



Original Article

More than just sleeping in: a late timing of sleep is associated with health problems and unhealthy behaviours in adolescents

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ABSTRACT

Objective: New research suggests that the timing of sleep, or chronotype, affects the mental well-being of adolescents, however evidence of its links to physical health is limited. We investigated the associations between chronotype and various health outcomes and behaviours in a national sample of Canadian adolescents.

Methods: Data were from the 2014 Canadian Health Behaviour in School-Aged Children survey (29,470 students; ages 10–18). Chronotype was estimated using the midpoint of sleep on weekends, corrected for catch-up sleep. We tested the associations with physical health (headache, stomach ache, back ache, dizziness, overweight, self-rated health) and health behaviours (consumption of fruits, vegetables, sweets, soft drinks, and energy drinks, smoking, physical activity, screen time) using random-effects regressions adjusted for sleep duration and individual, family, and school characteristics.

Results: The average chronotype was 4:11 a.m. for boys and 4:10 for girls. Each 1-h delay in chronotype was associated with more headaches, stomach aches, and back aches [proportional odds ratios (PropORs) 1.08, 1.08, 1.07, respectively (boys), 1.10, 1.10, 1.08, respectively (girls)], and dizziness and worse self-rated health in girls (PropORs 1.10 and 1.09, respectively), but not overweight. A 1-h delay in chronotype also related to daily soft drink consumption [ORs 1.17 (boys), 1.11 (girls)], smoking [ORs 1.23 (boys), 1.37 (girls)], screen time [additional 0.64 h (boys), 0.74 h (girls)], less vegetable consumption in boys (OR 0.96), and daily energy drink consumption in girls (OR 1.42).

Conclusion: A later chronotype related to worse physical health and unhealthy behaviours in Canadian adolescents. Studies are needed to clarify the underlying mechanisms.

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1. Introduction

Sufficient sleep is crucial for the healthy development and well-being of youths [1,2]. Recently updated guidelines recommend that adolescents have a minimum of 8–9 h of sleep a night depending on their age (5–13 years old: 9–11 h; 14–17 years old: 8–10 h) [3,4]. Yet approximately one third of North American adolescents do not meet these recommendations [5]. The harmful health consequences of insufficient sleep on adolescents has been found in numerous studies [1,2]. Complementary to this literature is

emerging evidence that the timing of sleep – or *chronotype* – also plays a role in adolescent health. Chronotype refers to the natural preference in the timing of daily patterns of activities, such as eating, exercising, and sleeping, that is controlled by the biological circadian rhythm [6]. Individuals with an early chronotype naturally sleep earlier in the 24-h day cycle (eg, “early birds”), while those with a late chronotype sleep later (eg, “night owls”). Individual differences in chronotype have genetic underpinnings and vary by age and sex [7], although external factors are also involved, such as latitude [7], variability in light exposure [7], parenting [8], and household environment (eg, living in a low income household [9]). Notably, the normative developmental course of chronotype is to shift later by up to 2–3 h in adolescence and shift earlier in early adulthood [10].

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The evidence on adolescent chronotype points to an association between later sleep times and poor health [11] but the data are scant and focused on mental health [12–14]. Less is known about the implications of chronotype for physical health and healthy behaviours in youths. Adolescents with a late chronotype tend to get less sleep than their peers [15–17], which might be because a late sleep timing conflicts with their social obligations, such as an early school start time [18,19]. Insufficient sleep duration has been linked to physical health problems [1,2] and to unhealthy behaviours such as altered food preferences, particularly for high sugar and high fat food [20,21], use of stimulants [22], and physical inactivity [23], which may also conversely affect sleep times [24,25]. A related hypothesis is that the chronic mismatch between biological and societal schedules disrupts the circadian rhythm and dysregulates physiological pathways such as metabolism, blood pressure, immune functions, and pain [26–30]. A third hypothesis is that a later chronotype provides fewer opportunities for engaging in healthy behaviours because the biologically optimal times for activities, such as eating and physical exercise [30,31], are misaligned relative to their social times. For example, youths with a late chronotype are more likely to skip breakfast [32,33] or eat at the wrong time for their biology, affecting their digestion and nutrition [30]. Further, because of the constant struggle against their natural clock, adolescents with a late chronotype may have fewer resources for cognitive and behavioural self-regulation [34,35] which are needed for goal-oriented tasks like health-promoting behaviours.

Previous studies have found that adolescents with later chronotypes have higher rates of smoking [36], soda consumption [37,38], and sedentary activities such as screen time [36,39–41], and lower consumption of fruits and vegetables [37,42] and levels of physical activity [36,37,39,41] compared to their peers with early chronotypes, but results have been inconsistent and a number of findings did not account for sleep duration, a potentially important confounding factor. The evidence linking adolescent chronotype and physical health is more limited. Most of the research focused on markers of excess body weight in adolescents and found that chronotype related to a higher body-mass index and waist-to-hip ratio [41–43]. Other studies reported an association between a later chronotype and migraine in a sample of children and adolescents [44] and with abdominal pain in a sample of adolescent girls [45] but their analyses did not account for sleep duration or health behaviours. In sum, the link between adolescent chronotype and physical health, independent of sleep duration and health behaviours, remains largely unknown.

Building on the growing research into circadian typology and adolescent health, the objectives of this study were to examine the associations of chronotype with a broad range of 1) common physical health indicators and 2) health behaviours, adjusting for sleep duration and important individual, family, and environmental factors. Since these associations could vary by gender, age, and socioeconomic groups, we tested the effect modification of these factors. Our aim was to provide a wide-ranging assessment of the link between chronotypes and physical health during adolescence, a critical time for development when sleeping patterns may be most vulnerable to disruption. We hypothesized that later chronotypes would relate to 1) worse health and 2) more unhealthy behaviours.

2. Methods

2.1. Participants

We used cross-sectional data from the 2013/2014 Canadian Health Behaviour in School-Aged Children (HBSC) survey. The HBSC

surveyed a nationally representative sample of 30,117 students in grades 6 to 10 (1320 classes in 367 schools) from all provinces and territories in Canada. The HBSC used a two-stage cluster approach to capture a representative sample of students by grade and school. Youth attending private, special needs, or home schools, and incarcerated or homeless youth were ineligible. The survey used a standard questionnaire format, item order, and testing conditions in accordance with the international HBSC protocol [46]. Teachers or trained interviewers distributed the questionnaires in class. The Queen's University General Research Ethics Board approved the research (Research Ethics Committee reference file #6010236). Consent was obtained from the participating school boards, individual schools, parents, and students. Student participation was voluntary. In this study, we excluded students from grades 5 ($n = 25$), 11 ($n = 294$), and 12 ($n = 5$) for whom survey weights were unavailable, children under 10 years old ($n = 12$) since we were interested in adolescents, students with missing information on gender ($n = 153$), and students from three schools where start time was unavailable because the schools had since permanently closed ($n = 132$) and from two schools that had no specific start time ($n = 5$). The final sample included 29,470 students between the ages 10 and 18 years from 362 schools.

2.2. Measures

2.2.1. Sleep measures

Students were asked what time, in the past week, they usually turned out the light to sleep and what time they usually woke up on school days and on weekends, separately (free entry to the nearest minute). From these data, we calculated the chronotype of the participants using the local time of mid-sleep on free (weekend) days (MSF) [47]. The measure of chronotype is independent of sleep duration. For example, the estimated chronotype of a participant who reports falling asleep at 12:00 a.m. and waking up at 8:00 a.m. would be 4:00 a.m., the mid-point of sleep. Similarly, the chronotype of a participant falling asleep at 1:00 a.m. and waking up at 7:00 a.m. would also be 4:00 a.m. We used weekend days instead of school days because they are more likely to capture the natural sleep patterns of adolescents. We corrected for any potential sleep debt that accumulated during the week because of shorter sleep on school days (MSF sleep corrected, or MSF_{SC}) [47]. Details on the calculation of chronotype are available in a previous report [14]. The MSF_{SC} provides a continuous measure of chronotype that was found to correlate with the dim light melatonin onset [48], the most reliable measure of circadian timing in humans [49]. We excluded values greater than 3 standard deviations from the mean ($n = 221$). We calculated average sleep duration on school days from bedtimes and wake times. This approach correlates with objective sleep measures in children [50] and in young adults [51]. We excluded values greater than 3 standard deviations from the mean ($n = 408$).

2.2.2. Physical health indicators

The HBSC measured the frequency of four physical health symptoms in the last 6 months using a symptom checklist that included headache, stomach ache, back ache, and feeling dizzy. Response categories were: about every day; more than once a week; about every week; about every month; rarely or never. The HBSC symptom checklist was shown to have good validity [52–54] and reliability [52,55,56] in samples of adolescents. We assessed self-rated health from the question “Would you say your health is excellent, good, fair or poor?” We calculated the standardized age- and sex-adjusted body-mass indices z-score (BMI_z) from self-reported weight and height (kg/m^2) and identified overweight status (≥ 1 SD of BMI_z) based on WHO child growth standards [57].

2.2.3. Health behaviours

The HBSC questionnaire asked about lifestyle factors including daily consumption of fruits (yes; no), vegetables (yes; no), sweets (yes; no), soft drinks (yes; no), and energy drinks (yes; no), current smoking (yes; no), physically active days, and screen time. Physically active days were assessed by asking the participants how many days they had been active for an hour or more in the past week (0–7 days). Screen time was estimated by adding the number of free-time hours spent per day watching television or videos, spent playing games on the computer or electronic devices and spent using the computer or other electronic devices, on week days (response scale 0, 0.5, 1, 2, 3, 4, 5, 6, 7+ hours for each item, respectively).

2.2.4. Covariates

We controlled for potential sociodemographic, family, school and geographic confounders based on the literature. Sociodemographic factors included the age, gender, and grade of students. Family characteristics included family affluence and parental involvement in daily scheduling. Family affluence was assessed with the Family Affluence Scale (FAS) III [58] which asks participants about six material indicators of family wealth (sum score range 6–19). For some analyses, we categorized the FAS score into approximate tertiles based on proportional ranks within grade and gender groups (low, medium, high). We used items about family support (1 = strongly agree to 6 = strongly disagree) and frequency of family dinners (1 = never to 6 = every day) as proxy for parental involvement in daily scheduling. School and geographic variables included the start time, latitude, rurality, and province of schools and the season of survey (spring: April–June; fall: September–December; winter: January–March). We collected information on school start times through the school websites or by contacting schools, pinpointed geographic latitudes based on the school addresses and using publicly available geospatial data (<http://www.gpsvisualizer.com/geocoder>), and identified rurality (rural vs. non-rural) based on the alphanumeric postal codes of the schools [59].

2.3. Statistical analysis

We applied multilevel ordinal logistic regressions to ordinal outcomes, modified Poisson regressions to binary outcomes, and linear regressions to continuous outcomes to examine the association between chronotype and each health indicators and health behaviours, while accounting for school-level clustering. All models were adjusted for sleep duration, sociodemographic, family, school, and geographic factors. Because health behaviours could also act as confounders, we included all concurrent health behaviours (consumption of fruits, vegetables, sweets, soda, and energy drinks, current smoking, physically active days, and screen time) in the models. To test for effect modification, we included interaction terms by gender, age, and affluence in the main model. In preliminary analyses, we found gender to be a significant effect modifier in most models and therefore present stratified analyses by gender and examined the influence of age and affluence separately for boys and girls.

We conducted several sensitivity analyses. We found that the tail-end distribution of sleep duration varied slightly by chronotype [14]. We therefore reran analyses only on participants with a sleep duration between 6:30 h and 10:30 h (<5th and >95th percentile) on school days ($n = 23,579$). Pubertal status, independent of age, could be a confounder [60,61] but information on pubertal stage was not available in the survey. To explore some of the potential confounding effect of pubertal status, we reran models including the age of menarche as proxies for pubertal timing among

menstruating adolescent girls ($n = 11,690$). Variables had between 0 and 5% missing except chronotype (14% missing data), sleep duration (12%), family affluence (11%), parental support (8%), overweight (23%), and screen time (10%). In a sensitivity analysis, we imputed missing values using multiple imputation by chained equations from the `mi` command in Stata.

Statistical analyses were conducted in Stata (version 14.1, Stata Corp, College Station, TX). All analyses were weighted using survey weights to ensure results were representative of public school students in Canada. Survey weights and school-level clustering were handled using Stata's complex survey (`svy`) commands. Because we tested multiple outcomes, we applied the Benjamini–Hochberg false discovery rate procedure [62], to account for multiplicity and the greater risk of type 1 errors. We calculated the Benjamini–Hochberg adjusted critical values, with a false detection rate at 5%, using a spreadsheet method [63,64], to assess the significance of the 12 p-values of physical health outcomes (6 outcomes by gender) and the 16 p-values of health behaviours (8 behaviours by gender).

3. Results

The characteristics of adolescent boys and girls were similar across sociodemographic, family, school, and geographic factors variables (Table 1). The average chronotype (MSF_{SC} , or time of mid-sleep) was 4:11 a.m. (standard deviation (SD) 1:25 h) in boys and 4:10 a.m. (SD 1:20 h) in girls and the average week day sleep duration was 8:43 h (SD 1:18 h) in boys and 8:43 h (SD 1:14 h) in girls. Chronotype was moderately correlated with sleep duration ($r = -0.30$) and weakly correlated with school start time ($r = 0.06$). Girls reported more frequent health complaints compared with boys (Table 2). Girls also reported eating fruits and vegetables more frequently and drinking soft drinks and energy drinks less frequently than boys (Table 2).

We found that a later chronotype was associated with more frequent physical health problems, independent of sleep duration, health behaviours, and individual, family, and geographic factors (Table 3 and Supplementary Tables 1 and 2). An hour delay in mid-sleep was associated with more frequent headaches (proportional odds ratio (PropOR) 1.08, 95% CI 1.04, 1.13 [boys] and 1.10, 95% CI 1.05, 1.15 [girls]), stomach aches (PropOR 1.08, 95% CI 1.03, 1.13 [boys] and 1.10, 95% CI 1.05, 1.15 [girls]), and back aches (PropOR 1.07, 95% CI 1.01, 1.14 [boys] and 1.08, 95% CI 1.03, 1.13 [girls]) in boys and girls, and with dizziness (PropOR 1.10, 95% CI 1.04, 1.16), and worse self-rated health (PropOR 1.09, 95% CI 1.04, 1.14) in girls specifically. Chronotype was not associated with overweight. Results remained statistically significant after correction for multiple testing (the Benjamini–Hochberg procedure required a p-value <0.033 for significance).

A later chronotype was also associated with poor lifestyle behaviours, independent of sleep duration and controlling for other concurrent health behaviours (Table 4 and Supplementary Tables 3 and 4). An hour delay in mid-sleep was associated with a greater odd of drinking soft drinks daily (OR 1.17, 95% CI 1.08, 1.27 [boys] and 1.11, 95% CI 1.04, 1.19 [girls]), of being a smoker (OR 1.23, 95% CI 1.09, 1.39 [boys] and 1.37, 95% CI 1.27, 1.47 [girls]), and more screen time (+0.64 h, 95% CI 0.52, 0.74 [boys] and +0.72 h, 95% CI 0.62, 0.85 [girls]) in boys and girls, a lower odd of eating vegetables daily (OR 0.96, 95% CI 0.94, 0.99) in boys, and greater odds of drinking energy drinks daily (OR 1.42, 95% CI 1.13, 1.77) in girls. There was no association between chronotype and daily consumption of fruits, sweets, or frequency of physically active days. Results were unchanged after correction for multiple testing (the Benjamini–Hochberg procedure required a p-value <0.025 for significance).

Table 1
Characteristics of study participants, by gender (n = 29,470).

	Boys n = 14,539	Girls n = 14,931
	Weighted % (n)	Weighted % (n)
Sociodemographic and family characteristics		
Age (years)		
Weighted mean (SD)	14.1 (1.5)	14.1 (1.4)
Grade		
6	15.3 (2231)	15.1 (2282)
7	19.6 (2880)	19.3 (2868)
8	18.8 (2795)	20.2 (2978)
9	24.1 (3461)	23.3 (3479)
10	22.2 (3172)	22.0 (3324)
Family affluence		
Weighted mean (SD)	15.0 (2.4)	15.0 (2.4)
Family support		
Strongly agree	31.3 (3879)	30.6 (4132)
Agree	35.3 (4841)	32.4 (4554)
Neither agree nor disagree	22.0 (2881)	23.7 (3325)
Disagree	6.4 (936)	8.3 (1250)
Strongly disagree	4.9 (624)	5.0 (751)
Family dinners		
Never	4.8 (742)	4.4 (713)
<Once a week	4.7 (728)	5.5 (822)
1–2 days a week	7.7 (1162)	8.3 (1259)
3–4 days a week	12.1 (1848)	12.9 (2040)
5–6 days a week	19.8 (2717)	19.8 (2895)
Every day	51.0 (6901)	49.1 (6853)
School and geographical characteristics		
School start time (h:min)		
Weighted mean (SD)	8:38 a.m. (0:23)	8:37 a.m. (0:23)
Travel time to school		
<5 min	17.0 (2930)	16.2 (2831)
5–15 min	41.8 (5995)	42.6 (6407)
16–30 min	23.1 (3016)	24.1 (3257)
31–60 min	13.1 (1666)	13.4 (1628)
>60 min	5.0 (505)	3.8 (423)
School latitude (°)		
Weighted mean (SD)	47.3 (3.4)	47.2 (3.4)
Rural area		
Rural	82.8 (10,157)	81.2 (10,545)
Non-rural	17.2 (4382)	18.8 (4386)
Season of survey		
Spring	67.8 (7634)	68.1 (8012)
Fall	8.2 (1650)	8.3 (1656)
Winter	24 (5255)	23.6 (5263)
Sleep measures		
Sleep duration on school days (h:min)		
Weighted mean (SD)	8:45 (1:18)	8:43 (1:14)
Chronotype (MSFsc) (h:min)		
Weighted mean (SD)	4:11 a.m. (1:25)	4:10 a.m. (1:20)

SD: standard deviation.

MSFsc: mid-sleep on free days, sleep corrected (measure of chronotype).

In the effect modification analysis, we found that the association between chronotype and headaches among girls was modified by affluence group ($p = 0.002$). A later chronotype was associated with a higher frequency of headaches among girls in the highest (PropOR 1.18, 95% CI 1.10, 1.26) and middle (PropOR 1.15, 95% CI 1.05, 1.27) tertile of family affluence but not among those in the lowest tertile (PropOR 0.98, 95% CI 0.90, 1.06). In addition, age moderated the association with screen time in girls (beta coefficient of interaction term -0.16 , 95% CI -0.25 , -0.08 , $p < 0.001$), suggesting that the association between a later chronotype and more screen time decreased with age. There was no evidence of effect modification by affluence or age for other health outcomes or behaviours.

Results remained largely unchanged when we restricted the sample to students who slept between 6:30 and 10:30 h on school days or when we controlled for age of menarche among menstruating adolescent girls, although confidence intervals were wider due to smaller sample sizes (Supplementary Tables 5–8). Results were also robust to imputation of missing data (Supplementary Tables 5–8).

Table 2
Physical health indicators and health behaviours of study participants, by gender (n = 29,470).

	Boys n = 14,539	Girls n = 14,931
	Weighted % (n)	Weighted % (n)
Physical health indicators		
Head aches		
About every day	3.7 (478)	8.0 (1145)
More than once/week	7.7 (1113)	14.9 (2227)
About every week	10.9 (1558)	15.4 (2231)
About every month	25.3 (3658)	23.8 (3504)
Rarely or never	52.4 (7242)	37.9 (5535)
Stomach aches		
About every day	1.9 (238)	3.9 (597)
More than once/week	4.1 (577)	9.6 (1415)
About every week	7.7 (1109)	11.5 (1727)
About every month	24.8 (3643)	34.1 (4944)
Rarely or never	61.4 (8389)	40.9 (5879)
Back ache		
About every day	4.6 (616)	8.4 (1186)
More than once/week	6.1 (858)	9.3 (1318)
About every week	9.9 (1399)	11.2 (1593)
About every month	18.4 (2595)	20.1 (2943)
Rarely or never	61.0 (8398)	51.0 (7407)
Feeling dizzy		
About every day	3.4 (478)	5.5 (980)
More than once/week	5.3 (780)	9.2 (1408)
About every week	8.0 (1120)	9.1 (1473)
About every month	15.9 (2300)	16.8 (2444)
Rarely or never	67.4 (9316)	59.4 (8282)
Overweight		
No	70.7 (8030)	79.1 (8740)
Yes	29.3 (3402)	20.9 (2435)
Health behaviours		
Daily fruit consumption		
No	54.7 (8349)	46.1 (7401)
Yes	45.3 (5993)	53.9 (7400)
Daily vegetable consumption		
No	58.1 (8817)	48.8 (7864)
Yes	41.9 (5305)	51.2 (6729)
Daily sweet consumption		
No	84.4 (11,637)	84.8 (11,987)
Yes	15.6 (2191)	15.2 (2275)
Daily soft drink consumption		
No	88.6 (12,258)	93.0 (13,422)
Yes	11.4 (1907)	7.0 (1200)
Daily energy drink consumption		
No	97.7 (13,908)	99.0 (14,604)
Yes	2.3 (386)	1.0 (179)
Current smoking		
No	93.5 (12,847)	94.2 (13,506)
Yes	6.5 (1054)	5.8 (1036)
Physically active days		
Weighted mean (SD)	4.9 (2.0)	4.3 (2.0)
Screen time (h:min)		
Weighted mean (SD)	12:26 (5:15)	12:20 (5:11)

SD: standard deviation.

4. Discussion

We reported on the association between chronotype and a broad range of common physical health indicators and health behaviours in a representative sample of adolescents. A later chronotype was associated with more physical health symptoms, including more frequent headaches, stomach aches, and back aches in boys and girls, and with dizziness and lower self-perceived health in girls. Chronotype was not associated with overweight in our study. Moreover, a later chronotype related to more unhealthy behaviours, including drinking soft drinks, smoking, and more screen time in boys and girls, eating fewer vegetables in boys, and drinking energy drinks in girls. These findings controlled for sleep duration, individual and environmental factors, and concurrent

Table 3
Regression analysis of physical health indicators in Canadian adolescent boys and girls: coefficient estimates and 95% confidence intervals.

Variable	Headache	Stomach ache	Back ache	Dizziness	Overweight	Self-rated health
	Proportional odds ratio (95% CI)	Odds ratio (95% CI)	Proportional odds ratio (95% CI)			
Chronotype (h)						
Boys	1.08*** (1.04 1.13)	1.08*** (1.03 1.13)	1.07* (1.01 1.14)	1.03 (0.98 1.08)	1.02 (0.98 1.07)	1.05 (0.99 1.11)
Girls	1.10*** (1.05 1.15)	1.10*** (1.05 1.15)	1.08** (1.03 1.13)	1.10*** (1.04 1.16)	1.04 (0.99 1.09)	1.09*** (1.04 1.14)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Models were adjusted for student characteristics (age, gender, grade, travel time to school), health behaviours (fruits, vegetables, sweets, soft drink, and energy drink consumption, smoking status, physically active days, sedentary time), family characteristics (affluence, family support, family dinners), school geographic information (rurality, latitude, province) and season of survey and were weighted using survey weights.

Full results from the regression models are available in [Supplementary Tables 1 and 2](#).

Table 4
Regression analysis of health behaviours in Canadian adolescent boys and girls: coefficient estimates and 95% confidence intervals.

Variable	Daily fruit consumption	Daily vegetable consumption	Daily sweet consumption	Daily soft drink consumption	Daily energy drink consumption	Current smoking	Physically active days	Screen time (h)
	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Beta coefficient (95% CI)	Beta coefficient (95% CI)
Chronotype (h)								
Boys	0.99 (0.96 1.01)	0.96** (0.94 0.99)	0.97 (0.91 1.04)	1.17*** (1.08 1.27)	1.07 (0.87 1.30)	1.23*** (1.09 1.39)	0.03 (−0.00 0.06)	0.63*** (0.52 0.74)
Girls	0.98 (0.96 1.00)	0.99 (0.97 1.01)	0.97 (0.93 1.01)	1.11** (1.04 1.19)	1.42** (1.13 1.77)	1.37*** (1.27 1.47)	−0.04 (−0.09 0.01)	0.74*** (0.62 0.85)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Models were adjusted for student characteristics (age, gender, grade, travel time to school), concurrent health behaviours (fruits, vegetables, sweets, soft drink, and energy drink consumption, smoking status, physically active days, sedentary time), family characteristics (affluence, family support, family dinners), school geographic information (rurality, latitude, province) and season of survey and were weighted using survey weights.

Full results from the regression models are available in [Supplementary Tables 3 and 4](#).

health behaviours. Previous research on the link between chronotype and adolescent health has focused on mental health and body weight. Our findings extend previous literature by showing that the chronotype of adolescents further relates to a range of physical health problems. Consistent with our results, studies have found that later sleep times were associated with unhealthy behaviours in adolescents [36–42]. Our study adds to this body of work and further suggests that some of these associations may vary by gender.

Headaches, stomach aches, and back aches were more common among adolescents with a later chronotype, independent of their sleep duration and lifestyle factors. These results are the first to link the chronotype of adolescents to markers of physical health, independent of sleep duration and health behaviours, beyond body weight. Similar to our findings, previous studies have reported associations between adolescent chronotype and migraine [44] and abdominal pain [45] but these were unadjusted for sleep and lifestyle factors. Several possible mechanisms could explain these findings in adolescents. One hypothesis is that the biological clock of adolescents with a late chronotype conflicts with the societal schedule around school, eating, and sleeping times, affecting their health either directly through circadian disruptions, or indirectly by impeding on healthy behaviours. Another possibility is that having a late chronotype itself is associated with biological and health differences. For instance, chronotype is linked to differences in the timing and levels of cortisol, a marker of psychophysiological stress, in adolescents and young adults [65]. Conversely, symptoms of physical aches could delay the sleep timing of adolescents [25]. Alternatively, external factors could be contributing to a delayed chronotype and causing physical symptoms, such as light, noise, or air pollution [66]. The reason that a later chronotype is associated with dizziness and worse self-rated health specifically in girls is not clear and warrants further exploration. In contrast with others [41–43], we found no association between chronotype and indicators of overweight in adolescents. However, our study was

limited by self-reported weight and height, with a non-negligible proportion of missing (23%), which may have underestimated the association.

Adolescents with later chronotypes were more likely to smoke, drink soft drinks every day, and spend more time in front of a screen than those with earlier chronotypes. Previous studies have reported similar findings with smoking [36], soda consumption [37,38], and screen time [39,40]. Our study strengthens this evidence by showing that these associations are robust to several controls, such as sleep duration, school start time, parental involvement, and other concurrent lifestyle behaviours. The mechanism underpinning these associations is likely bidirectional. Although a later chronotype could hamper healthy behaviours through psychosocial and cultural factors described above, the specific health behaviours linked with chronotype in this study (smoking, consuming soft drinks, screen time) could be behavioural strategies to stay awake during the day and that can delay the onset of sleep [24]. Boys that had a later chronotype were less likely to eat vegetables every day and girls with a later chronotype were more likely to drink energy drinks daily. These findings point to gender differences in the role of chronotype on diet, potentially mediated through sociocultural norms or biological pathways. Future studies examining the links between dietary and sleep patterns by gender are encouraged.

Strengths of this study include use of data from a large nationally representative sample of adolescents, and adjustments for numerous potential confounders, some of which had been lacking or missing from the literature until now, such as sleep duration, school start time, health behaviours, parental factors, and geographic variables. We also conducted several sensitivity analyses to check the robustness of our findings and carefully explored heterogeneity by gender, age, and socioeconomic status. Limitations include the estimation of chronotype and sleep duration from self-reported sleep times in the past week. Although objective sleep measurements could yield more precise estimates, self-reported

sleep data correlate well with actigraphy data [48,50,51] and may be easier to collect in the context of large surveys. A period of one week may be too short to estimate habitual sleep times and the use of a longer timeframe and sleep diaries could be used in future studies. Further, our estimation of chronotype was based on weekend sleep patterns and assumed unrestricted sleep on weekends, which may not be true for all participants. This misclassification would underestimate effects, suggesting that actual associations may be even stronger. Pubertal status could be a confounder [60,61] but information on pubertal stage was not available in the dataset. However, in sensitivity analyses, adjusting for menarche timing, a proxy for pubertal timing, did not substantially alter the results among girls. Nonetheless, pubertal status differs from puberty timing and its impact in boys is unclear. Health outcomes and behaviours were self-reported, which might lead to measurement error or bias. Notably, self-reported weight and height tend to underestimate BMI and the prevalence of overweight [67]. Other sources of residual confounding are possible, such as environmental factors (eg, air pollution), that might impact both chronotype and physical health. Lastly, our data were cross-sectional, and the direction of causality could not be inferred. The relationship between chronotype and physical health in youths could be bidirectional or dynamic, potentially involving interactions of multiple systems and contextual effects. In addition to chronotype potentially affecting physical health, poor physical health can disrupt sleep patterns [25].

5. Conclusion

A later timing of sleep was associated with a broad range of health problems and poor health behaviours in a nationally representative sample of Canadian youths. These findings suggest that the timing of sleep, and not only the duration, is related to adolescent health. The misalignment of adolescents' sleep with the societal schedule is an emergent public health concern [2]. Although chronotype is largely governed by biology, external influences, such as light pollution, are modifiable factors that could be targeted by public health strategies. Future intervention studies are recommended. In addition, understanding the role of chronotype on health-impaired behaviours among adolescents may help tailor public health interventions to reduce adverse behaviours (eg, smoking), which have been less effective in some subgroups despite large-scale efforts. Further studies into the mechanisms that link circadian typology, health behaviours, and physical health in adolescents are needed.

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Author contributorship

GG conceptualized and designed the study, collected the school data, carried out the analyses, drafted the initial manuscript, and reviewed and revised the manuscript. ID and RDW critically reviewed and revised the manuscript. FJE contributed to the design of the study, coordinated data access, and reviewed and critically revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Conflict of interest

The authors report no conflict of interests.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <https://doi.org/10.1016/j.sleep.2018.10.029>.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.sleep.2018.10.029>.

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