Insufficient sleep, impaired sleep and medically treated injury in Canadian adolescents: a national cross-sectional study

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ABSTRACT

Background Insufficient and impaired sleep are common in adolescents and can adversely impact health and well-being. One likely consequence of poor sleep is a risk of unintentional injuries, yet the evidence base is limited for such relationships. We, therefore, documented contemporary sleeping behaviours of young people in Canada and examined relationships between these behaviours and risks for injury.

Methods A cross-sectional study was employed using records from the 2017/2018 Canadian Health Behaviour in School-aged Children study (n=21 745). Indicators of poor sleep (insufficient sleep on school and non-school days, impaired sleep, daytime sleepiness) and annual reports of medically treated injuries (any, serious) were obtained. Descriptive and hierarchical modified Poisson regression analyses were performed to explore these relationships, while controlling for potential confounders.

Results Insufficient sleep, impaired sleep and daytime sleepiness were reported by 11.3–35.3% of adolescents; variations in these estimates were observed by gender. Sleep indicators were modestly but consistently associated with risks for the occurrence of 'any injury', whereas impaired sleep and daytime sleepiness were the only meaningful and significant risk factors for 'serious injuries' in adjusted models (prevalence ratio range: 1.18–1.30). The analysis of interactions revealed boys with insufficient sleep on non-school days as well as impaired sleep to have higher injury risks compared with girls.

Discussion and conclusions Impaired sleep and its effects have emerged as a quiet epidemic, affecting up to one-third of Canadian adolescents and being associated with risks for injury. Sleep hygiene may therefore act as a plausible focus for clinical and public health initiatives to mitigate injury risks.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Poor sleep, such as insufficient sleep duration, trouble falling asleep and feeling tired during the daytime, are becoming increasingly common among Canadian adolescents and can negatively affect their health and safety. Some evidence has been related to poor sleep and the risk of adolescent injury, yet national evidence in Canada is scarce.

WHAT THIS STUDY ADDS

⇒ Several indicators of poor sleep patterns were robustly associated with the risk of medically treated injuries among a nationally representative sample of young people in Canada.

HOW MIGHT THIS STUDY AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Sleep hygiene campaigns may provide a novel focus for public health policies aimed at the prevention of adolescent unintentional injuries.

INTRODUCTION

Adolescence is a critical and transitory period of life where young people experience substantial growth and development.[1] Sleep plays an important role in these processes of maturation, promoting normative physical, psychological and cognitive functioning (ie, decision-making, attention, memory).[2 3] Despite recognition of its importance, many adolescents do not obtain sufficient and good quality sleep.[4] To illustrate, a global study of secular trends in adolescent sleep depicted a consistent decline in sleep duration experienced over the past century.[5] This finding has largely been attributed to societal modernisation and related technological advances in which young people's worlds are transformed by the presence of 24-hour virtual communities.[6]

In Canada, it is recommended that children ages 5–13 years old obtain 9–11 hours of sleep per night, with adolescents aged 14–17 years recommended a level of 8–10 hours.[7] Yet, nearly 30% of Canadian youth do not achieve these recommendations and around 20% report difficulties staying awake during the early daytime hours.[8] These statistics are concerning, given the negative health and safety concerns associated with poor sleep, including poor physical and immune health,[9] low mood and emotional well-being,[3] impairments to domains of cognitive functioning[10] and increases in risk-taking behaviours.[11]

One potential negative consequence of poor sleep is the risk of injury. Poor sleep is mechanistically associated with the occurrence of injuries among adolescents through deficits in behavioural and cognitive domains (ie, impaired decision-making, inattention) which can lead to injury risk behaviours and the occurrence of injury.[10] Epidemiological studies have examined this relationship. One cross-sectional study of 1559 adolescents in France related sleep difficulties (medically treated/untreated) with the occurrence of single (odds ratio (OR) range: 1.76–2.31) and multiple (OR range: 2.43–4.92) 'school or out of school'

injury.[12] Similarly, a US cross-sectional study of 112 student-athletes (grades 7–12) identified increased risks for a medically documented sports injury among those with insufficient sleep (<8 hours) during their sporting season (prevalence ratio (PR): 1.70, 95% CI: 1.00 to 3.00).[13] In contrast, a cross-sectional study among 17 track and field athletes (aged 15–18) objectively assessed sleep duration via actigraphy coupled with sleep diaries and failed to identify any significant association between sleep duration and injury.[14] Findings of a Canadian cross-sectional study identified associations between insufficient sleep and sleep debt with risks for injury (self-treated or medically-treated) in children ages 7–12 (PR range: 1.89–2.14), yet identified insufficient sleep on weekends to be protective of injury among adolescents ages 13–17 (PR: 0.53, 95% CI: 0.29 to 0.99).[15]

Despite recognition of this relationship, many studies are local in scope and display inconsistencies in case definitions of sleep and injury events, impacting their comparability.[16] Available Canadian studies on this issue are regional in scope.[15] To our knowledge, there are no studies which have addressed this association at a national level nor within subpopulations that may be particularly affected by poor sleep hygiene. The role of sleep as a potentially modifiable risk factor for unintentional injuries has public health relevance. Unintentional injuries are a leading cause of death and disability among adolescents and contribute to a substantial burden in terms of healthcare costs and utilisation.[17 18] Generating new evidence on determinants of injury, both structural and proximal, can assist in guiding clinical and public health interventions. Sleep hygiene may provide one plausible focus. In this novel study, we therefore documented the contemporary sleeping behaviours of Canadian youth and examined the relationship between poor sleep patterns and unintentional injuries.

METHODS
Design and study population
A cross-sectional analysis was conducted using nationally representative Canadian records from the 2017/2018 Health Behaviour in School-aged Children (HBSC) study.[19] The HBSC study involves a cross-national study, conducted in collaboration with the World Health Organization (WHO), that is administered every 4 years among young people (target ages 11–15) in schools across 50+ countries.[20] HBSC employs a multistage clustering design sampling approach and gathers nationally representative adolescent samples in each participating country.[20] Further details on the international study protocol can be found elsewhere (https://hbsc.org/).

The current analysis focused on available data from the 2017/2018 Canadian HBSC study. The initial sample included 21 745 participants from 287 publicly funded schools. A total of 18 612 participants (weighted n=18 856) were included in this study, representing 85.6% of the original sample. Exclusions included participants with missing information on: age and gender (n=428), medically treated injury (n=1277), sleep measures (bedtime, wake time, impaired sleep and daytime sleepiness) (n=1035) or those aged 18+ (n=11; not allocated a survey weight in the data set), those who reported their gender as 'neither term describes me' (n=328; cell sizes in stratified analyses were lower than minimum requirements for reporting) and participants with a sleep duration value that was an outlier (n=54; beyond 3 SD from the mean).

Key measures
Sleep indicators
Participants were asked about their usual sleeping behaviours through a series of questions. Sleep duration on school and non-school days was derived from participants' reported sleep timing in these situations separately. Insufficient sleep was defined as having a sleep duration not meeting the minimum age-specific Canadian guidelines (ie, <9 hours for those aged 5–13 years and <8 hours for those aged 14–17 years).[7] Sleep impairment was described as how often adolescents experienced trouble going to sleep or staying asleep (ie, 'never/rarely', 'sometimes', 'most/all of the time'). Daytime sleepiness referred to how often adolescents experienced trouble staying awake during daytime hours when they preferred to be awake (ie, 'never/rarely,' 'sometimes,' 'most/all of the time'). Social jetlag was defined as a difference of 2 or more hours between school and non-school day bedtime to assess variability in sleep onset on school and non-school days.[21] Screen time 1 hour before bed reflected how often (nights per week) participants watched television, use a cellphone and a computer/tablet in their bedroom within 1 hour of falling asleep (ie, 'no' or 'yes').

Medically treated injury
Injuries were measured through two standard indicators. First, any injury in the past 12 months that required treatment from a doctor or nurse (responses dichotomised as 'no' or 'yes')[22] and second, reports of injuries in the past 12 months that required more serious medical treatment, such as a cast, stitches, surgery or an overnight stay in a healthcare setting (response options: 'no' or 'yes'), as per the Modified Abbreviated Injury Score criteria.[23]

Potential confounders
The following literature-informed[12 15] potential confounders were selected for inclusion in multivariable modelling, as they have been identified to be associated with sleep patterns and injury risks. Participants' ages were categorised into two groups (11–13 and 14–17 years old) which fall within the Canadian sleep guideline age groupings.[7] Gender was self-reported as 'boys' or 'girls'. Ethnicity was described in 14 categories, later grouped as those identifying as 'white' or 'non-white'. Relative material wealth was assessed by asking participants 'how well off do you think your family is?'; responses were grouped as 'well off,' 'average', or 'not well off'. Geographical location was based on adolescents' school postal code and address and stratified according to the municipality population centre size of their school: rural area (<1000 population), small (1000–29 999 population), medium (30 000–99 999 population) or large urban (≥100 000 population).[24] Neighbourhood social capital was assessed via a 5-item scale on participants' perceptions of the social features of their neighbourhood (eg, 'people say 'hello' and often stop to talk to each other on the street', 'it is safe for younger children to play outside during the day', etc).[25] Response options ranged on a 5-point Likert scale from 'strongly agree' to 'strongly disagree' and generated a composite sum score ranging from 5 to 25 in which larger scores indicate higher social capital. Family and friend support were individually assessed through two 4-item subscales adapted from the Multidimensional Scale of Perceived Social Support and dichotomised into 'low support' or 'high support' based on established cut-points.[26] Moderate-to-vigorous physical activity (MVPA) was assessed by asking participants the number of days in the past week they engaged in at least 1 hour of MVPA. Alcohol use and cigarette smoking status

were evaluated through items asking participants about their engagement in these behaviours in the last 30 days (response options: 'never' or 'yes'). Lastly, self-reported comorbidities (eg, attention deficit hyperactivity disorder/attention deficit disorder, learning disability, mental illness) were categorised as 'none', '1' and '2 or more'.

Statistical analysis

Descriptive analyses were performed to describe the sample, sleep behaviours and the prevalence of injuries, overall and by gender. Bivariate tests (Rao-Scott χ^2 tests and t-tests) were conducted to quantify associations between sleep indicators and injury outcomes. Multivariable modified Poisson regression analyses were then conducted to test associations between sleep indicators and injury outcomes.[27] A hierarchical model-building strategy was employed for the inclusion of literature-informed potential confounders via three models; model 1 adjusted for age and gender, model 2 added sociodemographic variables (ethnicity, relative material wealth, geographical location, neighbourhood social capital) and model 3 added individual-level health and behavioural factors (family and friend support, MVPA, screen time before bed, cigarette smoking status, alcohol use, and number of comorbidities). Effect modification by age and gender was tested via the inclusion of separate interaction terms into model 3. Adjusted PR's and 95% CIs were estimated via the generalised estimating equation. Sample weights were applied to ensure national representativeness which reflected actual enrolments of students in grades 6–10 from the participating Canadian provinces/territories and accounted for oversampling of particular groups within those jurisdictions. School-level clustering was accounted for in all analyses. Analyses were conducted using SAS V.9.4. (SAS Institute, Cary, North Carolina, USA, 2013).

RESULTS

The descriptive characteristics of study participants are presented in table 1. A total of 53.3% were girls and 51.2% of adolescents were 11-13 years old. Most participants identified as having a white ethnicity (70.8%), were 'well off' relative to peers (56.1%) and resided in a small population centre (44.9%). The prevalence of any injury was 48.6%, with 18.1% of adolescents reporting a serious injury.

Table 2 displays the sleep behaviours of the sample overall and by gender. Sleep behaviours varied during the week, with earlier average bedtimes (22:23 vs 23:56), wake times (06:56 vs 09:37) and shorter sleep durations (8 hour 33 min vs 9 hour 41 min) reported on school days compared with non-school days. Insufficient sleep was more common on school days than on non-school days (35.3% vs 16.3%). While 23.8% of participants reported sleep impairment 'most/all of the time', daytime sleepiness was less common, with 11.3% reporting this at the same level. Gender-stratified analyses revealed significant differences in sleep patterns, with girls reporting poorer sleep compared with boys for nearly all indicators.

Table 3 displays bivariate associations between sleeping patterns and injury outcomes. Significant relationships were identified with higher proportions of insufficient sleep, impaired sleep and daytime sleepiness shown among those who sustained injuries.

Hierarchical multivariable regression model estimates are displayed in table 4. For any injury, poor sleep was consistently associated with an increased risk of injury across models. In fully adjusted models, risk estimates were generally weak and similar

Table 1 Descriptive characteristics of the 2017/2018 Canadian HBSC sample included in this study (n=18 856)

Gender, % (n)		
Boys	46.7	(8800)
Girls	53.3	(10 056)
Age (years), % (n)		
11–13 years old	51.2	(9659)
14–17 years old	48.8	(9197)
Ethnicity, % (n)		
White	70.8	(13 183)
Non-white	29.2	(5428)
Relative material wealth, % (n)		
Well off	56.1	(9778)
Average	36.0	(6284)
Not well off	7.9	(1371)
Geographical location, % (n)		
Rural area	1.0	(190)
Small population centre	44.9	(8459)
Medium population centre	18.1	(3411)
Large urban population centre	36.0	(6796)
Neighbourhood social capital (range: 5–25), mean (SD)	18.7	(3.9)
Family support, % (n)		
Low	47.7	(8805)
High	52.3	(9652)
Friend support, % (n)		
Low	53.1	(9816)
High	46.9	(8667)
Moderate-to-vigorous physical activity (days/ week), mean (SD)	4.6	(2.0)
Smoking cigarettes (last 30 days), % (n)		
No	96.3	(17 202)
Yes	3.7	(655)
Alcohol use (last 30 days), % (n)		
No	81.9	(14 504)
Yes	18.1	(3216)
Number of comorbidities, % (n)		
0 or not specified	79.0	(14 891)
1	16.8	(3175)
2 or more	4.2	(790)
Any medically treated injury, % (n)		
No	51.4	(9692)
Yes	48.6	(9164)
Serious medically treated injury, % (n)		
No	81.9	(14 346)
Yes	18.1	(3174)

All values (n) are weighted to ensure national representativeness. Some variables contained missing data and thus their frequencies do not align with the overall sample size (n=18 856).
HBSC, Health Behaviour in School-aged Children.

for reports of insufficient sleep (school and non-school days). However, stronger associations were observed for impaired sleep and daytime sleepiness, with some evidence of dose-response displayed for sleep impairment (ie, reporting 'sometimes' had 1.13 (95% CI: 1.08 to 1.18) times the risk for injury, whereas reporting 'most/all of the time' had 1.18 (95% CI: 1.11 to 1.25) times the risk for injury). For serious injury, after adjustment for potential confounders, impaired sleep and daytime sleepiness were the only meaningful and consistent risk factors for injuries

Table 2 Contemporary sleeping patterns of participants of the 2017/2018 Canadian HBSC sample included in this study overall and by gender (n=18 856)

	Overall (n=18 856)		Boys (n=8800)		Girls (n=10 056)		P value
School Days							
Wake time (hh:mm), mean (SD)*	06:56	(00:37)	07:00	(2 m)	06:52	(2 m)	<0.01
Bedtime (hh:mm), mean (SD)*	22:23	(01:10)	22:21	(3 m)	22:23	(3 m)	0.33
Sleep duration, mean (SD)*	8 h 33 m	(1 h 13 m)	8 h 39 m	(3 m)	8 h 29 m	(4 m)	<0.01
Insufficient sleep, % (n)							
No	64.7	(12 196)	67.5	(5943)	62.2	(6253)	<0.01
Yes	35.3	(6660)	32.5	(2857)	37.8	(3803)	
Non-school days							
Wake time (hh:mm), mean (SD)*	09:37	(01:38)	09:33	(3 m)	09:41	(2 m)	<0.01
Bedtime (hh:mm), mean (SD)*	23:56	(01:41)	00:00	(3 m)	23:52	(3 m)	<0.01
Sleep duration, mean (SD)*	9 h 41 m	(1 h 35 m)	9 h 33 m	(2 m)	9 h 49 m	(2 m)	<0.01
Insufficient sleep, % (n)							<0.01
No	83.7	(15 786)	81.1	(7138)	86.0	(8648)	
Yes	16.3	(3071)	18.9	(1662)	14.0	(1409)	
School and non-school days							
Impaired sleep, % (n)							<0.01
Never/rarely	44.1	(8312)	52.8	(4649)	36.4	(3663)	
Sometimes	32.1	(6060)	29.1	(2557)	34.9	(3504)	
Most/all of the time	23.8	(4484)	18.1	(1595)	28.7	(2889)	
Daytime sleepiness, % (n)							<0.01
Never/rarely	63.0	(11 883)	68.4	(6016)	58.4	(5868)	
Sometimes	25.7	(4848)	22.5	(1980)	28.5	(2868)	
Most/all of the time	11.3	(2125)	9.1	(804)	13.1	(1320)	
Social jetlag, % (n)							<0.01
No	64.0	(12 063)	60.8	(5351)	66.7	(6712)	
Yes	36.0	(6793)	39.2	(3449)	33.3	(3344)	
Screen time 1 hour before bed, % (n)							<0.01
No	16.8	(3039)	18.4	(1541)	15.4	(1498)	
Yes	83.2	(15 081)	81.6	(6822)	84.6	(8260)	

All values (n) are weighted to ensure national representativeness and account for school-level clustering. Wake and bedtimes are presented in a 24-hour time format. Mean (SD) for sleep duration is expressed in hours (h) and minutes (m).
*Mean (SE) reported for continuous variables in gender-stratified analyses.
HBSC, Health Behaviour in School-aged Children.

across all models. Evidence of a dose-response relationship was similarly observed for these sleep measures.

Table 5 presents stratified results related to the significant tests for interaction identified between sleep indicators and gender. We observed that boys were more vulnerable to the effects of impaired sleep ('sometimes' and 'most/all of the time') for 'any' and 'serious' injuries and of insufficient sleep on non-school days with 'serious' injuries, when compared with the reference group of girls reporting 'never/rarely' or 'no' for impaired or insufficient sleep, respectively.

DISCUSSION AND CONCLUSIONS

This study provides contemporary estimates describing indicators of poor sleep among Canadian adolescents and examines their relationship with medically treated injuries. The most important findings of this study include: (1) poor sleep affected between 11.3–35.3% of Canadian adolescents and varied according to gender, with girls faring worse in most sleep indicators; (2)

each indicator of poor sleep was a risk factor for any injury; (3) impaired sleep and daytime sleepiness were also moderately associated with risks for serious injury, after full adjustment for potential confounders; (4) boys were more vulnerable to the effects of insufficient sleep on non-school days and impaired sleep on various injury risks compared with girls.

Adolescent sleep therefore has clearly emerged as a public health priority, given the 'epidemic' levels of insufficient and impaired sleep being reported among young people and their potential negative health and safety consequences.[11 28] We observed that over one-third (35.3%) of Canadian adolescents had insufficient sleep on school days, a figure that is consistent with past national estimates.[29 30] Reports of sleep in other domains (ie, impaired sleep, daytime sleepiness) moderately aligned with existent Canadian evidence[31] and further emphasised the magnitude of this burden among Canadian adolescents. We observed some gendered differences in sleep patterns. While girls tended to report less favourable sleep across a majority of

Table 3 Bivariate associations between key sleep behaviours and medically treated injuries

	Any injury (n=18 856)			Serious injury (n=17 520)			
	No (n=9692)	Yes (n=9164)	P value	No (n=14 346)	Yes (n=3174)		P value
Insufficient sleep, % (n)							
School days			<0.01				0.03
No	66.5 (6441)	62.8 (5755)		65.1 (9340)	62.1 (1971)		
Yes	33.5 (3251)	37.2 (3409)		34.9 (5006)	37.9 (1203)		
Non-school days			<0.01				<0.01
No	85.4 (8274)	82.0 (7512)		84.4 (12 108)	81.2 (2577)		
Yes	14.6 (1418)	18.0 (1653)		15.6 (2237)	18.8 (597)		
Sleep impairment, % (n)			<0.01				<0.01
Never/rarely	46.8 (4538)	41.2 (3774)		45.3 (6493)	39.8 (1264)		
Sometimes	31.6 (3062)	32.7 (2998)		31.7 (4552)	32.1 (1019)		
Most/all of the time	21.6 (2092)	26.1 (2392)		25.0 (3300)	28.1 (892)		
Daytime sleepiness, % (n)			<0.01				<0.01
Never/rarely	66.1 (6410)	59.7 (5473)		64.0 (9187)	59.4 (1887)		
Sometimes	23.9 (2318)	27.6 (2530)		25.3 (3628)	27.1 (860)		
Most/all of the time	10.0 (963)	12.7 (1161)		10.7 (1531)	13.5 (427)		

All values (n) are weighted to ensure national representativeness and account for school-level clustering. Rao-Scott χ² test was conducted to compare proportions of sleep behaviours by gender.

indicators, some of these differences were quite small. To illustrate, while statistically significant (p<0.01), as shown in table 2, we posit that a 10-min longer average sleep duration on school days among boys compared with girls may not be clinically or socially significant. The magnitude of our gendered patterns detected and their conservative interpretation is consistent with previous studies.[30]

In understanding why poor sleep is commonly observed among adolescents, research often points to biological, behavioural and social influences which create the 'perfect storm' for poor adolescent sleep.[32] Factors such as hormonal shifts during puberty that delay sleep propensity and onset, coupled with changes in attitudes and priority placed on sleep (in order to fulfil academic and social obligations) and environmental influences, such as

Table 4 Results of hierarchical multivariable modified Poisson regression models describing associations between sleeping behaviours and medically treated injuries

	Model 1			Model 2			Model 3		
	PR	95% CI	P value	PR	95% CI	P value	PR	95% CI	P value
Any injury	n=18 856			n=16 726*			n=14 888*		
Insufficient sleep (ref.=no)									
School days	1.09	(1.05 to 1.14)	<0.01	1.12	(1.06 to 1.17)	<0.01	1.07	(1.02 to 1.13)	0.01
Non-school days	1.12	(1.05 to 1.19)	<0.01	1.15	(1.08 to 1.22)	<0.01	1.10	(1.02 to 1.18)	<0.01
Impaired sleep (ref.=never/rarely)									
Sometimes	1.11	(1.07 to 1.16)	<0.01	1.11	(1.07 to 1.16)	<0.01	1.13	(1.08 to 1.18)	<0.01
Most/all of the time	1.21	(1.14 to 1.28)	<0.01	1.22	(1.15 to 1.29)	<0.01	1.18	(1.11 to 1.25)	<0.01
Daytime sleepiness (ref.=never/rarely)									
Sometimes	1.16	(1.10 to 1.22)	<0.01	1.18	(1.13 to 1.30)	<0.01	1.17	(1.11 to 1.24)	<0.01
Most/all of the time	1.22	(1.14 to 1.30)	<0.01	1.21	(1.12 to 1.25)	<0.01	1.17	(1.09 to 1.26)	<0.01
Serious injury	n=17 520			n=15 611*			n=13 898*		
Insufficient sleep (ref.=no)									
School days	1.13	(1.02 to 1.24)	0.01	1.20	(1.08 to 1.33)	<0.01	1.10	(0.99 to 1.23)	0.07
Non-school days	1.17	(1.03 to 1.32)	0.03	1.18	(1.04 to 1.35)	0.05	1.10	(0.95 to 1.26)	0.21
Impaired sleep (ref.=never/rarely)									
Sometimes	1.18	(1.06 to 1.31)	<0.01	1.22	(1.09 to 1.36)	<0.01	1.24	(1.10 to 1.40)	<0.01
Most/all of the time	1.40	(1.24 to 1.57)	<0.01	1.46	(1.28 to 1.68)	<0.01	1.30	(1.12 to 1.50)	<0.01
Daytime sleepiness (ref.=never/rarely)									
Sometimes	1.18	(1.05 to 1.32)	<0.01	1.20	(1.05 to 1.36)	0.01	1.18	(1.03 to 1.36)	0.02
Most/all of the time	1.35	(1.16 to 1.57)	<0.01	1.35	(1.15 to 1.59)	<0.01	1.26	(1.06 to 1.49)	<0.01

All analyses are weighted to ensure national representativeness and account for school-level clustering. Outcomes (injury) were modelled as 'no vs yes'. Model 1 adjusted for age and gender. Model 2 further adjusted for ethnicity, relative material wealth, geographical location, and neighbourhood social capital. Model 3 further adjusted for family support, friend support, MVPA, screen time 1 hour before bed, cigarette smoking status, alcohol use and number of comorbidities.
*Complete case analysis was employed in these models and resulted in a subsequent loss of sample size with adjustment for additional potential confounders.
MVPA, moderate-to-vigorous physical activity; PR, prevalence ratio; ref, reference group.

Table 5 Fully adjusted multivariable analyses presenting with significant gendered interactions

	Girls			Boys		
	PR	95% CI	P value	PR	95% CI	P value
Any injury (n=14 888)						
Impaired sleep						
Never/rarely	1.00	Ref.		1.13	(1.05 to 1.22)	<0.01
Sometimes	1.17	(1.08 to 1.26)	<0.01	1.25	(1.16 to 1.35)	<0.01
Most/all of the time	1.26	(1.16 to 1.37)	<0.01	1.23	(1.10 to 1.36)	<0.01
Serious injury (n=13 898)						
Impaired sleep						
Never/rarely	1.00	Ref.		1.61	(1.34 to 1.94)	<0.01
Sometimes	1.48	(1.23 to 1.80)	<0.01	1.77	(1.45 to 2.17)	<0.01
Most/all of the time	1.54	(1.24 to 1.92)	<0.01	1.83	(1.41 to 2.39)	<0.01
Insufficient sleep (non-school days)						
No	1.00	Ref.		1.34	(1.18 to 1.53)	<0.01
Yes	1.27	(1.07 to 1.51)	<0.01	1.27	(1.07 to 1.60)	<0.01

All models adjusted for age, ethnicity, relative material wealth, geographical location, family support, friend support, screen time 1 hour before bed, cigarette smoking status, alcohol use and number of comorbidities.
Ref, reference group.

school start times and job employment, have all been cited as relevant determinants.[33][34] The additional influences that have emerged in recent decades that may disproportionately impact adolescent sleep, compared with prior generations, also warrant recognition.[5] Most notably, the rise of technology and increased accessibility to portable electronic devices among youth populations are suggested to 'delay' and 'displace' nighttime sleep.[35] In our study, 83.2% of adolescents used an electronic device within 1 hour of falling asleep, confirming the presence and potential magnitude of this contemporary influence.

With regard to injuries, our aetiological analyses revealed modest but consistent and statistically significant associations between indicators of sleep and risks for any injury. These observations align with the larger body of evidence conducted among youth populations.[12][13][16] However, for serious injuries, sleep impairment and daytime sleepiness emerged as the only statistically significant and meaningful risk factors, after controlling for potential confounders. As very few prior studies have evaluated differing thresholds of injury severity,[15] these findings are novel. However, the lack of association between insufficient sleep and serious injury was unexpected. Interpretively, this may indicate that other social, contextual and behavioural factors may be more important as risk factors than insufficient sleep for such severe injuries which typically possess a more complex aetiology.[36] Further investigation is warranted to test and confirm our findings. Our evaluation of interactions revealed that boys experiencing poor sleep (ie, insufficient sleep on non-school days, impaired sleep) had higher risks for some injuries. This suggests that gender may play a modifying role in this pathway between sleep and injury, with boys particularly affected.

Strengths of this study include our use of nationally representative Canadian records from the HBSC study.[19] HBSC is one of three Canadian studies documenting adolescent sleep; our survey measures are therefore comparable to these surveys.[37] We assessed multiple sleep measures and non-fatal injuries, providing insight into which injuries are potentially more vulnerable to particular sleep patterns. With respect to limitations, the HBSC study data are based on self-reports and are subject to potential recall error and social desirability biases. Due to our cross-sectional design, we cannot definitively infer causality as we were unable to establish temporality and thus the risk of

reverse causality must be acknowledged (ie, whether poor sleep preceded injuries or alternatively if an injury event contributed to poor sleep patterns due to physical or emotional pain). Our estimates of association should therefore be interpreted with this caveat in mind and longitudinal confirmation of the implied direction of effects is required. While the use of subjective and single-item sleep measures is common in population-based Canadian studies,[37] we did not use fully validated sleep scales typically employed in clinical settings. Our reliance on 'usual' sleep timing to compute sleep duration may have led to an overestimation (ie, reporting 'time in bed' rather than time spent asleep).[38] Injury reports were exclusive to those receiving medical treatment and thus may not capture injuries not receiving formal care, injuries among those experiencing barriers to accessing care or (in rare circumstances) fatalities.

Study findings have implications for public health, policy and practice. Longitudinal studies, randomised trials and other controlled studies are warranted to confirm temporal aspects and overcome the risks of reverse causality of the hypothesised relationships in cross-sectional designs and assess underlying causes of sleep loss, such as technology and social media use. As our injury measures represented composite (or 'overall') occurrences, an assessment of sleep with homogenous injury outcomes would be valuable aetiologically; this may detect associations that were potentially masked through the use of a composite injury measure. It would also be valuable to explore the mechanistic pathways that connect sleep with injury occurrence via mediation and other structural models. From policy and practice perspectives, existent systematic evidence suggests that school-based sleep health promotion campaigns, described as 'easily implementable', equitable and have the capacity to reach large audiences, may be one plausible form of intervention.[39] However, some have cautioned that such campaigns may not be as effective in promoting behavioural change long-term. Systematic evidence has evaluated the potential roles that parents and family members play in improving adolescent sleep (ie, parent-set bedtimes, support received from parents, parent role-modelling of positive sleep habits); small-to-moderate effects were identified across various domains of modifiable parental factors related to adolescent sleep.[40] The involvement of parents and family members in adolescent sleep health initiatives, coupled

with educational campaigns targeted toward adolescents, may be efficacious.

In summary, this study indicates that insufficient sleep, impaired sleep and daytime sleepiness are common among Canadian adolescents and are associated with risks for various medically treated injuries. Clinicians, public health officials and policymakers should be cognisant of our observed associations and the efforts required to address this 'quiet epidemic' of poor sleep affecting the health and safety of Canadian adolescents.

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