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Original Article

Protective and risk factors associated with adolescent sleep: findings from Australia, Canada, and The Netherlands

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ABSTRACT

Background: Sleep is vital for adolescent functioning. Those with optimal sleep duration have shown improved capacity to learn and decreased rate of motor vehicle accidents. This study explored the influence of numerous protective and risk factors on adolescents' school night sleep (bedtime, sleep latency, total sleep time) simultaneously to assess the importance of each one and compare within three countries.
Method: Online survey data were collected from Australia, Canada, and The Netherlands. Overall, 325 (137 male), 193 (28 male), and 150 (55 male) contributed to data from Australia, Canada, and The Netherlands, respectively (age range 12–19 years).
Results: Regression analyses showed mixed results, when comparing protective and risk factors for sleep parameters within different countries, with combined behavioural factors contributing to small to large shared portions of variance in each regression (9–50%). One consistent finding between countries was found, with increased pre-sleep cognitive emotional sleep hygiene related to decreased sleep latency ($beta = -0.25$ to -0.33, $p < 0.05$). Technology use (mobile phone/Internet stop time) was associated with later bedtime, or less total sleep, with the strength of association varying between device and country.
Conclusion: Results indicate that when designing interventions for adolescent sleep, multiple lifestyle factors need to be considered, whereas country of residence may play a lesser role.

1. Introduction

Sleep is critical for adolescents' daily functioning [1,2]. With longer sleep duration, adolescents have improved capabilities to learn, remember and perform well academically [3,4], and decreased rates of motor vehicle accidents [5], whereas less than seven hours of sleep per night is associated with higher rates of delinquency and crime [6]. Poorer mental health is associated with adolescents who obtain less than seven hours sleep per night, compared to adolescents who sleep seven to nine hours per night [7]. Earlier bedtimes, shorter sleep latencies (ie, the time it takes to fall asleep) and longer sleep length are also related to lower anxiety, depressed mood, suicidal ideation, and fatigue scores [8,9].

The transition from middle childhood to adolescence is marked, for some, by an increase in the time it takes for sleep pressure to accumulate, and a delay in the circadian rhythm [10]. Consequently, adolescents may struggle to fall asleep at a time which allows for an adequate sleep opportunity during the school week, when sleep may be constrained by school start times [10]. In addition to biological factors, extrinsic factors also play a part in delaying bedtimes, increasing sleep latency and decreasing sleep time, particularly on school days. As adolescents' sleep can be affected by a plethora of environmental factors, it is important to understand the relative influence of such factors so that appropriate interventions may minimise their impact. Whilst we review many influential factors here, it is important to note that most research studies investigate one-to-a-few factors without consideration of the majority of risk and protective factors [11]. Thus, the primary aim of the present study will be to analyse the relative importance of multiple risk and protective factors associated with adolescents' sleep, such as *technology use, substance use, pre-sleep cognitive and emotional arousal, home environment,* and *after school sport*, and to ascertain whether these factors pertain to adolescent sleep in a similar manner for different countries.

Age is a potential risk factor, with older adolescents sleeping less than younger adolescents – a phenomenon found across Australia, Europe, North America, and Asia [12,13]. Gender is also influential on sleep, with girls sleeping more than boys, yet girls' time in bed decreasing at a larger rate than boys for each increasing year of age [13].

Concerning adolescents' "screen consumption," multiple studies, particularly surveys, have found links between *technology use* and

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later bedtimes (eg, Gamble et al. [14]) and short sleep duration and longer sleep latency (eg, Hysing et al. [15]). However, some controlled laboratory experiments (eg, Heath et al. [16]; van der Lely et al. [17]; Weaver et al. [18]) have found little-to-no negative causal effects of pre-bed technology use on sleep. Indeed, a meta-analysis found, if anything, that technological devices are predominantly related to adolescents' later bedtimes [11].

The link between substance use and adolescent sleep remains unclear [11]. Although there seems to be no association between sleep latency and *alcohol* or *tobacco use*, links between these substances and sleep duration and bedtime are less distinct, with the potential for moderating or mediating factors, such as negative family interactions [11]. In terms of *caffeine*, its use is associated with less total sleep, especially when consumed in the evening [11,19]. However, links between caffeine use and sleep latency and bedtime are varied [19].

Sleep hygiene comprises multiple factors, such as pre-sleep cognitive and emotional arousal, physiological arousal, sleep environment, sleep stability, behavioural arousal, and daytime sleep (ie, napping [20]). Good sleep hygiene has typically benefitted adolescent sleep parameters (eg, Bartel et al. [11]; Storfer-Isser et al. [20]). Less pre-sleep worry in adolescents has shown to be related to decreased sleep latency [11], and less cognitive and emotional arousal prior to bed has been shown to relate to earlier bedtimes, a shorter sleep latency, and longer sleep time [20].

Adolescents' sleep has consistently shown to be enhanced when their *home environment* is positive [11,21–24]. A home environment encompasses many components, such as stress of demands [25], conflict [24] and disorganisation [22]. Sufficient sleep may be supported in a positive home environment, where a foundation is laid for health promoting behaviours [26], and less chaos is present [22]. Similarly, *parent-set bedtimes* are consistently linked with longer sleep durations, but not sleep latency [11], above the effects of age [27], thus improving adolescents' daytime wakefulness and decreasing their fatigue [28].

Activities outside of school (ie, extracurricular, work, study, sport) have been proposed to shorten sleep [29,30]. Although a meta-analysis found a beneficial relationship between *physical activity* and bedtime, the association between other activities on bedtime, sleep latency or total sleep time was not found [11]. Moreover, access to *indoor room lighting* may also decrease adolescents' sleep, even at low lux [31].

Despite the multiple factors which have been proposed to positively or negatively affect adolescents' sleep, these variables have not been studied simultaneously or in multiple countries, to determine the strength of their influence, when accounting for the presence of each other. Considering sleep broadly impacts daily functioning [1–3,5,29], it is within the best interests of the scientific community to determine which extrinsic factors provide the largest contribution in assisting, and hindering, the chances of a teenager getting to bed early, falling asleep quickly, and sleeping for longer. Such knowledge can direct healthcare professionals, parents, and adolescents themselves in achieving these sleep goals. In line with this, we created an online survey to collect data on adolescents' technology use, substance use, home environment, parent-set bedtime, and physical activity, at a single time point. In doing so, all factors could be analysed together, thus assessing which variables were more highly associated with adolescent bedtime, sleep latency, and total sleep than others. The added benefit of sampling across multiple countries was to assess the generalisability of findings to various adolescent populations across the globe.

2. Methods

2.1. Participants

A total of 460 588, and 354 adolescents commenced the survey from Australia, Canada, and The Netherlands, respectively. Of those, 325 (137 male), 193 (28 male), and 150 (55 male) contributed to data from the 178-item questionnaire battery, respectively. See Table 1 for descriptive statistics and frequencies for each sample.

2.2. Materials

All variables, other than caffeine, alcohol, and tobacco use, pre-sleep cognitive-emotional arousal, and sleep reduction, asked adolescents about their school day and weekend habits separately. Only school day data were reported, as restriction of sleep, imposed by school start times, offers a larger threat for daytime consequences [28], as well as altered weekend behaviour patterns (eg, decreased prevalence of parent-set bedtimes on weekend nights [27,28]. Demographic information on age, gender, and school were collected.

2.2.1. Sleep

Participants were asked about their bedtime (*At what time do you usually go to bed to sleep at night?),* sleep onset latency (*How long does it usually take you to fall asleep?*), awakenings after sleep onset, wake-up time, time out of bed and total sleep time (*How many hours do you usually sleep?),* over the previous two weeks. Answers reported for bedtime, sleep latency, and total sleep were used for analyses. Adolescents were also asked if they had any health conditions affecting their sleep, using a free text response. As this survey was aimed at looking at the general population of adolescents in

Table 1
Descriptive statistics and frequencies: Australia, Canada, The Netherlands M ± SD (N)/percentage yes (N).

Variable (scale range)	Australia	Canada	Netherlands
Age (12–19 years)	15.85 ± 1.34 (323)	15.90 ± 1.60 (193)	16.38 ± 1.86 (149)
Weekday BT (decimal)	22.71 ± 1.16 (322)	23.06 ± 1.22 (192)	22.53 ± 0.91 (150)
Weekday SOL (min)	44.57 ± 41.27 (322)	48.34 ± 41.18 (192)	36.59 ± 28.53 (148)
Weekday TST (min)	451.36 ± 74.05 (317)	429.65 ± 78.90 (189)	472.12 ± 65.33 (149)
Mobile stop time (weekday, decimal)	22.07 ± 2.04 (123)	22.04 ± 2.01 (93)	22.43 ± 1.63 (99)
Internet stop time (weekday, decimal)	21.97 ± 1.82 (174)	22.32 ± 1.73 (125)	22.19 ± 1.63 (100)
Cognitive emotional arousal (ASHS-r cognitive emotional scale; 1–6)	3.77 ± 1.07 (323)	3.59 ± 1.14 (192)	4.44 ± 0.92 (148)
Caffeine after 6 pm (1–6)	2.34 ± 1.54 (324)	3.13 ± 1.26 (193)	3.02 ± 1.61 (150)
Home environment (CHAOS; 1–5)	2.53 ± 0.89 (295)	2.79 ± 1.02 (169)	2.07 ± 0.72 (141)
Sports after school/week (min)	102.16 ± 138.79 (274)	116.24 ± 172.12 (165)	151.62 ± 122.38 (139)
Daytime functioning (SRSQ; 9–27)	17.6 ± 4.16 (245)	19.06 ± 3.95 (172)	16.18 ± 3.65 (141)
Tobacco (after 6 pm)	4.94% (324)	6.74% (193)	8.00% (150)
Alcohol (after 6 pm)	16.05% (324)	17.1% (193)	18.67% (150)
Parent-set BT	38.33% (300)	40.23% (174)	72.70% (143)

Note. ASHS-r = Adolescent Sleep Hygiene Scale – revised, BT = bedtime, CHAOS = Confusion Hubbub and Order Scale, SOL = weekday sleep onset latency, SRSQ = Sleep Reduction Screening Questionnaire, TST = weekday total sleep time.

secondary schools, all data were analysed together, regardless of any sleep problem.

2.2.2. Technology use

Adolescents were asked how many hours and minutes they spent on media, after 6:00 pm. The categories were as follows: television, mobile phone (not including Internet on mobile phone, includes checking text messages for short periods of time), computer (other than Internet use), Internet (including Internet use on desktop, laptop, tablet and mobile phone), video gaming, and Wii/other electronic games involving movement. They were also asked what time they start and stop using each device, after 6 pm. To limit the impact of collinearity [32] if including all technological devices, only Internet and phone use were used in analyses, as these devices have consistently been linked with sleep [11] and are used increasingly during adolescence [33].

2.2.3. Sleep hygiene and substance use

The Adolescent Sleep Hygiene Scale – revised (ASHSr [20]) is a 24-item scale, used to measure sleep hygiene. Participants from all countries were asked to respond in regard to the previous two weeks, using a six-point scale, ranging from *1* (*never*, *0%*) to *6* (*always*, *100%*). Scores were reversed so that higher scores indicated better sleep hygiene. The ASHSr has six subscales: physiological (five items), behavioural arousal (three items), cognitive/emotional (six items), sleep environment (five items), sleep stability (three items), and daytime sleep (two items). Each subscale score is the average of the items of which it comprises, with the mean of the subscale scores used to calculate the total sleep hygiene score. Internal consistency for the 24 items was good (Cronbach's $\alpha = 0.83$, $N = 324$, for the Australian data; Cronbach's $\alpha = 0.87$, $N = 193$, for the Canadian data, and; Cronbach's $\alpha = 0.77$, $N = 150$, for the Dutch data). Only one factor (cognitive/emotional scale) was chosen to enter into the regressions, as effects of pre-sleep cognitive and emotional arousal have been demonstrated previously (eg, Storfer-Isser et al. [20]), and other aspects of sleep hygiene (eg, caffeine use, consistent bedtime) were measured as independent variables. Respondents were also asked whether they "Smoked/chewed tobacco after 6 pm, or drank alcohol after 6 pm," using the same response scale.

2.2.4. Home environment and parent-set bedtime

Home environment was measured using five items from the Confusion, Hubbub and Order Scale (CHAOS [34]). Responses were on a five-point scale, ranging from 1 (*always)* to 5 (*never)*. Participants were asked to indicate how they felt at home, during the last two weeks, concerning the following items; "Our home is a good place to relax", "There is very little commotion in our home", "I often get drawn into other people's arguments at home", "There is often a fuss going on at our home", and "The atmosphere in our home is calm." The third and fourth items were reverse coded. Higher scores indicated more chaos. Internal consistency for the five items was good (Cronbach's $\alpha = 0.86$, $N = 298$, for the Australian data; Cronbach's $\alpha = 0.90$, $N = 169$, for the Canadian data; Cronbach's $\alpha = 0.80$, $N = 141$, for the Dutch data).

Adolescents were asked whether their parents set their bedtimes on weekdays, with response options measured on a seven-point scale (*never–always*). For the purpose of analysis, this question was recoded as 1 = *never/almost never*, 2 = *sometimes-always*.

2.2.5. Activities outside of school

Activities undertaken outside of school hours were assessed using modified questions from the School Sleep Habits Survey (SSHS [35]). Participants were asked about "Working at a job for pay, organized sports or a regularly scheduled physical activity, organised extracurricular activities; and study/homework outside of school hours" during the past two weeks. They were asked the number of hours/minutes spent doing each activity separately, before school and after school.

2.2.6. Room lighting

Room lighting was measured by asking, "Think about the room you spent the most time in after 6 pm, over the last two weeks." Participants were also asked which type of light they used (dim overhead, dim lamp, bright overhead, bright lamp), with adolescents able to respond to multiple options, and the start and stop time of these lights.

2.2.7. Daytime consequences

The Sleep Reduction Screening Questionnaire (SRSQ [36]) is a nine-item scale, used to assess the daytime consequences of chronic sleep reduction. It has been validated against actigraphy, with moderate-to-strong correlations found between SRSQ scores and objective sleep measures [36]. Items are scored on a three-point ordinal scale, and adolescents were asked to consider the previous two weeks when answering questions. Higher scores indicated more chronic sleep reduction. Internal validity was good for all data (Cronbach's $\alpha = 0.83$, $N = 246$, for the Australian data; Cronbach's $\alpha = 0.82$, $N = 172$, for the Canadian data; Cronbach's $\alpha = 0.78$, $N = 141$, for the Dutch data).

2.3. Procedure

An online survey, approved by the Social and Behavioural Research Ethics Committee at Flinders University, was conducted using the survey website Qualtrics. Data collection in South Australia occurred from October 2013 to May 2014, with the exception of the holiday period which may impact sleeping patterns [37,38]. As such, no data were collected between 13 December 2013 and 9 February 2014. The survey took approximately 30 min to complete, and upon completion participants could select one of four charities, of which AUD$1 would be donated.

Data from Canada were collected between 17 January to 27 February 2014 and 16 September 2014 to 23 February 2015. Ethics approval was received from the McGill University Research Ethics Board. Canadian adolescents were entered into a draw to win an iPad. Data from The Netherlands were collected between 7 November 2013 and 21 May 2014. Ethics approval was received from the Faculty Ethics Review Board of the Faculty of Social and Behavioural Sciences, University of Amsterdam. No reimbursements were offered to participants.

2.4. Statistical analysis

Data were visually inspected, with any outliers deleted [39]. Among the Australian data, bedtime (BT), sleep onset latency (SOL), mobile stop time, ASHS cognitive-emotional scale, sport after school, and caffeine use were found to be skewed; among the Canadian data, SOL, caffeine use, sport after school, and mobile phone stop time were skewed; and among the Dutch data SOL was skewed. These were corrected via appropriate transformations [39]. In terms of weekday parent-set bedtime, answers '*never/almost never*' were re-coded as 1, and responses '*sometimes to always*' were re-coded as 2, as these responses had less than 12% of participants in each response category in both the Australian and Canadian data. In terms of gender, '*male*' was coded as 1, and '*female*' coded as 2. Tobacco and alcohol use were both unevenly distributed, therefore they were recoded, such that answers of '*never*' were re-coded as 1, and responses 2–6 from the ASHS-r were re-coded as 2 (see Table 1 for frequencies). Due to the highly uneven split (ie, a 90/10 split [40]) of tobacco, all relevant regressions were performed with and without inclusion of the tobacco variable, with minimal difference to outcomes. As such, tobacco was included in analyses in order to observe any effects. Collinearity was found to be within acceptable limits (ie, variance inflation factor <10 [32]). Room lighting could not be included in analyses, due to low response rates, particularly among Australian adolescents (ie, <45%).

Multiple hierarchical regression analyses were performed using IBM SPSS Statistics 22 (IBM Corporation, United States of America) to assess the impact of protective and risk factors on BT, SOL, and total sleep time (TST). A correlation matrix between analysed factors is provided as supplementary data for each country (Tables S1, S2, S3). Age and gender were entered in step 1 for all regressions. Factors under behavioural control were entered at step 2, to ensure that any effects found in step 2 were above those found due to factors outside the participant's behavioural control. Unstandardised coefficients are not reported, due to data transformations making the units uninterpretable to the reader.

3. Results

3.1. Behavioural protective and risk factors

Hierarchical regression analyses were performed to assess the impact of protective and risk factors on BT, SOL, and TST. Different predictive factors for each sleep variable were chosen based on the results from a previous meta-analysis on the protective and risk factors on adolescents' sleep [11], such that factors previously found to have no relationship with a specific sleep variable were not included in regression models for that sleep variable.

3.1.1. Bedtime

For Australian adolescents, variables at step 1 predicted 9.6% of the variance of bedtime, $R^2 = 0.096$, $F(2,114) = 6.02$, $p = 0.003$. Additional variables added to step 2 were: mobile phone stop time, Internet stop time, tobacco, alcohol, pre-bed cognitive and emotional arousal, home environment (ie, CHAOS scores), parent set BT, and sport (after school). Of these, after school sport was associated with earlier bedtimes, whereas mobile phone and Internet stop times contributed significantly to delaying bedtimes (see Table 2). Variables in step 2 explained an additional 49.8% of variance, R^2 *change* $= 0.498$, *F change* $(8,106) = 16.22$, $p < 0.001$.

For Canadian adolescents, variables at step 1 did not significantly predict any of the variance of bedtime, $R^2 = 0.028$, $F(2,84) = 1.22$, $p = 0.301$. Of step 2 variables, good cognitive and emotional sleep hygiene was related to earlier bedtimes, whereas Internet stop times contributed significantly to delaying bedtimes (see Table 2). Variables in step 2 explained an additional 43.6% of variance, R^2 *change* $= 0.436$, *F change* $(8,76) = 7.73$, $p < 0.001$.

Among Dutch adolescents, variables at step 1 predicted 36.1% of the variance of bedtime, $R^2 = 0.361$, $F(2,89) = 25.09$, $p < 0.001$. In step 2 age and mobile phone stop time contributed significantly to delaying bedtimes (see Table 2). Variables in step 2 explained an additional 16.5% of variance, R^2 *change* $= 0.165$, *F change* $(8,81) = 3.53$, $p = 0.001$.

Table 2
Hierarchical regression analysis for variables predicting weekday BT in Australian (N = 117), Canadian (N = 87), and Dutch (N = 92) adolescents.

	Model factors	Australia		Canada		Netherlands	
		Beta	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<0.001		<0.001		<0.001
	Age	0.311	0.001	–0.044	0.682	0.611	<0.001
	Gender	0.021	0.812	0.165	0.129	–0.164[a]	0.061
2	(Constant)		<0.001		<0.001		<0.001
	Age	0.043	0.553	0.037	0.705	0.387	<0.001
	Gender	0.030	0.666	–0.058[a]	0.540	–0.071[a]	0.399
	Mobile phone stop time (weekday)	0.202	0.005	–0.155	0.106	0.287	0.005
	Internet stop time (weekday)	0.536	<0.001	0.494	<0.001	0.183	0.061
	Tobacco	0.060	0.366	0.007	0.941	–0.003	0.970
	Alcohol	0.018	0.792	0.027	0.777	0.062	0.500
	ASHS-r cognitive emotional	–0.129	0.080	–0.261	0.007	0.074	0.411
	Home environment (CHAOS)	–0.126	0.084	0.011	0.906	0.016	0.852
	Parent-set BT	–0.043	0.534	–0.169	0.081	–0.080	0.371
	Sport (after school)	–0.240	<0.001	0.063	0.487	0.031	0.711

Note. ASHS-r = Adolescent Sleep Hygiene Scale – revised, BT = bedtime, CHAOS = Confusion Hubbub and Order Scale. [a] Negative beta value indicates non-significant trend of later BT for males than females.

Table 3
Hierarchical regression analysis for variables predicting weekday SOL in Australian (N = 292), Canadian (N = 167), and Dutch (N = 136) adolescents.

	Model factors	Australia		Canada		Netherlands	
		Beta	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<0.001		<0.001		<0.001
	Age	–0.071	0.226	–0.179	0.021	–0.062	0.473
	Gender	0.075	0.199	0.145	0.061	–0.011	0.901
2	(Constant)		<0.001		<0.001		<0.001
	Age	–0.082	0.134	–0.160	0.031	–0.070	0.405
	Gender	–0.044	0.446	0.049	0.524	–0.082	0.340
	ASHS-r cognitive emotional*	–0.316	<0.001	–0.334	<0.001	–0.249	0.006
	Home environment (CHOAS)	0.120	0.047	–0.023	0.761	0.121	0.172

Note. ASHS-r = Adolescent Sleep Hygiene Scale – revised, CHAOS = Confusion Hubbub and Order Scale, * indicates p < 0.05 for all three countries.

3.1.2. Sleep onset latency

For Australian adolescents, variables in step 1 did not account for a significant amount of SOL variance, $R^2 = 0.011$, $F(2,289) = 1.60$, $p = 0.20$. In step 2, the variables explained an additional 13.1% of variance, R^2 *change* $= 0.131$, *F change* $(2,287) = 21.91$, $p < 0.001$. Higher CHAOS scores (ie, home environment) increased SOL, whereas increased cognitive and emotional sleep hygiene scores decreased SOL (see Table 3).

For Canadian adolescents, variables in step 1 accounted for 4.6% of variance in SOL, $R^2 = 0.046$, $F(2,164) = 3.94$, $p = 0.02$. In step 2, the variables explained an additional 12.3% of variance, R^2 *change* $= 0.123$, *F change* $(2,162) = 9.27$, $p < 0.001$. Better cognitive and emotional sleep hygiene scores and younger age predicted decreased SOL (see Table 3).

Among Dutch adolescents, variables in step 1 did not account for a significant amount of SOL variance, $R^2 = 0.004$, $F(2,133) = 0.275$, $p = 0.760$. In step 2, the variables explained an additional 9.1% of variance, R^2 *change* $= 0.091$, *F change* $(2,131) = 6.55$, $p = 0.002$. Increased cognitive and emotional sleep hygiene scores decreased SOL (see Table 3).

3.1.3. Total sleep time

For Australian adolescents, variables at step 1 predicted 7.4% of the variance of TST, $R^2 = 0.045$, $F(2,112) = 4.51$, $p = 0.013$. Additional variables added to step 2 were: mobile phone stop time, Internet stop time, tobacco, alcohol, caffeine use after 6:00 pm, pre-sleep cognitive and emotional arousal, home environment, parent-set BT, and sport (weekday, after school). Of these, Internet stop time was found to significantly predict a decrease in TST, and good cognitive emotional sleep hygiene, having a parent-set BT, and consuming alcohol one or more times per week were found to significantly increase TST. Variables in step 2 explained an additional 34.4% of variance, R^2*change* $= 0.344$, *F change* $(9,103) = 6.19$, $p < 0.001$ (see Table 4).

For Canadian adolescents, variables at step 1 did not predict a significant amount of variance in TST, $R^2 = 0.035$, $F(2,83) = 1.49$,

Table 4
Hierarchical regression analysis for variables predicting weekday TST in Australian (N = 115), Canadian (N = 86), and Dutch (N = 91) adolescents.

Model factors		Australia		Canada		Netherlands	
		Beta	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<0.001		<0.001		<0.001
	Age	–0.276	0.003	0.012	0.912	–0.449	<0.001
	Gender	–0.042[a]	0.646	–0.187[a]	0.088	0.041	0.677
2	(Constant)		<0.001		0.002		<0.001
	Age	–0.065	0.458	–0.149	0.205	–0.423	<0.001
	Gender	0.025	0.758	0.024	0.833	–0.019[a]	0.848
	Mobile phone stop time (weekday)	–0.124	0.151	0.087	0.436	–0.358	0.005
	Internet stop time (weekday)	–0.365	<0.001	–0.255	0.028	–0.025	0.837
	Tobacco	–0.059	0.468	0.035	0.756	0.184	0.087
	Alcohol	0.191	0.029	0.176	0.124	0.070	0.530
	Caffeine	–0.062	0.434	0.085	0.488	–0.045	0.659
	ASHS-r cognitive emotional	0.227	0.012	0.428	<0.001	0.028	0.848
	Home environment (CHAOS)	0.045	0.611	–0.041	0.706	0.060	0.576
	Parent-set BT	0.201	0.018	0.032	0.784	–0.187	0.080
	Sport (after school)	0.152	0.058	0.094	0.376	0.072	0.475

Note. ASHS-r = Adolescent Sleep Hygiene Scale – revised, BT = bedtime, CHAOS = Confusion Hubbub and Order Scale. [a] Negative beta value indicates non-significant trend of longer TST for males than females.

$p = 0.231$. From variables added in step 2, Internet stop time was found to significantly predict a decrease in TST, and good cognitive emotional sleep hygiene was found to increase TST. Variables in step 2 explained an additional 25.1% of variance, $R^2change = 0.251$, $F\ change(9,74) = 2.89$, $p = 0.006$ (see Table 4).

Among Dutch adolescents, variables at step 1 predicted 19.6% of the variance of TST, $R^2 = 0.196$, $F(2,88) = 10.72$, $p < 0.001$. Variables at step 2 did not explain additional variance in TST, $R^2change = 0.142$, $F\ change(9,79) = 1.89$, $p = 0.066$, although older age and later mobile phone stop time still significantly predicted less TST (see Table 4).

3.2. *Daytime consequences*

Relationships between sleep parameters and daytime functioning were analysed, to ascertain whether variations in adolescents' sleep are associated with daytime functioning. Significant, positive correlations were found between the SRSQ and BT ($r = 0.41$, $N = 244$, $p < 0.001$) and SOL ($r = 0.29$, $N = 244$, $p < 0.001$), whereas a negative correlation was found between SRSQ and TST ($r = –0.42$, $N = 241$, $p < 0.001$) for Australian adolescents. Similar trends were observed among SRSQ scores and sleep variables as follows for the Canadian data; BT ($r = 0.35$, $N = 171$, $p < 0.001$); SOL ($r = 0.30$, $N = 171$, $p < 0.001$), and; TST ($r = –0.44$, $N = 169$, $p < 0.001$); and the Dutch data; BT ($r = 0.29$, $N = 141$, $p = 0.001$); SOL ($r = 0.19$, $N = 139$, $p = 0.032$), and; TST ($r = –0.31$, $N = 140$, $p < 0.001$). This indicates that as adolescents go to bed later, and take longer to fall asleep, they experience more symptoms of chronic sleep reduction during the day, yet those who sleep more experience less chronic sleep reduction symptoms.

4. Discussion

Overall, although the magnitude of effect varied slightly between countries, many similarities also arose, with a large portion of variance attributed to extrinsic factors. For each country the time adolescents stopped using their mobile phone and/or the Internet, was associated with sleep, with later stop times related to later bedtimes and shorter sleep duration. In general, substance use was not related to sleep. Lower pre-sleep cognitive and emotional arousal decreased sleep latency across countries, and was related to longer total sleep length for Australian and Canadian adolescents.

4.1. *Demographic risk and protective factors*

The effects of age on bedtime and total sleep time were smaller after adding additional variables, for both Australian and Dutch data, although age remained the most notable factor associated with Dutch adolescents' total sleep, with older age predicting less sleep. Although age was unrelated to bedtime or sleep duration for the Canadian adolescents, older Canadian adolescents also had shorter sleep onset latencies. No effects of gender were found for any sleep variables, for any country. This is contrary to previous meta-analysis findings of gender differences in adolescents' time in bed [13], however, the present results of weekday data may reflect previous findings that gender differences are smaller on weekdays than weekends [13].

4.1.1. *Behavioural risk and protective factors*

Regarding *technology use*, the time adolescents stopped using either the Internet or their mobile phone had the largest harmful association with bedtime, in each country. Internet stop time also had the largest negative relationship with Australian and Canadian adolescents' sleep duration. Among Dutch adolescents, mobile phone stop time had a smaller association than adolescents' age, on decreasing sleep. Overall, this suggests that adolescents are using at least one of these devices, right before bedtime, and that this is interfering with choosing an appropriate bedtime; this reduces the amount of sleep they obtain during the week.

Concerning *substance use*, neither tobacco use nor alcohol consumption, after 6:00 pm, was related to adolescents' bedtimes. Among Australian adolescents, alcohol consumption led to more sleep. However, it should be noted that of the significant protective factors, alcohol had the smallest association. Caffeine after 6:00 pm was unrelated to total sleep time. Although the alerting effects of caffeine have been previously documented (see Snel & Lorist [41] for a review), and a relationship between evening caffeine use and sleep duration exist [11], the current study's results suggest that other factors, such as technology use, are more of a risk to sleep than stimulant use. This could be due to increased accessibility of technology (eg, up to 94% of Canadian adolescents have home WiFi [42]) comparatively diminishing the relationship between caffeine and sleep.

Having less pre-sleep cognitive emotional arousal resulted in earlier bedtimes for Canadian adolescents. Importantly, less pre-sleep cognitive emotional arousal significantly decreased sleep latency for all adolescents. Among Australian and Canadian adolescents, less pre-sleep cognitive emotional arousal also resulted in longer sleep. This shows that better cognitive and emotional pre-sleep hygiene is an important factor in aiding adolescent sleep, and should be used when designing intervention or educational programs for adolescent sleep [43,44].

Home environment was only a contributing factor for Australian adolescents. A more chaotic household was associated with longer sleep latency. A non-significant trend occurred among Australian adolescents between higher household chaos and going to bed earlier, hence it is possible that these adolescents went to bed earlier, yet took longer to fall asleep, therefore their overall sleep duration remained unaffected. Previous research suggested that sleep hygiene fully mediated the relationship between chaotic household environments and sleep latency, and partially mediated the relationship between chaotic household environments and total sleep [22]. Although not measuring sleep hygiene broadly, pre-sleep cognitive emotional arousal accounted for more variance than a chaotic household for bedtime, sleep latency, and sleep duration, for all countries (other than total sleep for Dutch adolescents). This supports the hypothesis that in less disorganised homes, good sleep hygiene enables healthy sleep habits to form [22]. Thus it appears that good sleep hygiene has a stronger relationship with sleep than a disorganised home environment. Another factor to consider, although not measured in the present study, is that adolescents' sleep latency may be related to parent sleep patterns, in particular mothers' sleep latency and night awakenings [21], hence for a full picture of the relationship between adolescent's home environment and sleep, parent sleep patterns may need to be simultaneously measured.

Surprisingly, a parent-set bedtime was not related to bedtime, and only lengthened sleep for Australian adolescents. It could be that the effects of age were larger for the Canadian and Dutch adolescents, therefore overriding any potential significance of parent-set bedtime on total sleep, particularly as older adolescents are less likely to have a parent-set bedtime [28]. Increased parental monitoring (eg, the extent to which parents are aware of their adolescent's whereabouts after school) is related to earlier bedtimes and longer sleep duration [45]. Therefore, given the large effects of mobile and Internet phone use, it may be that parents also need to increase their involvement by setting a "bedtime" for electronic devices [46], rather than just adolescents themselves.

Doing more after school sports was associated with an earlier bedtime for Australian adolescents only, whereas sports were not related to sleep duration in any country. It can be seen that, on average, adolescents played less than 2.5 h of sports after school per week. However, we did not measure the intensity of the exercise performed. Delisle and colleagues [47] asked adolescents how frequently and how intensely they exercised per week. High intensity exercise was associated with longer sleep duration, when engaged in more often. However, there was no difference in sleep length among adolescents who performed moderate physical exercise, regardless of the number of times performed per week [47]. The timing of after-school exercise is also important [48,49]. Physical activity performed after school and in the early evening may bring adolescents' bedtimes earlier, hence should be seen as a protective factor, whereas after school sports played at night (ie, within three hours of dim light melatonin onset) may result in later bedtimes [49]. Exercising that on a regular basis may also promote healthy sleep [50]. It may be that intensity, timing, and/or regularity, rather than duration, has a greater impact on adolescent sleep.

One strength of the present study is the assessment of protective and risk factors within different countries allowing determination of whether a one-size-fits-all approach can be taken regarding factors related to adolescent sleep. Underlying cultural discrepancies between samples may include legislation regarding legal drinking age [51], promotion of cycling and active lifestyle in The Netherlands [52,53]; and health care [54], including perceived availability of help for mental health problems [55]. Although this paper did not assess the direct impact of these factors on sleep, it is plausible that these differences in culture at a broader social level create cultural differences that allow factors to manifest differently between countries as helpful, harmful, or of little influence, in relation to adolescent sleep.

4.2. Limitations and future directions

We examined the sleep of adolescents in three different countries. However, future research could include countries from other continents, particularly Asia, where greater sleep restriction occurs [12], which would provide further insights into the role of 'country' in adolescents' sleep. The online survey was self-report, introducing the potential of reporting error. Moreover, the study only measured adolescents' sleep and behavioural habits at a single time point, therefore the association between the long-term impact of protective and risk factors on sleep could not be determined. Also, as the present study was not experimental, causality cannot be assumed. This also gives rise to the possibility that 'country' is in fact an epiphenomenon, thus less relevant than other extrinsic variables. Future research should use experimental designs to investigate the link between factors consistently linked to sleep, such as Internet and/or mobile phone use and cognitive and emotional pre-sleep hygiene, to determine cause and effect, as well as the best manner in which to intervene to assist adolescents' sleep.

5. Conclusion

In conclusion, behavioural factors share a small-to-large portion of variance on sleep parameters. In terms of individual protective factors, less pre-sleep cognitive emotional arousal is related to shorter sleep latencies, and is beneficially related to total sleep. Later use of a mobile and/or Internet is associated with later bedtimes and short sleep duration, with the strength of the association differing for each device between countries. Internet stop time had higher associations for Australian and Canadian adolescents, whereas the time Dutch adolescents stopped using their mobile phones showed a stronger relationship. Future experiments are needed to determine the cause and effect direction of protective factors, particularly cognitive emotional arousal, and risk factors, in particular pre-sleep technology use, as well as interventions employing helpful strategies to minimise pre-sleep cognitive emotional arousal or technology use. Experiment and intervention designs should take into account the relative importance of each factor, which has the potential to vary depending on country of residence. Moreover, clinicians should consider that whilst similar patterns for the most pertinent protective and risk factors exist between countries, some factors may be more relevant in their country of residence, and hence their adolescent clients.

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Conflict of interest

None.

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Appendix: Supplementary data

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