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Original Article

Associations of sleep duration on school nights with self-rated health, overweight, and depression symptoms in adolescents: problems and possible solutions

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ABSTRACT

Objective: To investigate associations between sleep duration and health-related measures, and factors associated with short sleep, in adolescents in an East Asian society with strong emphasis on academic achievement.

Methods: Adolescents aged 13–19 years (n = 2346) from eight schools in Singapore (five local, three international) took part in a cross-sectional survey of sleep habits, school life, and health. Self-rated health, overweight (International Obesity Task Force Criteria), and depression symptoms were compared in adolescents with short (<7 h), moderately short (7 to <8 h), or an appropriate amount of sleep (8–10 h) on school nights.

Results: Short sleep on school nights was associated with poorer self-rated health, increased odds of being overweight (adjusted odds ratio [OR_{adj}] = 2.56, 95% confidence interval = 1.39–4.70), and increased odds of feeling depression symptoms (sadness, irritability, worthlessness, low motivation, difficulty concentrating, anhedonia, anxiety, and thoughts of self-harm/suicide) compared with an appropriate sleep duration (OR_{adj} = 2.10–4.33, $p < 0.05$ for each symptom). Barriers to healthy sleep included later preferred sleep timing (a relative indicator of later chronotype), lower parental supervision of bedtime, longer study time, early school start time, and longer travel time. Students at local schools were less likely to have a parent-set bedtime, and spent more time on homework/studying. Later bedtime in local schools attenuated the benefit of later school start time on nocturnal sleep duration.

Conclusions: Short sleep may contribute to poorer adolescent health and well-being. Strategies for improving sleep in hard-driving East Asian societies should take into account sociocultural factors that may impede removal of barriers to healthy sleep.

1. Introduction

Many adolescents do not get adequate sleep on school nights. This can result in sleep deficiency, defined as a deficit in the quantity or quality of sleep obtained versus the amount needed for optimal performance, health, and well-being [1]. Nonrestorative sleep associated with sleep deficiency can give rise to daytime sleepiness and impaired cognitive functioning [2]. Adolescents who are repeatedly exposed to insufficient sleep show cumulative deficits in cognitive processes essential for learning, including attention, processing speed, and working memory [3]. Memory encoding and recall are also impaired by sleep restriction [4,5], which may contribute to poorer academic performance in adolescents with short sleep [6,7]. Napping and recovery sleep on weekends can mitigate daytime sleepiness and temporarily restore cognitive functioning, but these coping behaviors are likely insufficient to counteract fully the effects of chronic partial sleep deprivation on adolescents' performance [8].

Sleep deficiency in adolescents is also associated with absenteeism, behavioral problems, and negative health outcomes [9,10]. Short sleep in adolescents is prospectively associated with obesity [11] and has been linked to health-risk behaviors for weight gain, including increased dietary intake and sedentary activity [12–15].

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Sleep is also important for adolescents' mental health and well-being, as evidenced by cumulative negative effects of chronic partial sleep deprivation on mood and emotional regulation [3,16]. In addition, adolescents with short sleep are more likely to experience anxiety and depression symptoms, and are at greater risk for suicidal behavior [17–19].

Chronic sleep restriction in adolescents is caused by the convergence of biological and sociocultural factors [20]. During adolescence, there is a phase-delay shift in circadian rhythms that results in a preference for later bedtimes and wake-up times [21]. In addition, the build-up of homeostatic sleep pressure during wakefulness occurs more slowly in adolescents compared with younger children [22], making it easier for postpubertal children/adolescents to delay their bedtime. With increased autonomy and independence, adolescents are more likely to make their own decisions regarding when to go to bed. This can result in late bedtimes and reduced nocturnal sleep in adolescents who have poor sleep hygiene or who sacrifice sleep for homework/studying time [23–25]. These effects are often compounded by the need to wake up early, when the circadian drive for sleep is near its peak and homeostatic sleep pressure has not been fully dissipated. Adolescents who attend a school with an early start time or that is located far from home are often forced to wake up early to reach school on time [26–28], which in turn can reduce nocturnal sleep duration and adversely affect daytime functioning, health, and well-being.

Sleep deficiency may be especially problematic in East Asian societies with heavy emphasis on academic achievement, where many students believe that it is necessary to sacrifice sleep to pursue academic goals. Cross-cultural comparisons have shown that adolescents in Asian countries go to bed later and sleep less than their counterparts in Western cultures [29,30]. Singapore is a typical East Asian society with a Confucian-heritage culture in which academic achievement is highly valued [31–33]. Based on the Program for International Assessment (PISA; used worldwide to test skills and knowledge of 15-year-old students), Singapore ranks first in the world in science, reading, and mathematics [34]. However, adolescents in Singapore also rank near the top in the world on schoolwork-related anxiety and time spent on learning (both in the classroom and after school) [35,36]. This may be driven, in part, by the importance of high-stakes examinations that determine students' placement in various educational streams, which in turn have an impact on advancement to subsequent levels of schooling and career/salary prospects [31,37]. Many students may feel that they need to prioritize work over sleep to achieve their academic objectives because there is not enough time in the day for both.

In Singapore and other East Asian cultures, there is growing concern that insufficient sleep may take a toll on students' health and well-being. To help adolescents achieve better sleep, performance, and health outcomes, it is important to identify factors that can be modified to facilitate earlier bedtimes and later wake-up times. With this long-term goal in mind, we conducted a cross-sectional survey of sleep habits in adolescents attending schools in Singapore. The first objective of our research was to assess the relationship between nocturnal sleep duration on school days and health-related outcomes. We hypothesized that shorter sleep would be associated with poorer self-rated health, and the odds of being overweight/obese and experiencing depression symptoms would be greater in adolescents with short sleep (<7 h) or moderately short sleep (7 to <8 h) relative to individuals with an appropriate sleep duration (8–10 h). The second objective was to identify behavioral and environmental factors associated with nocturnal sleep behavior. We hypothesized that older age, later chronotype, student-determined bedtime, more time spent on homework, more time spent on media use, early school start time, and increased travel time would be associated with shorter nocturnal sleep on school days. Furthermore, we hypothesized that these associations would differ between local versus international schools due to sociocultural and/or environmental influences.

2. Methods

2.1. Schools and participants

We invited 74 schools in Singapore to take part in an anonymous survey of adolescent sleep habits. Among the schools contacted, 65 were local schools and nine were international schools (see description below). Given that Singapore is a densely populated country, all schools were located in an urban setting. There were eight schools that agreed to take part in the research (five local schools and three international schools), with approval obtained from the school principal. Although we did not select for schools with higher academic performance, all six of the local schools that agreed to take part in the survey were among the top 10% of all secondary schools in Singapore, based on the cutoff national examination score for students admitted to each school. Hence, the local schools included in our study are widely regarded as elite in the Singapore context. By comparison, there is no clear way of ranking international schools in Singapore, which follow different types of overseas curricula and predominantly serve the expatriate community. Schools that did not participate in the research were either not interested or indicated that there was not enough time in their curriculum for students to take part in the survey.

In each school, a study description and a permission form were distributed to students and parents by school staff. Recruitment was managed internally by the schools; hence the researchers were not given information on the number of students/parents contacted or their identities. Students who returned a signed parent permission form were eligible to take part in the survey. The school staff then invited these students to attend a one-time session during school hours in which the research team administered the survey. Participants provided their consent by checking an option box on the front page of the anonymous survey. There were 2475 adolescents aged 13–19 years who indicated their willingness to participate in the research. There were 153 adolescents who indicated that they did not want to participate. These individuals were excluded from the analyses, even if they responded to survey questions. Survey data were collected between 2016 January and 2017 July. Research procedures were approved by the Ministry of Education, Singapore, and the National University of Singapore Institutional Review Board.

2.2. Adolescent sleep habits survey

2.2.1. Data collection

The survey comprised 40 items that collected data on (1) demographic information, (2) sleep habits on school days, (3) sleep habits on weekends, (4) daytime sleepiness and caffeine use, (5) sleep quality, and (6) sleep preferences. Most items were taken or modified from the School Sleep Habits Survey [38], which has been widely used to assess sleep behavior in adolescents. Depression symptoms were assessed using the 11-item Kutcher Adolescent Depression Scale (KADS), which has been shown to have psychometric properties similar to other self-report instruments used to evaluate adolescent depression [39,40]. Together, the sleep habits survey and the KADS took about 20 min to complete.

In seven of the eight participating schools, students completed the survey by pen and paper in a classroom or an auditorium during school hours while being monitored by the researchers. In the remaining school, the sleep survey and KADS were administered online as part of a larger study examining the effects of delaying

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school start time on sleep behavior and mood [41]. Surveys filled out by pen and paper were digitally transcribed in duplicate (ie, data were double-entered by different researchers), and conflicts were resolved by comparing data entries to the original hard copy. Among the 2475 adolescents who took part in the survey, 129 participants were excluded because of missing data, based on the criterion that <33% of the items were completed (ie, only a few questions were answered beyond demographic information, in which comparisons between sleep duration and health-related measures were not possible). The remaining 2346 adolescents were included in our analyses (local schools, $n = 1589$; international schools, $n = 757$).

2.2.2. Assessment of sleep behavior on school days and weekends

Participants reported their bedtime, wake-up time, and nocturnal sleep duration separately for school days and weekends (in hours and minutes). Bedtime was assessed with the questions, "What time do you usually go to bed on school days?" and "What time do you usually go to bed on weekends?" Wake-up time was assessed with the questions, "What time do you usually wake up on school days?" and "What time do you usually wake up on weekends?" Participants were asked to report their nocturnal sleep duration on school days based on the following description: "Figure out how long you usually sleep on a normal school night and fill it in here. Do not include time you spend awake in bed." Nocturnal sleep duration on weekends was assessed with the following description: "Figure out how long you usually sleep on a night when you do not have school the next day (such as a weekend night) and fill it in here. Do not include time you spend awake in bed."

2.2.3. Symptoms of sleep deficiency

We examined several symptoms of sleep deficiency and increased homeostatic sleep pressure, including daytime sleepiness, napping, caffeine use, short sleep onset latency, reliance on an alarm clock or family member in order to be awakened in the morning, poor sleep quality, and recovery sleep on weekends:

(1) Daytime sleepiness was assessed with the following question: "People sometimes feel sleepy during the daytime. During your daytime activities, how much of a problem do you have trying to stay awake (feeling sleepy, struggling to stay awake)?" A daytime sleepiness problem was defined as responding, "More than a little problem," "A big problem," or "A very big problem," whereas not a problem was defined as either "No problem at all" or "A little problem."
(2) Napping on school days was assessed with the question, "How many school days per week do you nap for more than 30 min?" Napping was defined as at least one nap per week on school days lasting longer than 30 min (responding either "1–2 school days/week", "3–4 school days/week" or "every day"), as compared with responding "I never nap."
(3) Caffeine use was assessed with the question, "How many days per week do you drink a caffeinated beverage (like coffee, Coke, Redbull) for the purpose of helping you to stay awake?" Caffeine use was defined as taking a caffeinated beverage at least one day per week (responding either "1 or 2 days", "3 or 4 days", "5 or 6 days", or "Every day"), as compared with responding "Never."
(4) Sleep onset latency was assessed with the question, "On school days, after you settle into bed at night for sleep, about how long does it usually take you to fall asleep?" Participants entered their response in minutes, and short sleep onset latency was defined as ≤5 min to fall asleep.
(5) The cause of waking up on school days was assessed using the following question, after asking participants to indicate their usual wake-up time: "What wakes you up at this time on school days? (Choose only one)." The need to be awakened in the morning was defined as responding "I set my alarm clock for that time" or "My parents or other family members wake me up." Other answers included "Noises wake me up," "I need to go to the bathroom," "I don't know, I just wake up naturally," and "Other."
(6) Sleep quality was assessed with the question, "In the last two weeks, how would you rate your sleep quality?" Poor sleep quality was defined as responding "Bad" or "Very Bad." Other responses included "Very good," "Good," or "Okay." This question was followed by "If you answered "Bad" or "Very Bad," why was your sleep quality poor? You can check multiple options." The options included "Stress or anxiety about school results/tests/grades," "I can't fall asleep," "I have to wake up too early," "I wake up in the middle of the night," "I don't have enough time to sleep," and "Other."
(7) Nocturnal sleep extension on weekends was determined by subtracting self-reported nocturnal sleep duration on school days from nocturnal sleep duration on weekends.
(8) Napping on weekends was assessed with the question, "On weekends, how often do you usually nap for more than 30 min?" Napping was defined as responding either "Once" or "Twice or more," as compared with responding "I don't nap."

2.2.4. Health-related measures

Self-rated health was assessed using the question, "Compared to other people your age, would you say that your health is: Poor, Fair, Good, Excellent?" Good health was defined as responding "Good" or "Excellent."

Body mass index (BMI, kg/m^2) was calculated based on self-reported height and weight. Overweight/obese was defined using age- and sex-specific cutoffs for children established by the International Obesity Task Force [42].

The 11-item KADS was used to assess the severity of depression symptoms including sadness, irritability, sleep difficulties, apathy, feelings of worthlessness, fatigue or low motivation, lack of focus, anhedonia, anxiety, physical signs of anxiety, and thoughts of self-harm or suicide [39,40]. For each item, participants were instructed to choose the response that best described how they had been feeling "on average" or "usually" over the past week. Response options included "Hardly ever," "Some of the time," "Most of the time," and "All the time." These options were assigned a score from 0 to 3, with a higher KADS global score (ie, the sum of scores across the 11 items) indicating greater severity of depression symptoms. In item-by-item analyses, we categorized participants as exhibiting a symptom of depression if they responded "Most of the time" or "All the time" in the past week.

2.2.5. Factors associated with sleep behavior

Data were collected on several factors previously shown to associate with sleep behavior on school days, including age, preferred sleep timing, parent-set bedtime, time spent on homework/studying, school start time, and time spent on transportation.

Preferred sleep timing, which is a relative indicator of chronotype, was defined as the midpoint of adolescents' preferred nocturnal sleep period (ie, the midpoint between preferred bedtime and preferred wake-up time). Preferred bedtime was assessed with the question, "Assuming you have no obligations and can pick your own bedtime, what time would you pick?" and preferred wake-up time was assessed based on the description,

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"Imagine: School is canceled! You can get up whenever you want to. When would you get out of bed?" Based on the distribution of preferred sleep timing in our sample of adolescents, we defined participants as having an early chronotype ("early type") if the midpoint of their preferred sleep episode occurred earlier than 04:00. Participants were defined as having a later chronotype ("not an early type") if the midpoint of their preferred sleep period occurred at 04:00 or later.

School type (local or international) was based on designations of the Ministry of Education (MOE), Singapore. Local schools are attended predominantly by Singapore citizens and permanent residents, with curricula that follow MOE criteria and guidelines. International schools are attended predominantly by foreign students and follow overseas curricula.

Parent-set bedtime was determined by asking participants to indicate the main reason for going to bed at their stated bedtime on school days. Participants were given a range of 10 options, including the option "My parents set my bedtime."

Time spent on "doing homework/studying," "transportation," and "media use (social media/phone/Internet/TV)" on school days were each assessed in hours and minutes using the following question: "On a typical weekday, state the average time you spend on each of the following activities."

2.3. Analysis and statistics

2.3.1. Associations between sleep duration and health-related measures

Demographic information, nocturnal sleep behavior, symptoms of sleep deficiency, and health-related measures were compared between adolescents with short sleep (<7 h), moderately short sleep (7 to <8 h), or an appropriate amount of sleep on school days (8–10 h). These definitions were based on recommendations for sleep duration by the National Sleep Foundation, USA [43], and the American Academy of Sleep Medicine [2]. One-way analysis of variance (ANOVA) and χ^2 tests were used to compare continuous and categorical variables across sleep duration groups. For those tests in which a significant difference was detected ($p < 0.05$), pairwise multiple comparisons were performed using independent t tests and χ^2 tests with Bonferroni-corrected p values (threshold for significant difference, $p < 0.017$). To examine the dose–response relationship between nocturnal sleep duration and behavioral/health-related outcomes in greater detail, we also examined responses across smaller sleep duration bins (<5 h, 5 to <6 h, 6 to <7 h, 7 to <8 h, 8 to <9 h, and ≥9 h). In these analyses, one-way ANOVA and χ^2 tests were also performed to test for associations between nocturnal sleep duration on school days and behavioral/health-related outcomes.

Multivariable logistic regression was used to model the association between sleep duration on school nights and the odds of being overweight/obese. Participants with short sleep (<7 h) and moderately short sleep (7 to <8 h) were compared to those with an appropriate amount of sleep who served as the reference group (8–10 h). The unadjusted odds ratio (ORs) was calculated for overweight/obesity using the IOTF criteria, in which cutoffs are based on sex-specific BMI-for-age growth curves in children. Hence, age and sex were already factored into the unadjusted model. In the adjusted model, ethnicity was included as a covariate (Chinese, Malay, Indian, Others) to calculate the adjusted OR (OR_{adj}). In item-by-item analyses of depression symptoms on the KADS, logistic regression models were used to test for associations between nocturnal sleep duration and feelings of depression most or all the time in the past week. Models were adjusted for age, sex, and ethnicity. All variables were entered into the model at the same time, and listwise exclusion was used for handling missing data in adjusted models. In the overweight/obesity regression model, data were missing for ethnicity in 0.7% of adolescents ($n = 14$). In the depression symptom models, data were missing for age in 0.7% of adolescents ($n = 16$), for sex in 0.6% of adolescents ($n = 14$), and for ethnicity in 0.7% of adolescents ($n = 15$). All statistical tests were carried out using SPSS software, version 25.0.

2.3.2. Behavioral and environmental factors associated with sleep behavior

Separate groups of analyses were performed to assess behavioral and environmental factors associated with bedtime, wake-up time, and nocturnal sleep duration on school days. Initially, bedtime analyses focused on associations with age, preferred timing of sleep on free days (ie, midpoint of the preferred sleep period), and school type. One-way ANOVA was used to test for effects of age on preferred sleep timing, as well as effects of preferred sleep timing on bedtime on school nights. Two-way ANOVA was used to test for interaction and main effects of age (in years) and school type (local, international) on bedtime. The combined influence of these factors on bedtime was explored by determining the mean ± 95% confidence intervals [CIs] for unique combinations of age (<15 years, ≥15 years), chronotype (early type, not an early type), and school type (local, international). There were eight possible unique combinations of factors (three factors, each with two categories). We analyzed results only for combinations of factors with at least 50 participants.

Secondary analyses focused on differences in bedtime-related behaviors in students attending local versus international schools. Separate χ^2 tests were performed to compare the proportion of adolescents in local versus international schools with a parent-set bedtime, with a daily study duration <3 h, and with a daily social media use duration <2 h on school days. For multiple comparison testing within different age groups (<15 years, ≥15 years), statistical significance was assessed using Bonferroni-corrected p values (threshold for significant difference, $p < 0.025$). Separate two-way ANOVAs were performed to test for effects of age (<15 years, ≥15 years) and either parent-set bedtime (parent-set bedtime, no set bedtime), study duration (<3 h, ≥3 h), or social media use duration (<2 h, ≥2 h) on bedtime.

Wake-up time analyses focused on associations with school start time and daily travel time. Effects of school start time were assessed by comparing the mean ± 95% CIs for wake-up time across individual schools. One-way ANOVA was used to test for effects of daily travel time (ranging from 0 to 150 min, in 30-min bins) on wake-up time. In one school, participants completed the sleep survey before and approximately one month after their start time was delayed by 45 min from 07:30 to 08:15 [41]. A paired t test was used to test for a difference in wake-up time after the change in school start time. The combined influence of school start time and daily travel time on wake-up time was assessed by comparing the mean ± 95% CIs for participants grouped by different combinations of school start time (<08:00, ≥08:00) and travel time (≤30 min, >30 min). Analyses were performed for all four combinations of factors.

Associations between school start time and school type on nocturnal sleep duration were assessed by comparing the mean ± 95% CIs for sleep duration across individual schools. In the school that implemented the 45-min delay in start time, a paired t test was used to test for a difference in nocturnal sleep duration. We also explored the combined influence of age (<15 years, ≥15 years), chronotype (early type, not an early type), school type (local, international), school start time (<08:00, ≥08:00), and daily travel time (≤30 min, >30 min) on nocturnal sleep duration on school days. Among the 32 possible combinations of factors (five factors, each with two categories), we compared the mean ± 95% CIs for

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nocturnal sleep duration for combinations with at least 50 participants. Analyses and statistical tests were performed using SPSS software.

3. Results

3.1. School and participant characteristics

The range of school start times in our sample was 1 h (07:30–08:30), with most local schools having an earlier start time than international schools (Table S1). Most participants were ethnic-Chinese (69.7%), and the percentage of ethnic-Chinese adolescents was much higher in local schools compared with international schools (89.7% vs 27.3%, $\chi^2 = 933.9$, $p < 0.001$). The girl-to-boy ratio varied across schools (including one school with only boys and one school with only girls), but there was a similar percentage of girls and boys in the full sample (54.1% girls).

Demographic characteristics differed between adolescents with short sleep (<7 h, $n = 1449$), moderately short sleep (7 to <8 h, $n = 518$), and an age-appropriate amount of sleep (8–10 h, $n = 346$) on school nights (Table 1). Sleep duration was negatively associated with age, whereby participants with either short or moderately short sleep were older compared with those with an appropriate amount of sleep ($P < 0.001$ for both comparisons). Shorter sleep was also associated with Chinese ethnicity, local school type, and earlier school start time. The proportion of girls was marginally higher among short sleepers (Table 1).

The duration and timing of nocturnal sleep differed on school nights versus weekends (Supplementary Results, Fig. S1). Only 14.8% of adolescents reported an appropriate amount of sleep on school nights compared with 79.7% on weekends (Table 1). On average, adolescents reported sleeping about 2 h more on weekends, with later bedtimes and much later wake-up times relative to school nights. The degree of social jet lag, defined as the discrepancy in sleep midpoint between school nights and weekends, was marginally greater in shorter sleepers (Table 1). Adolescents with short sleep on school nights showed greater signs of sleep deficiency, including daytime sleepiness, napping on school days, caffeine consumption to help stay awake, short sleep latency at night, reliance on an alarm clock or family member to wake them up in the morning, poor sleep quality, extension of nocturnal sleep duration on weekends, and napping on weekends (Table 1, Supplementary Results, Fig. S2).

3.2. Sleep duration and health-related measures

There was a positive dose-dependent association between nocturnal sleep duration on school days and self-reported health (Fig. 1A, Table 1), in which the proportion of adolescents who rated their health as good or excellent relative to their peers was higher among participants with an age-appropriate amount of sleep (85.6%), relative to those with moderately short sleep (75.6%) or short sleep (64.9%; $\chi^2 \geq 12.5$ and $p < 0.001$ for both comparisons). Next, we examined associations between sleep duration and overweight/obesity (Fig. 1B). The odds of being overweight were about 2.5-fold higher in adolescents with short sleep ($OR_{adj} = 2.56$, 95% CI = 1.39–4.70) compared with individuals with an appropriate sleep duration on school days. By comparison, the odds of being overweight did not differ between adolescents with moderately short sleep versus an appropriate sleep duration ($OR_{adj} = 1.90$, 95% CI = 0.99–3.66) (Table S2).

Depression scores were negatively associated with nocturnal sleep duration on school days (Table 1 and Fig. 2A). Based on item-by-item analyses, all depression symptoms showed a negative dose-dependent association with nocturnal sleep duration (Fig. S3). In logistic regression models adjusted for age, sex, and ethnicity, for 10 of the 11 items on the KADS, the odds of experiencing depression symptoms most or all the time in the past week were more than

Table 1
Adolescents' characteristics across different sleep duration categories ($n = 2313$).

Characteristic	All ($n = 2313$)	Nocturnal sleep duration on school days			χ^2/F	p
		<7 h ($n = 1449$)	7 to <8 h ($n = 518$)	8–10 h ($n = 346$)		
Demographic features						
Age (years)	16.0 ± 1.6	16.4 ± 1.3	16.1 ± 1.6	14.5 ± 1.5	242.8	<0.001
Girls, *n* (%)	1242 (54.1%)	806 (56.0%)	269 (52.4%)	167 (48.8%)	6.5	<0.05
Chinese, *n* (%)	1605 (69.9%)	1160 (80.3%)	346 (67.7%)	99 (29.1%)	344.9	<0.001
Local school (%)	1575 (68.1%)	1211 (83.6%)	313 (60.4%)	51 (14.7%)	627.2	<0.001
School start time (hh:mm)	07:59 ± 00:24	07:54 ± 00:24	08:01 ± 00:24	08:14 ± 00:15	107.9	<0.001
Sleep behavior on school days						
Bedtime (hh:mm)	23:32 ± 01:14	00:09 ± 00:58	22:55 ± 00:42	21:53 ± 00:48	937.3	<0.001
Wake-up time (hh:mm)	06:17 ± 00:34	06:10 ± 00:34	06:26 ± 00:31	06:32 ± 00:30	78.7	<0.001
Nocturnal sleep duration (h)	6.5 ± 1.3	5.7 ± 0.8	7.3 ± 0.3	8.6 ± 0.6	2398.0	<0.001
Sleep behavior on weekends						
Bedtime (hh:mm)	00:15 ± 01:27	00:39 ± 01:21	23:53 ± 01:15	23:05 ± 01:19	198.2	<0.001
Wake-up time (hh:mm)	09:16 ± 01:35	09:29 ± 01:35	09:03 ± 01:31	08:41 ± 01:29	38.2	<0.001
Nocturnal sleep duration (h)	8.8 ± 1.5	8.6 ± 1.6	9.0 ± 1.3	9.4 ± 1.4	37.7	<0.001
Social jet lag (h)	1.8 ± 1.1	1.9 ± 1.1	1.8 ± 1.1	1.7 ± 1.0	7.4	<0.001
Symptoms of sleep deficiency						
Daytime sleepiness problem, *n* (%)	807 (35.2%)	642 (44.7%)	129 (25.3%)	36 (10.5%)	170.2	<0.001
Nap >30 min on school days, *n* (%)	1120 (48.5%)	871 (60.2%)	199 (38.5%)	50 (14.5%)	259.3	<0.001
Caffeine to stay awake, *n* (%)	940 (40.9%)	642 (44.6%)	186 (36.2%)	112 (32.8%)	21.8	<0.001
Sleep latency ≤5 min, *n* (%)	567 (24.8%)	401 (27.9%)	117 (22.9%)	49 (14.5%)	27.9	<0.001
Awakened by alarm/family, *n* (%)	2045 (91.1%)	1305 (93.2%)	457 (91.0%)	283 (82.7%)	37.3	<0.001
Poor sleep quality, *n* (%)	312 (13.6%)	248 (17.3%)	50 (9.8%)	14 (4.1%)	48.5	<0.001
Sleep extension on weekends (h)	2.3 ± 1.8	2.9 ± 1.7	1.7 ± 1.3	0.9 ± 1.4	275.1	<0.001
Nap >30 min on weekends, *n* (%)	871 (38.5%)	630 (44.1%)	175 (34.9%)	66 (19.8%)	70.7	<0.001
Health-related outcomes						
Self-rated good health, *n* (%)	1606 (70.4%)	931 (64.9%)	384 (75.6%)	291 (85.6%)	64.8	<0.001
IOTF overweight/obese, *n* (%)	181 (8.8%)	131 (9.9%)	36 (7.8%)	14 (5.0%)	7.5	<0.05
KADS depression score	8.7 ± 5.2	9.5 ± 5.3	7.9 ± 4.8	6.6 ± 4.2	53.3	<0.001

Mean ± standard deviation is shown for continuous variables. Data are excluded for 12 participants who reported a sleep duration >10 h, and for 21 subjects who did not report their sleep duration on school days. IOTF, International Obesity Task Force; KADS, Kutcher Adolescent Depression Scale.

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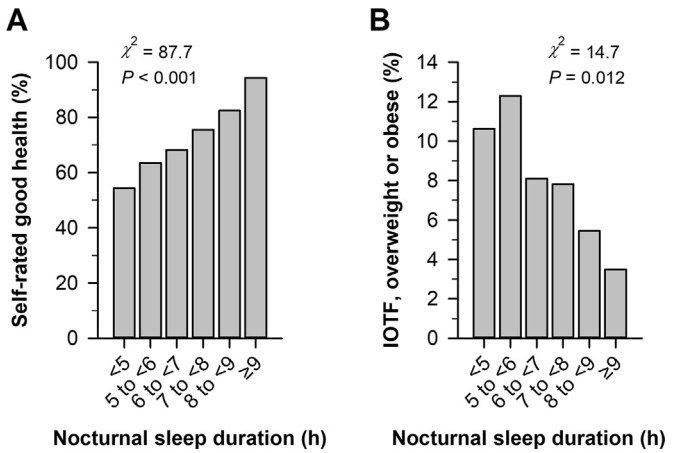

Fig. 1. Associations between sleep duration on school nights with self-rated health and overweight/obesity. (A) The frequency of adolescents who reported their health as good or excellent is shown for participants grouped by their nocturnal sleep duration on school days. Shorter sleep was associated with poorer self-rated health. (B) The frequency of adolescents categorized as overweight or obese is shown for different sleep durations, defined using International Obesity Task Force (IOTF) criteria. The frequency of overweight/obese was greater for shorter sleep durations.

twofold higher in adolescents exposed to short sleep compared with an appropriate sleep duration (Fig. 2B and Table S2). This included feelings of sadness, irritability, sleep difficulties, worthlessness, fatigue and/or low motivation, lack of focus, life not fun/anhedonia, anxiety, physical signs of anxiety, and self-harm thoughts or suicide ideation. The odds of feeling depression symptoms most or all the time in the past week were also greater in adolescents with moderately short sleep compared with an appropriate amount of sleep, for sleep difficulties, worthlessness, fatigue and/or low motivation, lack of focus, and anxiety (Table S2).

3.3. Factors associated with bedtime on school nights

With increasing age, there was a delay in the preferred sleep period (midpoint of preferred sleep) by about 1 h (Fig. 3A), indicating a shift toward later chronotype. As expected, later preferred sleep timing was associated with later bedtime on school nights (Fig. 3B). Bedtimes were later in adolescents attending local schools compared with international schools (Fig. 3C), with a greater difference in bedtime between school types at younger ages (school type × age: $F_{5,2146} = 8.0$, $p < 0.001$, partial $\eta^2 = 0.018$). In early adolescence, students attending local schools went to bed about 1 h later than those attending international schools (about 23:00 vs 22:00), whereas bedtimes converged between school types in late adolescence (near 24:00 [midnight]).

Next, we assessed the combined associations of age (<15 years, ≥15 years), chronotype (early type, not an early type), and school type (local, international) on bedtime (Fig. 3D). Adolescents who were young, an early type (midpoint of preferred sleep period before 04:00), and attended an international school had the earliest average bedtime, before 22:00. Relative to this group, bedtimes were about 1 h later among students at international schools who were either older or not an early type, whereas the combination of older age and not an early type was associated with a delay in bedtime of more than 2 h. Older adolescents with an early sleep timing preference went to bed about 40 min earlier in international schools compared with local schools. However, adolescents who were older, not an early type, and attended a local school went to bed at about the same time as their counterparts at international schools, with a bedtime near midnight.

Secondary analyses were performed to explore factors that may contribute to earlier bedtime in adolescents attending international schools versus local schools. Because the greatest difference in bedtime between school types was in adolescents aged 13–14 years, we stratified participants into young (<15 years) and older (≥15 years) age groups. In both age groups, the proportion of early types was similar in adolescents attending local versus international schools (<15 years: $\chi^2 = 1.20$, $p = 0.27$; ≥15 years: $\chi^2 = 1.52$, $p = 0.22$), suggesting that the difference in bedtime between school types was not due to a difference in chronotype. Few participants in our study had a parent-set bedtime (6.7%), but the proportion was much greater among young adolescents (<15 years) attending international schools compared with local schools (24.6% versus 7.8%; $\chi^2 = 14.9$, $p < 0.001$) (Fig. 4A). There was no association between school type and parent-set bedtime among older adolescents (≥15 years; $\chi^2 = 0.083$, $p = 0.77$). Accounting for effects of age, adolescents with a parent-set bedtime went to bed about 1 h earlier compared with those who were free to choose their own bedtime (main effect, parent-set bedtime: $F_{1,2007} = 104.1$, $p < 0.001$, partial $\eta^2 = 0.049$) (Fig. 4B).

The proportion of participants who reported <3 h of studying/homework on school nights was greater among young adolescents

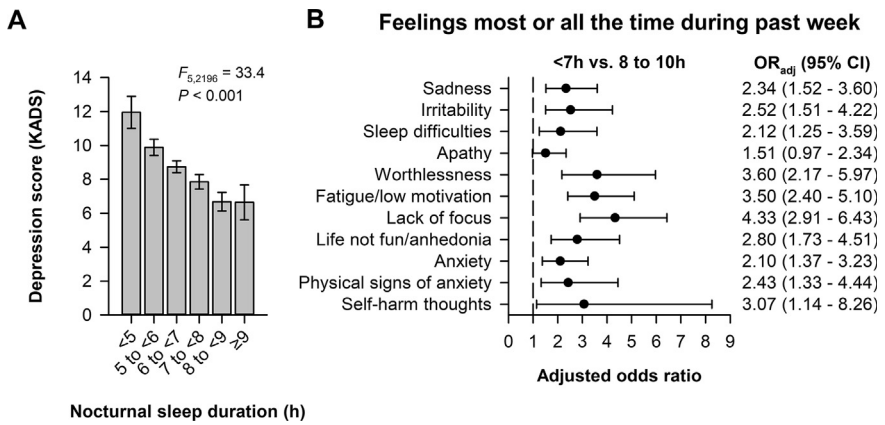

Fig. 2. Associations between sleep duration on school nights and depression symptoms. (A) Global depression score (mean ± 95% confidence interval [CI]) on the Kutcher Adolescent Depression Scale (KADS) is shown for adolescents grouped by their nocturnal sleep duration on school days. Shorter sleep was associated with higher depression scores (one-way analysis of variance, $p < 0.001$). (B) Adjusted odds ratios (OR_{adj}) for feeling each depression symptom most or all the time are shown for adolescents with short sleep on school days (<7 h) compared with an age-appropriate amount of sleep (8–10 h), adjusted for age, sex, and ethnicity. Shorter sleep was associated with increased odds of reporting depression symptoms.

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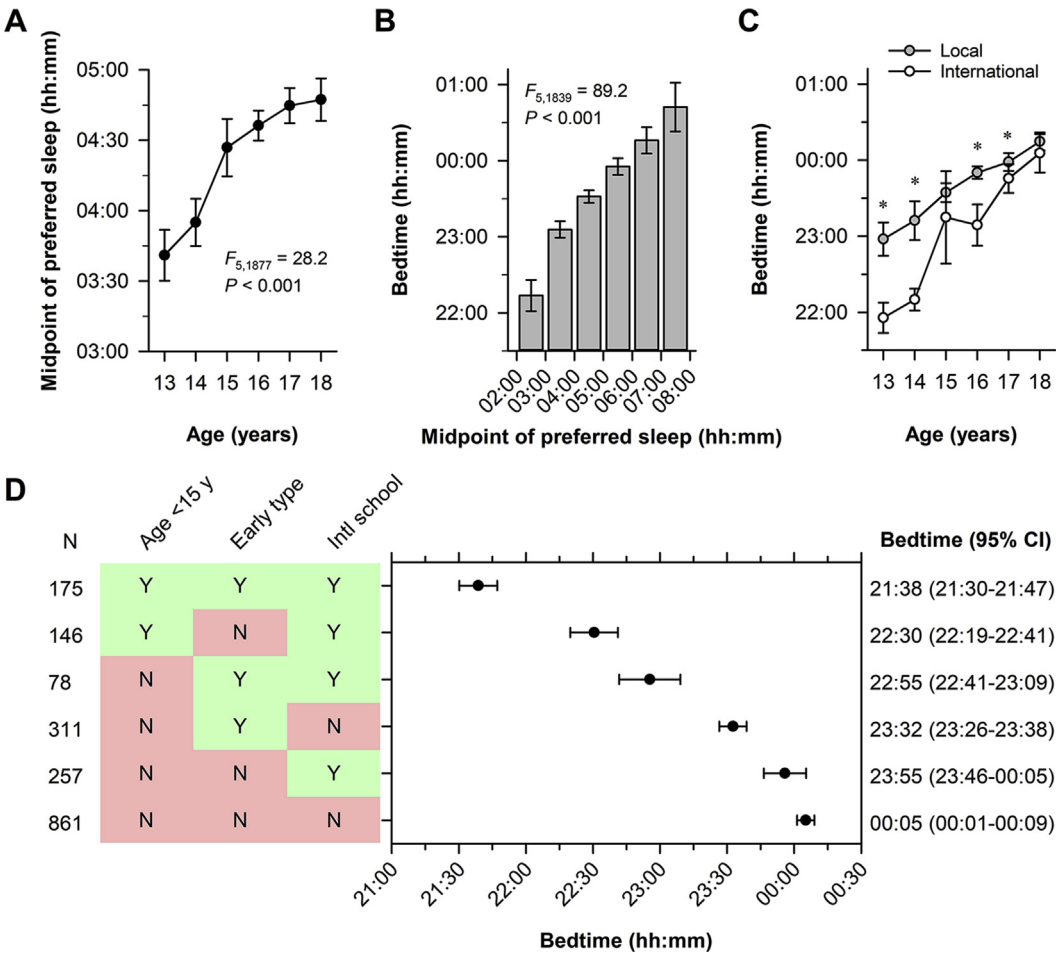

Fig. 3. Factors associated with bedtime on school nights in adolescents. (A) With increasing age, there was a delay in the midpoint of the preferred sleep period (one-way analysis of variance [ANOVA], $p < 0.001$), indicating a shift toward later chronotype. (B) Later preferred sleep timing was associated with later bedtime on school nights (one-way ANOVA, $p < 0.001$). (C) Bedtime on school nights was later in students attending local schools compared with international schools, with the greatest difference observed at younger ages (age × school type, $p < 0.001$; asterisks indicate significant differences between school types for multiple comparison testing). (D) The combined influence of age (<15 years, ≥15 years), chronotype (early type = midpoint of preferred sleep period before 04:00, not an early type = midpoint of preferred sleep period at 04:00 or later), and school type (local, international) on bedtime was evaluated. Each combination of factors (Y = yes, N = no) is shown on the left with the corresponding sample size. The mean ± 95% confidence interval (CI) for bedtime is shown on the right for each combination of factors (minimum sample size, $n = 50$). The mean ± 95% CI is also shown for results in panels A, B, and C.

attending international schools compared with local schools (74.4% vs 52.3%; $\chi^2 = 16.3$, $p < 0.001$), but did not differ significantly between school types in older adolescents ($\chi^2 = 4.8$, $p = 0.03$, greater than the Bonferroni-adjusted threshold of $p = 0.025$) (Fig. 4C). Accounting for effects of age, adolescents who spent <3 h studying on school days went to bed about 20 min earlier than those who spent ≥3 h studying (main effect of studying duration: $F_{1,2078} = 41.6$, $p < 0.001$, partial $\eta^2 = 0.020$) (Fig. 4D). In contrast to findings for studying/homework, the proportion of adolescents who reported <2 h of media use on school nights was higher among students attending local schools compared with international schools (59.5% vs 40.5% for participants aged <15 years, and 40.5% versus 31.8% for participants aged ≥15 years; $\chi^2 > 8.7$, $p < 0.01$ for both comparisons) (Fig. 4E). Adolescents who spent <2 h on media use went to bed about 10 min earlier than those who spent ≥2 h on media use (main effect of media use duration: $F_{1,2038} = 23.5$, $P < 0.001$, partial $\eta^2 = 0.011$) (Fig. 4F).

3.4. Factors associated with wake-up time on school days

Wake-up time on school days closely tracked school start time (Fig. 5A). Across the 1-h range of school start times in our sample, the average wake-up time in individual schools spanned about 45 min (from 05:55 to 06:39). There was one local school in our study that delayed their start time by 45 min (from 07:30 to 08:15), which allowed for a longitudinal assessment of the relationship between school start time and wake-up time (Fig. 5B). One month after the change in start time, adolescents at this school showed a delay in their wake-up time of about 30 min relative to their prior wake-up time when school started earlier ($n = 125$, mean delay = 32 min, 95% CI = 28–37 min; paired t test, $p < 0.001$). Among the 8 schools that took part in the survey, wake-up time was also negatively associated with total daily time spent on transportation (Fig. 5C). On average, adolescents with the shortest daily travel time (≤30 min) woke up at about 06:40, whereas those who spent more than 2 h per day on transportation woke up before 06:00.

Next we examined the combined associations of school start time (<08:00, ≥08:00) and daily transportation time (≤30 min, >30 min) on wake-up time (Fig. 5D). Adolescents with a later school start time and short daily travel time woke up shortly before 07:00. Exposure to either an early school start time or longer daily travel resulted in a wake-up time that was about 20 min earlier. The combination of an early start time and >30 min of daily travel was associated with an average wake-up time near 06:00.

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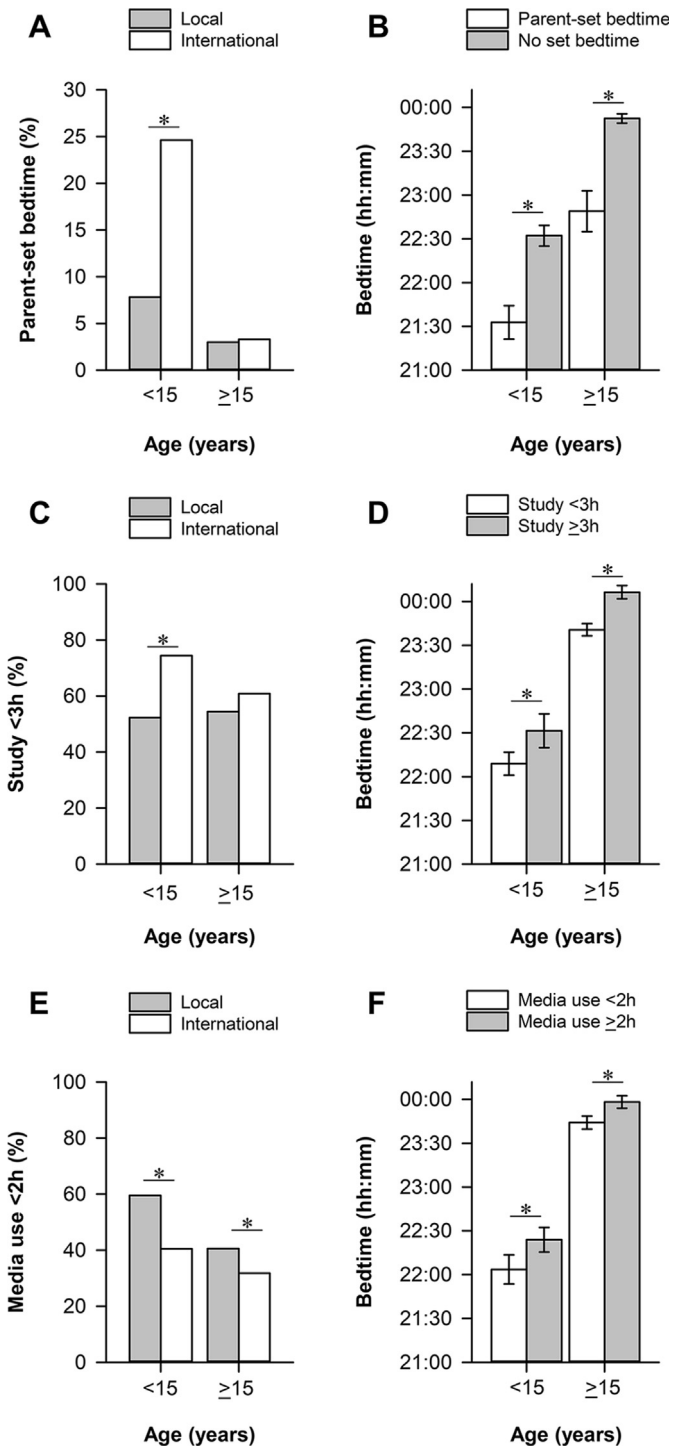

Fig. 4. Behaviors associated with bedtime on school nights in local versus international schools. (A) The proportion of students with a parent-set bedtime was higher among young adolescents (<15 years) attending international schools. (B) Irrespective of age (<15 years, ≥15 years), parent-set bedtime was associated with an earlier bedtime. (C) The proportion of adolescents who reported <3 h of studying on school nights was higher among young adolescents enrolled in international schools. (D) Irrespective of age, <3 h of study time was associated with an earlier bedtime compared with ≥3 h of study time on school days. (E) The proportion of adolescents who reported <2 h of media use on school days was higher in students attending local schools. (F) Adolescents with <2 h of media use per day had an earlier bedtime compared with those who reported ≥2 h of media use. Asterisks in panels A, C, and E indicate significant associations for each behavior with school type (χ^2 test, $p < 0.05$). Asterisks in panels B, D, and F indicate significant differences in bedtime between school types (independent t test, $p < 0.05$). The mean ± 95% confidence interval is shown in panels B, D, and F.

3.5. Factors associated with nocturnal sleep duration on school days

Factors associated with bedtime and wake-up time were also associated with nocturnal sleep duration on school days (Table S3). In univariate analyses, the proportion of adolescents with younger age (<15 years), early chronotype (midpoint of preferred sleep period before 04:00), enrollment in an international school, parent-set bedtime, shorter study time (<3 h), later school start time (08:00 or later), or shorter daily travel time (≤30 min) was higher among participants with an appropriate sleep duration, as compared with those with moderately short sleep ($\chi^2 \geq 8.2$, $p < 0.01$ for all factors) or short sleep on school days ($\chi^2 \geq 59.3$, $p < 0.001$ for all factors). Social media use was the only factor that did not associate with nocturnal sleep duration.

The effect of school start time on sleep duration appeared to be influenced by whether the school enrolled local students (Fig. 6A). Among the three international schools in our sample, the only school with open admission to local students had an average nocturnal sleep duration (6.2 h) that was comparable to local schools (mean sleep duration, 6.0–6.4 h). By comparison, the two international schools with predominantly foreign student enrollment had an average nocturnal sleep duration that was more than 1 h greater than for local schools. In addition, students at the local school with the latest start time in our sample (08:30) had an average nocturnal sleep duration of 6.1 h, which was similar to students at other local schools with much earlier start times (07:30 or 07:40). This was explained by the later average bedtime in this school compared with other local schools (about 30 min later), which largely offset the effect of the later wake-up time (about 40 min later) on nocturnal sleep duration. In students at the local school that delayed their start time from 07:30 to 08:15 (Fig. 6B), the average delay in bedtime (8 min) was smaller than the delay in wake-up time (32 min), resulting in an increase in self-reported nocturnal sleep duration of 16 min after the change in start time ($n = 125$; mean change = 16 min, 95% CI = 7–24 min; paired t test, $p < 0.001$).

Next, we examined the combined associations of age, chronotype, school type, school start time, and daily travel time on nocturnal sleep duration (Fig. 6C). Adolescents with the optimal combination of young age, early chronotype, enrollment in an international school, later school start time, and shorter daily travel time had an average nocturnal sleep duration on school days of about 8.5 h. By comparison, adolescents with the least favorable combination of factors for nocturnal sleep duration (older age, not an early type, enrollment in a local school, early school start time, and longer daily travel time) had an average sleep duration <6 h on school nights. The combination of two or more factors associated with shorter sleep resulted in a nocturnal sleep duration <8 h on school nights, and the combination of three or more factors associated with shorter sleep resulted in a nocturnal sleep duration <7 h.

4. Discussion

The present study examined sleep behaviors, health-related measures, and factors associated with sleep in a hard-driving East Asian society. Shorter sleep was associated with poorer self-rated health, overweight/obesity, and depression symptoms. Barriers to healthy sleep included later chronotype, lower parental supervision of bedtime, more time spent on studying or homework, early school start time, and longer travel time. In addition, we found that sleep behavior differed between local schools and international schools, suggesting that sociocultural differences may play an important role in determining whether adolescents can achieve an

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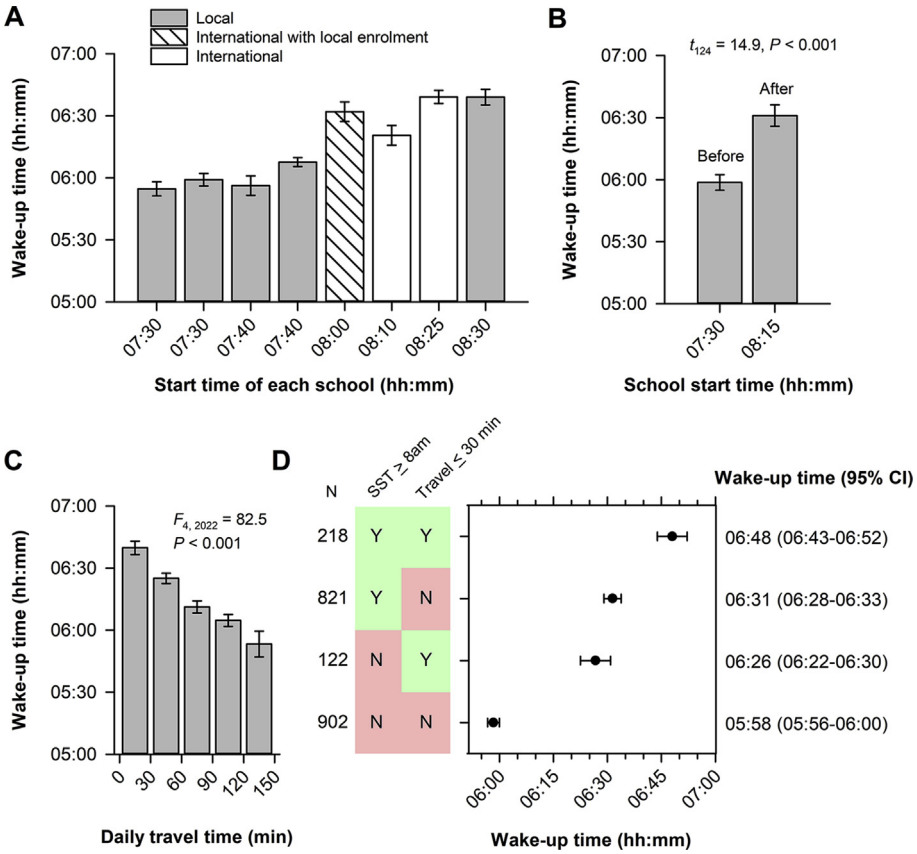

Fig. 5. Factors associated with wake-up time on school days in adolescents. (A) Later school start times were associated with later wake-up times. (B) In a school that delayed its start time by 45 min, students woke up significantly later compared with the period before the change in start time (paired t test, $p < 0.001$). (C) Longer daily travel time was associated with earlier wake-up time (one-way analysis of variance, $p < 0.001$). (D) The combined influence of school start time (SST: <08:00, ≥08:00) and daily travel time (≤30 min, >30 min) on wake-up time was evaluated. Each combination of factors (Y = yes, N = no) is shown on the left with the corresponding sample size. In all panels, the mean ± 95% confidence interval (CI) is shown.

appropriate amount of sleep. As discussed below, our results suggest that short sleep negatively affects adolescents' health and well-being. Solutions for increasing sleep duration should focus on behavior modification strategies and administrative changes (eg, later school start time) that take into account sociocultural factors that may affect barriers to healthy sleep.

4.1. Most adolescents showed signs of sleep deficiency

We found that on school days, most adolescents (~85%) slept less than the amount recommended for optimal health and cognitive functioning (ie, 8−10 h) [2,43]. Associations between sleep duration and symptoms of sleep deficiency were strongly dose-dependent. Similar to previous studies, short nocturnal sleep on school days was associated with daytime sleepiness, and coping behaviors including napping and caffeine intake to help stay awake [44,45]. Adolescents with short sleep were more likely to fall asleep quickly at night and to rely on help to wake up in the morning, suggesting that their homeostatic sleep pressure is high after extended wakefulness on school days but that it does not fully dissipate [3,46]. Consistent with this interpretation, adolescents attempted to recover their sleep on weekends by extending nocturnal sleep duration (primarily by waking up later) and by napping. Moreover, the most common reason cited for poor sleep quality was not having enough time in bed for sleep. Collectively, our results indicate that most adolescents in our sample were chronically sleep deprived and needed more sleep at night to feel their best.

4.2. Short sleep associated with health-related outcomes and well-being

Similar to previous findings [47], we found that shorter sleep duration was associated with poorer self-rated health. In our cross-sectional study, the odds of being overweight or obese were more than twofold greater in adolescents with short sleep compared with individuals with an appropriate amount of sleep. Notably, longitudinal studies have shown that short sleep is a risk factor for the development of obesity in infants, children, and adolescents [11,48]. These findings are a major cause of concern because short sleep and obesity are risk factors for type 2 diabetes [49], which is a rapidly growing health problem in Asia. Exposure to short-term sleep restriction has been shown to decrease insulin sensitivity in healthy adolescents [50], suggesting that sleep is important for maintaining normal glucose metabolism.

It has long been recognized that sleep problems and mood disturbances have a bidirectional relationship [51]. Analyses of longitudinal studies indicate that sleep problems in adolescents are associated with the development of depression [52,53]. In the present cross-sectional study, strong dose-dependent associations were observed between sleep duration and depression symptoms. Adolescents with shorter sleep were more likely to report feeling irritable, anxious, worthless, and that life is not fun. Short sleepers were also more likely to feel unmotivated and to have difficulty concentrating. Similar to previous studies of adolescents in Korea (another hard-driving East Asian society) [54,55], we found that students with insufficient sleep were more likely to have thoughts

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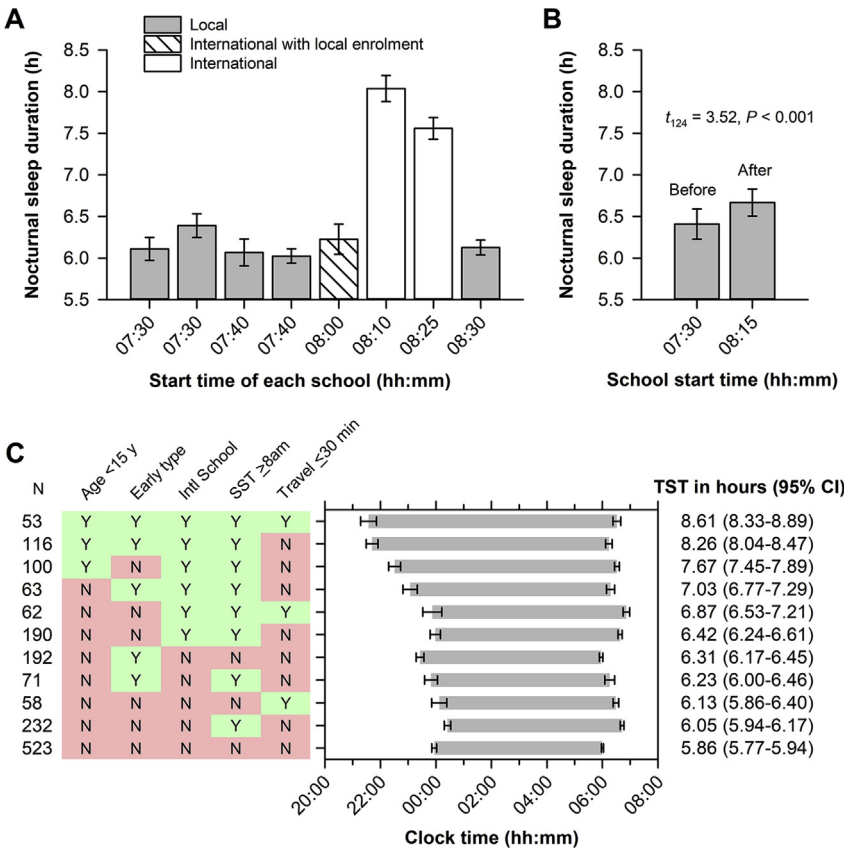

Fig. 6. Factors associated with nocturnal sleep duration on school days in adolescents. (A) Schools that enrolled local students had a shorter nocturnal sleep duration on school days than schools with foreign students. (B) In a school that delayed its start time by 45 min, students slept longer at night compared with the period before the change in start time (paired t test, $p < 0.001$). In panels A and B, the mean ± 95% confidence interval (CI) is shown for wake-up time. (C) The combined influence of age (<15 years, ≥15 years), chronotype (early type = midpoint of preferred sleep before 04:00, not an early type = midpoint of preferred sleep at 04:00 or later), school type (local, international), school start time (SST: <08:00, ≥08:00) and daily travel time (≤30 min, >30 min) on nocturnal sleep duration was assessed. Each combination of factors (Y = yes, N = no) is shown on the left with the corresponding sample size (minimum of 50 subjects per combination). The gray bars indicate the average nocturnal sleep period for each combination of factors, with the mean ± 95% CIs for bedtime and wake-up time indicated at the beginning and end of each sleep period. On the right of panel C, the mean ± 95% CI is indicated for self-reported total sleep time (TST).

of self-harm or suicide. Collectively, these results suggest that inadequate sleep in adolescents contributes to mental health problems and lower life satisfaction.

Our findings that sleep duration on school nights was associated with health-related measures may be especially important for convincing policymakers, educational professionals, and parents in East Asia that short sleep is a problem worth addressing. Based on international, cross-country assessments of academic performance, adolescents from East Asian countries rank near the top despite their relatively poor sleep habits. Therefore, the argument that sleep is important for optimizing cognitive performance and learning outcomes may not resonate as well in East Asian societies compared with Western societies, even though there is strong empirical evidence that short sleep results in cumulative performance deficits in Asian adolescents [3,8]. To encourage better sleep practices in East Asian societies, it may be better to focus on the importance of sleep for adolescents' mental health and holistic growth.

4.3. Possible solutions for improving sleep behavior in adolescents

There are two main types of approaches for helping adolescents who are otherwise healthy to achieve more nocturnal sleep: (1) to encourage and enforce healthy sleep hygiene practices that facilitate earlier bedtime, and (2) to enact administrative changes (eg, later school start time) that facilitate later wake-up time. In the present study, we identified several modifiable factors associated with sleep behavior. Below, we discuss barriers to and solutions for improving nocturnal sleep duration in adolescents.

Preferred sleep timing is an important factor contributing to late bedtime on school nights in adolescents. Consistent with earlier work [21], we found an age-dependent shift toward later chronotype that was associated with later bedtime. This shift is thought to arise in part by a delay in circadian rhythms with the onset of puberty [56]. Consequently, the onset of melatonin secretion occurs later in the evening in adolescents compared with earlier in childhood. When coupled with slower accumulation of homeostatic sleep pressure [22], bedtime is progressively delayed in adolescence. The impact of these biological factors on chronotype can be exacerbated by poor sleep hygiene practices. Hence, preferred sleep timing and chronotype should be viewed as having both biological and environmental components. The effects of evening chronotype on bedtime can potentially be minimized by ensuring that adolescents avoid activities prior to bedtime that promote cognitive arousal (eg, video games or studying). In addition, adolescents should avoid exposure to bright light (or blue-enriched light) in the late evening, which can perpetuate later bedtime by eliciting a circadian phase-delay shift [57].

In the present study, there were marked differences in bedtime-related behaviors in students attending local versus international schools. In early adolescence, students at local schools went to bed about 1 h later than those at international schools, whereas

bedtime was similar between school types in late adolescence. Because local schools enroll predominantly Singapore citizens and permanent residents, and international schools enroll predominantly foreign students (with diverse nationalities), differences in sleep behavior are likely driven by differences in sociocultural practices toward sleep and school-life. For example, we found that students at international schools were far more likely to have a parent-set bedtime than their counterparts at local schools. Consistent with previous studies [58,59], we found that parent-set bedtime was associated with a much earlier bedtime (by about 1 h) compared with allowing students to choose their bedtime. Similar to past work, we also found that younger adolescents were more likely to have a parent-set bedtime compared with older adolescents [59]. Hence, encouraging parents to set their child's bedtime, in particular at younger ages, represents a viable strategy for improving nocturnal sleep duration.

We also found that students at local schools were more likely to have long study hours compared with students at international schools. About half of local students reported $\geq$3 h of studying/homework on school days. The greater amount of time spent on studying in local students (at younger ages) may reflect the strong emphasis placed on academic achievement. This is exemplified by the popularity of evening tuition classes (ie, additional private schooling), which are often viewed as necessary for providing a competitive academic advantage. Consistent with previous studies, longer studying/homework was associated with later bedtime [24]. Therefore, reducing adolescents' workload (eg, assigning less homework) and helping them to improve their time management may facilitate an earlier bedtime. Related to the latter point, growing evidence suggests that evening use of electronic devices may contribute to later bedtimes [25]. Although daily media use did not associate with nocturnal sleep duration in our study, we did not specifically examine media use in the time period preceding bedtime. Additional studies are therefore needed to evaluate the cross-cultural impact of media use on bedtime and sleep duration on school nights.

Based on studies conducted in Western societies, later school start time is associated with later wake-up time and longer nocturnal sleep duration [60–62]. The present results suggest that later school start time may not be enough to help most adolescents in East Asian societies achieve an appropriate amount of sleep, unless good sleep hygiene practices are also encouraged and adopted to prevent a delay in bedtime. In the local school with the latest start time (08:30), adolescents went to bed later than students at other local schools that started much earlier (07:30–07:40). This negated the benefit of the later wake-up time in these students, resulting in a nocturnal sleep duration that was similar to that in other local schools (ie, close to 6 h). Recently, we showed that delaying school start time can lead to sustained improvements in sleep behavior and mood for at least nine months [41]. In that study, it was made clear to all stakeholders (students, parents, teachers, and school officials) that improving sleep was an important and desired outcome of the change in school start time, and parents and teachers were encouraged to help their children/students to sleep more. It is worth noting, however, that the average nocturnal sleep duration after the change in school start time was still far less than the amount of sleep reported by students in international schools with comparable start times, and also far less than the amount of sleep recommended for optimal cognitive functioning and health [2,43]. Nonetheless, even small improvements in sleep duration after delaying school start time have been shown to benefit adolescents' well-being [41,63].

We found that daily travel time (an indirect measure for time to reach school) was strongly associated with wake-up time. This finding is consistent with previous work demonstrating that adolescents who spend more time on travel wake up earlier for school and have less nocturnal sleep [64,65]. With the advent of technologies that make it possible to monitor traffic patterns and to determine the optimal route for pick-up of children, it may be possible to shave off time from a student's commute to school. Providing shuttle services from strategic locations and taking advantage of ride-sharing services may also reduce time to reach school, hence allowing students to sleep in later. The "one school, one bus company" model for transporting children may eventually be rendered obsolete, with benefits on adolescents' sleep.

In summary, the types of barriers to healthy sleep that we examined are shared across cultures (eg, later chronotype, low parental supervision of bedtime, longer study hours, early school start time, and longer time spent on transportation). However, the strength of these barriers and the ability to remove them are likely influenced by sociocultural factors. As reviewed elsewhere, East Asian societies with Confucian-heritage cultures differ from Western societies in their style of parenting, educational philosophy, and underlying motivations for academic achievement [32,33]. Socioeconomic factors, family structure, and cultural values also vary between and within individual countries. These forces likely interact to shape norms and attitudes on sleep behavior, school life, and academic achievement. Here, we identified differences between local schools and international schools (East Asian vs non–East Asian school systems) in bedtime, sleep duration, parent-set bedtime, time spent on studying, and effects of school start time on sleep behavior. Additional studies are needed to identify the underlying drivers (sociocultural or otherwise) that give rise to these differences in sleep-related behavior.

4.4. Study limitations and considerations

The present study included a convenience sample of schools and students who agreed to take part in the research, which may have resulted in selection bias. For example, school personnel may have been more interested, or perhaps less interested, in participating if they felt that sleep was a problem in their students. Similarly, parents may have been more likely to sign the permission form if they had an interest in their child's sleep habits. In addition, the local schools that took part in our study have a strong academic reputation with high-performing students based on national examination scores. It is therefore unclear whether our results for sleep behavior can be generalized to students attending other schools. To address selection bias, future studies should implement a random sampling approach for recruiting schools and students.

Another limitation of our study is that we did not collect information on adolescents' family structure or sleeping arrangements (eg, co-sleeping or sharing a bedroom with a sibling), which may influence both sleep timing and quality. Lower socioeconomic status has also been shown to associate with sleep problems [66], but we did not collect data on socioeconomic indicators. We also did not attempt to measure the degree of academic pressure, or motivations for academic achievement, across participating schools. Although academic achievement is highly valued in Confucian-heritage nations such as Singapore [33], many students attending international schools may also face high academic pressure, as well as acculturation issues [67]. Future studies are needed to elucidate the relationship between academic pressure/stress, academic achievement, and sleep behavior across different cultures.

Because our data were based on self-report, participants may have misestimated their sleep behavior parameters. In addition, participants were asked to indicate their responses for a typical school day or weekend, which does not capture day-to-day changes in sleep behavior or symptoms of sleep deficiency.

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Based on prior work, adolescents show cumulative effects of sleep restriction on performance and sleepiness [3,8]. Despite these limitations, our findings on associations of sleep duration with symptoms of sleep deficiency and health-related outcomes are consistent with those of previous studies on adolescent sleep behavior. In future work, inclusion of sleep diaries or continuous monitoring of sleep–wake behavior with actigraphy may allow for a more objective assessment of sleep behavior, with symptoms of sleep deficiency assessed at different times during the week.

In our study, it is difficult to tease apart the relative contribution of different factors on sleep behavior because of the uneven distribution of characteristics in the participating schools. For example, most local schools in our sample had an earlier school start time and comprised predominantly ethnic-Chinese adolescents. By comparison, none of the international schools in our sample had a start time before 08:00, and the ethnic make-up of these schools was more diverse. Rather than attempting to model the contribution of individual factors to sleep behavior (bedtime, wake-up time, and nocturnal sleep duration), we decided to perform descriptive analyses in which sleep behavior was compared among adolescents exposed to different combinations of factors. This approach allowed us to assess the relative importance of different factors on sleep behavior, without having to make assumptions regarding independence or interaction of the variables that were included. A drawback of this approach is that we could not examine too many variables at once because the number of possible unique combinations becomes too large, and the sample for each combination of factors becomes too small. We therefore limited our analysis of the combined association of factors on nocturnal sleep duration to five variables (age, chronotype, school type, school start time, and daily travel time), and performed secondary analyses of factors that differed between school types, including parent-set bedtime, time spent on studying/homework, and time spent on media use.

5. Conclusion

Improving nocturnal sleep behavior is a major challenge in East Asian cultures, where the pursuit of academic success may be prioritized over sleep. Our findings show that most adolescents in this setting are chronically sleep-deprived. Based on results demonstrating that shorter sleep is associated with signs of sleep deficiency, adolescents who trade sleep for the pursuit of academic success may not be reaching their full learning potential. Even if they do, it may come at the cost of their health and well-being. The greater frequency of overweight/obesity and depression symptoms among shorter sleepers indicates that greater priority should be placed on improving sleep in adolescents. Poor sleep practices adopted during childhood may be carried forward throughout life, giving rise to a large societal and economic burden. Strategies for improving sleep in East Asian societies should take into consideration sociocultural factors that may affect the ability to remove barriers to healthy sleep. A multipronged approach may be necessary for improving sleep behavior in adolescents, in which all stakeholders (students, parents, teachers, school leaders, and policymakers) are involved in promoting behavioral change. Sleep education is critical for improving sleep hygiene and changing cultural mindsets toward sleep, and administrative changes (eg, reduced workload, later school start time, and better transportation options) can help make more time for adolescents to sleep. Future studies should examine whether combining these approaches can help more adolescents to achieve an optimal amount of sleep, with benefits on their performance, health, and well-being.

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Conflict of interest

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.2018.10.041.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2018.10.041.

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