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Formula for Calculating Optimal Sleep Duration in Adolescents

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Abstract

*A recently proposed formula for estimating optimal sleep duration (OSD) incorporates social jetlag and standardized body mass index (BMI), both of which are challenging to measure accurately. In the current study, a formula using not standardized BMI but actual BMI to estimate OSD was proposed. Among 2,540 students in grades 5 to 11, "ideal" students were identified as those reporting no daytime sleepiness and having a standardized BMI within ±1.5. Their habitual sleep duration was regarded as their "assumed OSD." "Non-ideal" students were classified based on their reported sleepiness during class (on a scale from 1 = never to 4 = always) and their standardized BMI [high (≥1.5), medium (within ±1.5), and low (≤-1.5)]. The difference in average sleep duration between the ideal and non-ideal groups was added to each non-ideal student's habitual sleep duration to calculate their "assumed OSD." Multiple regression analysis was conducted using bedtime (on schooldays and non-schooldays), wake time (on schooldays and non-schooldays), BMI, grade, gender, self-reported academic performance, after-school activity (hours/week), breakfast frequency score, defecation frequency score, physical activity (days/week), and screen time (on schooldays and non-schooldays) as independent variables, with "assumed OSD" as the dependent variable. A significant linear formula for estimating OSD was derived: 23.375 - 0.710 * (bedtime before schooldays) - 0.286 * (bedtime before non-schooldays) + 0.714 * (wake time on schooldays) + 0.281 * (wake time on non-schooldays) + 0.513 * (sleepiness score; 1-4) + 0.009 * [gender (male: 1; female: 2)] + 0.003 * (BMI). A straightforward formula for estimating individual OSD was proposed, although further research is required for validation.*

Key words: Body mass index, Insufficient sleep syndrome, Sleepiness.

Introduction

It is known that 10–20% of adolescents suffer from insufficient sleep syndrome (ISS) [1-6], and those with ISS exhibit prolonged catch-up sleep (CUS) [7]. Knowing one's optimal sleep duration (OSD) is the first step in combating sleep deprivation, including ISS [8]. However, OSD exhibits considerable interindividual variability [9], with sleep duration influenced by various factors, including seasonal changes [10], lunar phases [11], and ambient temperature [12]. Although widely recommended sleep duration guidelines have been established [13, 14], their broad ranges limit practical applicability at the individual

level. To address this limitation, a recent study proposed a formula for estimating personalized OSD [15]. However, this formula included social jetlag and gender- and grade-standardized body mass index (BMI), which are not easily obtainable. Therefore, in this study, a similar process to determine each student's "assumed OSD" was used, but instead of social jetlag and standardized BMI, more easily obtainable indices such as bedtimes, wake times, and actual BMI values were adopted as explanatory variables.

Material and Methods

The data used in this study are the same as those from the previous research [15], and the analysis process followed the same steps as before, but the explanatory variables used in the final least squares regression calculation were modified.

The survey for the study proposing the formula was approved in 2016 by the Committee for Medical Research Ethics at Tokyo Bay Urayasu Ichikawa Medical Center (Approval No. 199). It was conducted from October 2016 to November 2018 across 28 public schools, including 15 elementary schools, 8 junior high schools, and 5 senior high schools [15]. The study involved 2,540 students from grades 5 to 11. Teachers distributed questionnaires (Table 1) along with a letter assuring participants that responses would be anonymous and confidential, and that participation was voluntary. Written informed consent from each student's guardian, along with the completed questionnaires, was collected by the teachers and subsequently sent to the author.

Table 1. Questionnaire used for estimating OSD.

Queries.	Choices for answer
Please select your grade.	Elementary school (Grade 5, 6), Junior high school (Grade 1, 2, 3), High school (Grade 1, 2, 3)
Please select your gender.	Gender (male, female)
Please describe your height and weight.	Height (cm), Weight (kg)
Please select your bedtime before schooldays.	1: <8 PM; 2: 8–9 PM; 3: 9–10 PM; 4: 10–11 PM; 5: 11 PM–12 AM;6: 12–1 AM; 7: 1–2 AM; 8: 2–3 AM; or 9: >3 AM
Please select your bedtime before nonschooldays.	1: <8 PM; 2: 8–9 PM; 3: 9–10 PM; 4: 10–11 PM; 5: 11 PM–12 AM;6: 12–1 AM; 7: 1–2 AM; 8: 2–3 AM; or 9: >3 AM
Please select your waking time on schooldays.	1: <5 AM; 2: 5–6 AM; 3: 6–7 AM; 4: 7–8 AM; 5: 8–9 AM; 6: 9–10 AM; 7: 10–11 AM; 8: 11 AM–12 PM; or 9: >12 PM
Please select you waking time on nonschooldays.	1: <5 AM; 2: 5–6 AM; 3: 6–7 AM; 4: 7–8 AM; 5: 8–9 AM; 6: 9–10 AM; 7: 10–11 AM; 8: 11 AM–12 PM; or 9: >12 PM
Please select the frequency you feel sleepy during class. (sleepiness score)	1: never; 2: sometimes; 3: often; or 4: always
Please select your frequency of eating breakfast. (breakfast taking score)	1: always; 2: often; 3: sometimes; or 4: never
Please select your frequency of defecation. (defecation frequency score)	1: every day; 2: every other day; 3: once every 2–3 days; 4: twice a week or less
Please select the time you usually eat dinner.	1: around 6 PM; 2: around 7 PM; 3: around 8 PM; 4: around 9 PM; 5: around 10 PM; 6: around 11 PM; 7: later than 11 PM; or 8: not determined
Do you take part in any kind of after-school activity?	1: yes; 2: no
If yes, please select your frequency of participating in after-school activity.	1: once a week; 2: twice a week; 3: three times a week; 4: four times a week; 5: five times a week; 6: six times a week; or 7: every day
If yes, please select the average duration of a single after-school activity.	1: 1 hour; 2: 2 hours; 3: 3 hours; 4: 4 hours; or 5: 5 hours or more
How many days a week do you engage in habitual exercise except for school lessons?	0: none; 1: 1 day per week; 2: 2 days per week; 3: 3 days per week; 4: 4 days per week; 5: 5 days per week; 6: 6 days per week; or 7: 7 days per week
How long do you use variable media tools (television, video, video game, digital versatile disc, computer, tablet, mobile [cell] phone, smart phone) in a day? Please answer separately for schooldays and nonschooldays. (screen time score)	On a school day: 1: <2 hours; 2: 2–4 hours; 3: 4–6 hours; 4: 6–8 hours; or 5: 8 hours or more.
	On a non-school day: 1: <2 hours; 2: 2–4 hours; 3: 4–6 hours; 4: 6–8 hours; or 5: 8 hours or more.
Please select the best category for your overall academic performance.	1: very good; 2: good; 3: not good; or 4: poor.

Participants provided their grade, gender, height, and weight, with the latter two measurements used to calculate BMI (kg/m²). Both gender- and grade-standardized BMIs (expressed in standard deviations) were used for analysis. For bedtime and wake times, students selected from nine 1-hour interval categories (bedtime: 1, before 20:00; 2, 20:00–21:00; …; 8, 02:00–03:00; 9, after 03:00; waking time: 1, before 05:00; 2, 05:00–06:00; …; 8, 11:00–12:00; 9, after 12:00). Representative times for categories 2–8 were determined as the midpoints (bedtime: 20:30, 21:30, 22:30, 23:30, 24:30, 25:30, 26:30; waking time: 5:30, 6:30, …, 10:30, 11:30). For categories 1 and 9, the representative times were 19:30 and 27:30 for bedtime, and 04:30 and 12:30 for waking time. Students reported bedtimes and wake times separately for schooldays and non-schooldays. These times were used to calculate night-time sleep duration for the nights before schooldays and non-schooldays. Weekly sleep duration was computed using the formula: [(sleep duration before schooldays) × 5] + [(sleep duration before non-schooldays) × 2]. The average daily sleep duration was then calculated as: weekly sleep duration / 7. Sleepiness during school was assessed based on four subjective categories: 1, never; 2, sometimes; 3, often; 4, always.

Body mass index (BMI) and sleep duration show a U-shaped relationship [16-18], although some studies have reported different findings [19]. Based on this observation, it is expected that individuals who sleep for their OSD will have a BMI close to the average value for their population. Therefore, this study defines "ideal students (id-St)" as those who do not feel sleepy during class and have a gender- and grade-standardized BMI within ±1.5.

To determine whether the habitual sleep duration (HSD) of ideal students (id-St) can be considered OSD, two key issues were evaluated: (1) whether the sleep duration of id-St falls within the recommended range [13], and (2) whether the sleep duration of id-St is longer than that of non-id-St. After addressing these issues, individual OSD was estimated using self-reported sleepiness and standardized BMI. For the first issue, the lower limit of daily sleep duration recommended as "may be appropriate" for children aged 6 to 17 years by the National Sleep Foundation [13]—specifically, 7 hours per day—was used as a benchmark. Regarding the second issue, it was assumed that the sleep duration of id-St would be longer than that of non-id-St, since subjective sleepiness typically increases with reduced sleep duration [20]. Additionally, given the U-shaped relationship between BMI and sleep duration [16-18], non-id-St with a BMI significantly different from the mean are expected to have either longer sleep duration (if their standardized BMI is positive) or shorter sleep duration (if it is negative) as with the increase of absolute standardized BMI value. As a result, no consistent outcome is expected for this latter assumption. Therefore, by combining the consistent expectation of the first assumption with the inconsistent results of the second, it is concluded that the sleep duration of id-St is likely longer than that of non-id-St.

Non-ideal students were categorized into 11 groups based on their sleepiness scores (1, 2, 3, and 4) and standardized BMI [high (≥1.5), medium (within ±1.5), and low (≤-1.5)]. The difference in average sleep duration between ideal and each of these non-ideal student groups was added to the HSD of each non-ideal student to calculate their "assumed daily OSD." To simplify the process of determining an individual's OSD, this study replaced social jetlag and a gender- and grade-standardized BMI with more easily obtainable indices—bedtimes, waking

times, and actual BMI—as explanatory variables. A multiple regression model was then calculated using the least squares method, with “assumed daily OSD” as the dependent variable and the following as explanatory variables: grade, gender, sleepiness score, actual BMI, self-reported academic performance, after-school activity (hours/week), breakfast frequency score, defecation frequency score, physical activity (days/week), screen time (both on schooldays and non-schooldays), bedtimes before both schooldays and non-schooldays, and waking times on schooldays and non-schooldays. In this calculation, bedtimes and waking times were measured in hours. For instance, bedtimes were represented as 23:45 (23.75), 0:20 (24.33), and 3:15 (27.25), while waking times were represented as 6:00 (6.00) and 11:00 (11.00).

This study was approved in 2016 by the Committee for Medical Research Ethics of Tokyo Bay Urayasu Ichikawa Medical Center, with the approval number of 199.

Results

A total of 666 individuals (id-St) were identified. The average weekly sleep duration for these individuals was 62.0 hours during elementary school, 55.6 hours during junior high school, and 50.1 hours during senior high school, all exceeding the 49 hours considered "may be appropriate" for children aged 6 to 17 years by the National Sleep Foundation of the USA [13]. Moreover, the average daily sleep duration for id-St was longer than that of non-id-St across all school levels, with 61.2 hours for elementary school, 54.1 hours for junior high school, and 48.6 hours for senior high school. The percentage of students whose weekly sleep duration fell below 49 hours was also higher among non-id-St compared to id-St: 1.9% vs. 0.9% in elementary school, 17.1% vs. 12.7% in junior high school, and 47.1% vs. 39.3% in senior high school.

Since the two key issues were confirmed—namely, that the sleep duration of id-St fell within the recommended range [13], and that id-St slept longer than non-id-St—the HSD of each id-St was considered as their "assumed daily OSD." The differences in average daily sleep duration between the id-St group (8.49 hours) and the 11 groups of non-id-St, ranging from 0.04 hours (for those with a high standardized BMI and a sleepiness score of 1) to 1.92 hours (for those with a low standardized BMI and a sleepiness score of 4), were calculated. The "assumed daily OSD" for each non-id-St was then determined by adding these differences to the HSD of each individual non-id-St. The regression coefficients obtained via the least squares method, with “assumed daily OSD” as the dependent variable, are shown in Table 2. Consequently, a multiple regression equation to estimate daily OSD was derived as follows (adjusted $R^2 = 0.996$, $p < 0.001$): 23.375 - 0.710 * (bedtime before schooldays) - 0.286 * (bedtime before non-schooldays) + 0.714 * (wake time on schooldays) + 0.281 * (wake time on non-schooldays) + 0.513 * (sleepiness score; 1-4) + 0.009 * [gender (male: 1; female: 2)] + 0.003 * (BMI).

Table 2. Regression coefficients obtained by the least square method to calculate multiple regression line, setting assumed daily optimal sleep duration as the dependent variable.

Variables		Regression coefficient			β	
		95 CI				
Constant	**23.3755**	23.3086	to	23.4424	23.3755	0.0001>
Bedtime before schooldays	**-0.7101**	-0.7146	to	-0.7055	-0.8028	0.0001>

Bedtime before non-schooldays	**-0.2861**	-0.2903	to	-0.2820	-0.3541	0.0001>
Awake time on schooldays	**0.7141**	0.7091	to	0.7191	0.4294	0.0001>
Awake time on non-schooldays	**0.2814**	0.2789	to	0.2839	0.3751	0.0001>
Sleepiness score (1-4)	**0.5129**	0.5090	to	0.5168	0.3883	0.0001>
Gender male:1; female:2	**0.0091**	0.0032	to	0.0149	0.0043	0.0023
BMI (kg/m^2)	**0.0029**	0.0019	to	0.0039	0.0077	0.0001>
Screen time score on schooldays	-0.0038	-0.0089	to	0.0013	-0.0029	0.1464
Screen time score on non-schooldays	0.0005	-0.0033	to	0.0043	0.0005	0.7989
Breakfast taking score	-0.0027	-0.0080	to	0.0027	-0.0014	0.3295
Self-reported academic perfor-	0.0020	-0.0016	to	0.0056	0.0015	0.2715
Grade (5-11)	0.0005	-0.0015	to	0.0026	0.0010	0.6061
Defecation frequency score	0.0007	-0.0025	to	0.0039	0.0006	0.6793
Physical activity (days/week)	0.0002	-0.0008	to	0.0013	0.0006	0.6662
After school activity (hours/week)	0.0000	-0.0004	to	0.0004	0.0000	0.9867

BMI: body mass index; CI: confidence interval; β: standardized regression coefficient.

Discussion

In this study, a formula was developed to estimate daily OSD using easily obtainable indices. For instance, consider a grade 9 boy who typically sleeps 6 hours before schooldays (with a bedtime of 24.50 [0:30 am] and a wake time of 6.50 [6:30 am]), 9 hours before non-schooldays (with a bedtime of 25.50 [1:30 am] and a wake time of 10.00 [10:00 am]), occasionally feels sleepy in class, and has a BMI of 20.5. His estimated daily OSD would be calculated as follows: 23.375 - 0.710*24.5 - 0.286*25.5 + 0.714*6.5 + 0.281*10 + 0.513*2 + 0.009*1 + 0.003*20.5 = 7.235 hours.

However, despite the risks associated with social jetlag, busy adolescents often have no choice but to rely on weekend CUS [21-24] to compensate for the sleep debt accumulated during schooldays. If 1.5 hours of CUS is allowed, it is recommended that this student aim for 6.949 hours of sleep on schooldays and 8.449 hours on non-schooldays, calculated as follows: 6.806 hours = ([7.235 * 7 - 1.5 * 2] / 7) and 8.306 hours = 6.806 + 1.5. For these busy adolescents, expressing the OSD as a weekly total (50.645 hours) rather than as a daily value (7.235 hours) might be more practical. However, current recommendations [13, 14] are based on daily sleep durations, which can be difficult to maintain consistently. Advocating for weekly rather than daily sleep recommendations could allow adolescents to adjust their sleep schedules on schooldays and non-schooldays according to individual circumstances, potentially reducing or eliminating sleep debt.

The questionnaire used in the study proposing the OSD estimation formula has several limitations. Firstly, it is neither standardized nor validated, though it is used in foundational surveys for policy-making [25], which may imply a level of acceptance. Secondly, the questionnaire relies on self-reports. Despite this, the sleep duration and average BMI values reported align closely with those of Japanese elementary, junior high, and high school students [25], somewhat supporting its external validity. The third issue pertains to the sleepiness scale used. While there are various standardized scales for evaluating sleepiness, such as the Stan-

ford Sleepiness Scale, which is a one-item self-report scale (7 points) focused on sleepiness [26], and the Epworth Sleepiness Scale, which assesses sleep propensity [27], the questionnaire in this study employs a similar one-item self-report scale (4 points). The utility of single-item scales has been recognized [28], although the test-retest reliability of the Epworth Sleepiness Scale has been reported as low [29]. Lastly, the questionnaire does not account for socioeconomic status, a significant factor related to sleep [30], which remains an area for future research.

Additionally, some id-St obtained less than the recommended minimum of 49 hours per week, which is deemed "may be appropriate." Given the tendency for subjective sleepiness to underestimate actual sleep deficits [20], it is crucial to monitor these students closely for signs of sleep deprivation, despite their classification as id-St.

Conclusion

Despite these limitations, a straightforward formula for estimating individual OSD using easily obtainable parameters has been proposed. While further research is required to validate the current proposal, understanding one's own OSD is crucial for mitigating sleep debt [8]. It is anticipated that this study will assist students dealing with chronic sleep debt, including ISS.

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