study are notable. The HBSC study is comprised of nationally representative samples of adolescents and involves a standardized survey instrument. Our use of this robust dataset allowed for international comparisons to be performed based on consistent measures that were cross-validated and reliable. Our study aimed to establish cross-national consistency of effects of the association between sleep and injury (an important postulate of causal inference); our analyses mainly affirmed this notion of a consistency of effects. Study limitations also warrant comment. The HBSC study is based on cross-sectional records, and thus, one must take care to infer causality on our relationships tested, as we cannot establish temporality and there is the possibility of reverse causality (e.g. an injury event led to poor sleep patterns among adolescents). The recall periods differed for sleep (i.e. "usual" patterns or in last six months) and injury assessments (i.e. past 12 months), potentially increasing the risk of recall bias and reverse causality, particularly for items with longer recall periods. Some sleep indices were not available in all 46 countries (insufficient sleep, social jetlag); this limited our ability to form large-scale international comparisons for these measures. Our assessment of injury was limited to composite (or "overall") measures and did not examine types of injury which may provide deeper insights into the underlying mechanisms driving these relationships. The response rates to the HBSC study naturally varied across countries due to differing policies governing school-based research, and may affect our estimation of prevalence and associations cross-nationally. Lastly, as some countries had smaller sample sizes, country-level effect estimates may be less stable, and should therefore be interpreted with caution.

Conclusion

This international study examined the role of poor sleep as a determinant of medically treated injuries among adolescents in 46 countries. Sleep problems were robust and consistent injury risk factors across most countries, with boys and girls being particularly disadvantaged. Public health officials and policymakers should be cognizant of our observed trends and recognize adolescent sleep as a public health priority. Sleep hygiene may represent one novel focus area for injury prevention campaigns implemented at national and international levels.

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Supplementary data

Supplementary data are available at *EURPUB* online.

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Data availability

The data underlying this article will be shared on reasonable request to the HBSC study International Coordinating Centre.

Key points

- We tested the potential cross-national consistency of the relationships between poor sleep patterns and risks for medically treated injuries using nationally representative self-reports from 229 020 adolescents in 46 countries that were collected using a common survey procedure.
- Poor sleep, in the form of sleep difficulties, insufficient sleep, and social jet lag were robust and mainly consistent risk factors for medically treated injury injuries among adolescents across 46 countries.
- Public health officials and policymakers should recognize sleep hygiene as a novel focus for adolescent injury prevention at national and international levels.

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