Sleep Medicine 112 (2023) 30–38

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Assessing 'readiness' by tracking fluctuations in daily sleep duration and their effects on daily mood, motivation, and sleepiness

Alyssa S.C. Ng [a], Stijn A.A. Massar [a], Bei Bei [b], Michael W.L. Chee [a,*]

[a] Sleep and Cognition Laboratory, Centre for Sleep and Cognition, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

[b] Turner Institute for Brain and Mental Health, School of Psychological Sciences, Monash University, Melbourne, Australia

ARTICLE INFO

Keywords:
Sleep
Wearable
Mood
Motivation
Sleepiness
Ecological momentary assessment
University students

ABSTRACT

Study objectives: Consumer sleep trackers issue daily guidance on 'readiness' without clear empirical basis. We investigated how self-rated mood, motivation, and sleepiness (MMS) levels are affected by daily fluctuations in sleep duration, timing, and efficiency and overall sleep regularity. We also determined how temporally specific these associations are.

Methods: 119 healthy university students (64 female, mean age = 22.54 ± 1.74 years) wore a wearable sleep tracker and undertook twice-daily smartphone-delivered ecological momentary assessment of mood, motivation, and sleepiness at post-wake and pre-bedtime timings for 2–6 weeks. Naps and their duration were reported daily. Nocturnal sleep on 2471 nights were examined using multilevel models to uncover within-subject and between-subject associations between sleep duration, timing, efficiency, and nap duration on following day MMS ratings. Time-lagged analyses examined the temporal specificity of these associations. Linear regression models investigated associations between MMS ratings and sleep variability, controlling for sleep duration.

Results: Nocturnal sleep durations were short (6.03 ± 0.71 h), and bedtimes were late (1:42AM ± 1:05). Within-subjects, nocturnal sleep longer than a person's average was associated with better mood, higher motivation, and lower sleepiness after waking. Effects of such longer sleep duration lingered for mood and sleepiness till the pre-bedtime window (all *Ps* < .005) but did not extend to the next day. Between-subjects, higher intraindividual sleep variability, but not sleep duration, was associated with poorer mood and lower motivation after waking. Longer average sleep duration was associated with less sleepiness after waking and lower motivation pre-bedtime (all *Ps* < .05). Longer naps reduced post-nap sleepiness and improved mood. Controlling for nocturnal sleep duration, longer naps also associated with lower post-waking sleepiness on the following day.

Conclusions: Positive connections between nocturnal sleep and nap duration with MMS are temporally circumscribed, lending credence to the construction of sleep-based, daily 'readiness' scores. Higher sleep duration variability lowers an individual's post waking mood and motivation.

Clinical trial id: ClinicalTrials.gov NCT04880629.

1. Introduction

A good night's sleep prepares us for the next day. Conversely, inadequate sleep diminishes performance in laboratory-based tests of attention, memory, and executive functions [1], and of greater relevance, impacts performance in activities like driving, concentrating on a task, or memory [2]. A simple gauge of preparedness to perform real world tasks is appealing. However, such a measure needs to encompass multiple cognitive dimensions [3], and be repeatedly assessable without practice effects. This is virtually impossible outside the assessment of vigilance which takes several minutes to assay each time using tools such as the psychomotor vigilance task [4]. We thus propose to focus our investigation on three easily interpretable and deployable measures that have associations with both sleep and mental readiness to perform: self-assessed mood, motivation, and sleepiness (MMS).

Self-reported sleepiness relates to poorer performance in a variety of tasks requiring vigilance, such as driving performance [5,6], and has also been associated with reduced motivation to engage in social or physical activities [7]. Positive affect or better mood can result in more productive behaviour, better job performance [8], as well as higher

* Corresponding author. Sleep and Cognition Laboratory, Centre for Sleep and Cognition, Yong Loo Lin School of medicine, National University of Singapore , Tahir Foundation Building, MD1, 12 Science Drive 2, 117549, Singapore.

E-mail address: michael.chee@nus.edu.sg (M.W.L. Chee).

https://doi.org/10.1016/j.sleep.2023.09.028
Received 19 July 2023; Received in revised form 19 September 2023; Accepted 25 September 2023
Available online 28 September 2023

overall academic achievement [9]. Higher motivation has also been tied to higher productivity among working adults [10] and higher student grade-point averages [11].

Each component of MMS has been independently linked to sleep. Sleepiness increases with cumulative time spent awake both within a day [12] as well as over multiple days under laboratory [13] or quasi-laboratory conditions [14]. Sleep is important for the regulation of affect [15–21]. In studies involving healthy persons, shorter sleep durations have been associated with decreased positive affect and elevated negative affect [15]. Laboratory-based [22–25] as well as field studies [26] have shown that sleep deprived individuals are more likely to report stronger feelings of irritability, anger and depression, together with reduced expressions of happiness and excitement [27]. An emerging literature also suggests that sleep loss impairs motivation [28–31], while sleep loss and poor sleep quality have been found to decrease the willingness to exert effort towards a goal [32–35].

While mood, motivation, and sleepiness have individually been found to affect performance, the impact of sleep on these variables have not hitherto been concurrently evaluated in real-world settings in the same persons. Moreover, much of the current evidence for the effects of sleep on next-day mood or motivation is limited to in-laboratory sleep restriction studies [16]. Mindful of the importance of ecological relevance, several studies have begun to examine the associations between sleep quality or duration, and mood on a day-to-day level [36–40]. However, there is still a gap regarding the contributions of sleep timing or regularity to these outcomes. Sleep timing (i.e. bedtime, wake-up time) and sleep regularity (i.e. intraindividual variability in sleep patterns) are key elements in the multidimensional evaluation of sleep health [41]. However, there is inadequate evidence to support their influence on mental readiness [42–44]. This is largely due to logistical and technological challenges in collecting concurrent sleep and behavioural data of sufficient duration (at least 2 weeks) and granularity.

The present study addresses these gaps using a longitudinal approach to assess the impact of sleep timing, duration, efficiency, and regularity on mood, motivation, and sleepiness as indicators of mental readiness. The latter were reported twice daily (during a post-wake and pre-bedtime window) via short-expiry ecological momentary assessment (EMA) delivered by smartphones to healthy university students. Sleep was measured using a validated wearable tracker and EMA sleep diaries over 2–6 weeks in two samples. Daytime nap durations were accounted for in our models.

We hypothesized that within an individual, night-to-night changes in sleep measures (sleep duration, mid-sleep timing and/or efficiency) would affect next day mood, motivation and sleepiness, and that effects would be temporally restricted to the day after the night's sleep. We further expected that the duration of afternoon naps, when taken, would modulate post-nap, pre-bedtime assessment of mood, motivation and sleepiness. Between individuals, we expected that those with poorer sleep on average or more variable sleep would display poorer mood and motivation.

2. Methods

2.1. Participants

Data were collected from 119 university students (aged 21–30, 64 male) who were recruited in two separate studies using near-identical measures. Study 1 took place in March–May 2021 and Study 2 took place in August–October 2022, both during academic term times. In both studies, participants provided daily reports of sleep-wake times, mood, motivation and sleepiness ratings for four (Study 1) or two (Study 2) weeks.

Students were recruited by advertisements posted on the university's learning platform or through hostel mailing lists. Seventy-six individuals enrolled in Study 1, and 63 enrolled in Study 2 (including 11 returning participants from Study 1; reasons for this are disclosed in Supplementary Materials). All participants declared no known neurological, psychiatric or sleep disorders. Study 1 participants were all university dormitory residents, while participants in Study 2 were a mixture of persons staying in dormitories and those staying elsewhere.

Participants underwent additional screening during their baseline study visit. Those with moderate to severe risk of sleep disordered breathing assessed through the Berlin Sleep Apnoea Questionnaire, or moderate to severe risk of anxiety or depression assessed by a Beck's Anxiety Inventory category score ≥ 3 or a Beck's Depression Inventory ≥ 3, were excluded. Four participants in Study 1 and 5 participants in Study 2 were removed for these reasons, resulting in a total of 72 participants in Study 1 and 58 participants in Study 2 (including 11 individuals participating in both studies).

2.2. Study protocol

Ethics approval for all study procedures was obtained from the Institutional Review Board of the National University of Singapore. Participants provided written informed consent prior to participating in any procedures. Financial compensation was provided based on the participant's compliance to the study measures on a weekly basis ($25 per week; data must be provided on a minimum of 5 days, including at least one weekend day).

During the baseline visits, apps for data collection, the Oura client app (Oura Health Oy, Oulu, Finland) and Z4IP Ecological Momentary Assessment app were installed on participants' smartphones. Participants were fitted with a wearable sleep and activity tracker (the Oura Ring), and trained by research staff to use the ring and its app for data recording during the succeeding four weeks in Study 1 and two weeks in Study 2 (see Fig. 1). Participants in Study 1 underwent additional data collection procedures which are unrelated to the present paper. The details of these can be found in Supplementary Materials.

2.3. Sleep measurement using Oura Rings

Nocturnal sleep was measured using Oura Rings (Oura, Health Oy, Oulu, Finland) worn on a finger on the participant's non-dominant hand. Sleep-wake periods were estimated by Oura's proprietary algorithm that takes into account body movement, heart rate variability, a circadian factor and temperature [45]. Bedtime, wake-up time, time-in-bed (TIB), total sleep time (TST), sleep onset latency (SOL), and wake after sleep onset (WASO) were extracted from Oura's cloud application programming interface (API). Sleep efficiency (SE) was calculated as 100*(TST/TIB), and mid-sleep times (MST) were calculated as the midpoint between bedtimes and wake-up times as assessed by the wearable device. To measure intraindividual variability in sleep duration, standard deviations of TST were calculated for each week of measurement (containing sleep episodes on a minimum of 4 weekdays and 1 weekend day), and the average was taken across all qualifying weeks. The proprietary sleep assessment algorithm was locked for the entire period of both studies to reduce source data variability.

While Oura Rings can detect naps of >15 min duration, this feature has not been formally evaluated and was not used in the present study for the characterization of naps. Instead, self-reporting of naps through the EMA was implemented. Oura also generates a 'readiness' score which takes into account sleep, physical activity, recovery time and heart rate variability for consumers in their commercial app. This was blocked from participants' view through Oura's 'restriction period mode' to avoid influencing the EMA-based ratings of mood, motivation and sleepiness.

2.4. Daily mood, motivation, and sleepiness measures via ecological momentary assessment

Ecological momentary assessments, consisting of short questions and cognitive games (not reported here) were completed by participants

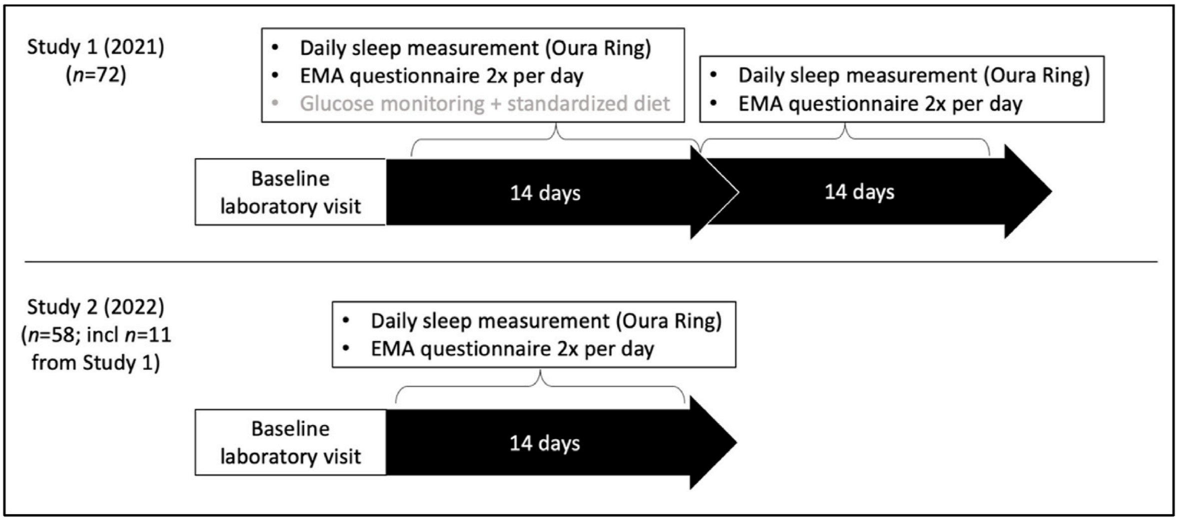

Fig. 1. Brief protocol overview of Study 1 and Study 2.

twice daily – once during a post-wake window (0800–1359 h) and once during a pre-bedtime window (2000–2359 h). They were asked to rate their momentary feelings of mood, sleepiness, and motivation in response to the questions: "How are you feeling right now?", "How sleepy are you feeling right now?" and "How motivated are you feeling right now?" Responses to each question were recorded on a sliding scale with values ranging from 0 to 100, where 0 = "not at all" to 100 = "very much" for the sleepiness and motivation questions, and 0 = "negative", 50 = "neutral" and 100 = "positive" for the mood question. Each EMA assessment took between 5 and 7 min to complete.

2.5. Sleep and nap self-reports via ecological momentary assessment

Participants reported their bedtime and wake-time for the previous night once per day. These were used only to check sleep periods determined by the Oura Ring. Participants also recorded the occurrence and duration of naps they had taken each day during the pre-bedtime window, in response to the question *"How long did you nap for today?"* using a sliding scale (0–120 min).

3. Statistical analysis

3.1. Data preparation

For 11 participants who took part in both studies, data from both studies was merged into a single record. All sleep-wake timings extracted from Oura's cloud API were manually reviewed using a semi-automated process that flagged and adjusted sleep onset or offset times that were inconsistent with participants' self-reported sleep timings (for example due to misclassification of an awake period as WASO). A section of the code enabling these functions is provided under supplementary materials. Six nights on which a complete nocturnal sleep period could not be determined (e.g. TIB<3 h or multiple short sleep episodes) were censored. A further 12 nights on which bedtime was after 0800 h on the following morning (n = 5) or wake-up time was after 1400 h (n = 10; 3 overlapping) were also excluded from analyses using mixed linear models. This was to eliminate the possibility of a main sleep episode taking place after the post-wake EMA session window. A total of 2471 nights which had a qualifying sleep period were used in the final analyses (percentage missing in Study 1 = 14.5%, percentage missing in Study 2 = 7.9%; average of 23.9 ± 4.6 nights/participant in Study 1 and 12.9 ± 1.3 nights/participant in Study 2). Post-wake MMS ratings were provided on a total of 2427 days (percentage missing in Study 1 = 15.9%, percentage missing in Study 2 = 10.0%; average of 23.6 ± 5.35 nights/participant in Study 1 and 12.6 ± 1.5 nights/participant in Study 2), while pre-bedtime MMS ratings were provided on a total of 2363 days (percentage missing in Study 1 = 17.1%, percentage missing in Study 2 = 14.8%; average of 23.2 ± 5.6 nights/participant in Study 1 and 11.9 ± 1.7 nights/participant in Study 2).

Group-mean centering was performed on all daily nocturnal sleep variables by subtracting the subject's mean from the daily value of a given sleep measure, decomposing each variable into a level 2 predictor representing between-person effects (the subject mean) and level 1 predictor representing within-person effects (deviation from that subject's mean). The level 2 variables were centered to the grand mean by subtracting the mean value of that parameter across all nights.

3.2. Mixed linear models

Data were analysed using SPSS Statistics (Ver 27.0.1.0, SPSS, Chicago, IL). A linear mixed effects modelling approach with maximum likelihood estimation was used to examine between and within-person effects of sleep variables on measures of mood, motivation and sleepiness.

A series of models were constructed to examine the effects of prior night's TST, MST (both represented in hours), and sleep efficiency (represented in percentages) on mood, sleepiness, and motivation ratings measured during the post-wake and pre-bedtime windows on the index day immediately following the sleep period. These were adjusted for age, sex, BMI, study (Study 1 or Study 2), weekday/weekend day type, and previous day outcome variable. Models examining associations with post-wake MMS ratings were also adjusted for self-reported nap duration on the previous day, while those examining associations with pre-bedtime MMS ratings were adjusted for self-reported nap durations on the same day. To account for potential temporal trends, an ordinal variable, "day of study" (ranging from 0 to 28 for Study 1 and 0–14 for Study 2), was included as a fixed effect to anchor all other effects to the first day of measurement. To account for possible influence of the period of data collection (e.g. different class arrangements between Study 1 and Study 2 due to COVID-19 context), the study from which the data was collected was included as a covariate.

Random intercepts and random slopes (where convergence was possible) were included in all models to account for possible interindividual differences in associations between sleep and outcome variables at the day-to-day level. The model equation is shown below:

Level 1 equation:

$$Y_{ij} = \beta_{0j} + \beta_1\left(Y_{(i-1)j}\right) + \beta_2\left(study_{ij}\right) + \beta_3\left(day_{ij}\right) + \beta_4\left(weekend_{ij}\right) + \beta_5\left(nap\_duration_{*j}\right) + \beta_6\left(X_{ij} - \bar{X}_j\right) + \varepsilon_{ij}$$

Level 2 equation:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\left(female_j\right) + \gamma_{02}\left(age_j\right) + \gamma_{03}\left(BMI_j\right) + \gamma_{04}\left(\bar{X}_j\right) + u_{0j}$$
$$\beta_1 = \gamma_{10}$$
$$\beta_2 = \gamma_{20}$$
$$\beta_3 = \gamma_{30}$$
$$\beta_4 = \gamma_{40}$$
$$\beta_5 = \gamma_{50}$$
$$\beta_6 = \gamma_{60} + u_{1j}$$

In these models i indexes days within subjects, j indexes subjects, Y denotes self-rated mood, motivation or sleepiness, X denotes the sleep predictor variable, β denotes level 1 coefficients, γ denotes level 2 coefficients and u denotes variance terms. Previous day nap duration (nap duration)$_{(i-1)j}$ was adjusted for in models examining associations with MMS ratings in the post-wake window; while same-day nap duration (nap duration)$_{ij}$ was adjusted for in models examining associations with MMS ratings in the pre-bedtime window.

Cohen's f^2 effect sizes were calculated for each independent within-subject and between-subject sleep predictor using the formula $f^2 = (R^2_{AB}-R^2_{A})/(1-R^2_{AB})$, where B is the sleep predictor of interest and A denotes other predictor variables related to sleepiness, mood or motivation; R^2_{AB} denotes the proportion of variance accounted for by both A and B, and R^2_{A}, obtained by dropping the relevant sleep predictor from the model, denotes the proportion of variance accounted for by A [46]. To ensure that reductions in variance were attributed to fixed effects only, R^2 values were taken from models without random slopes for the purposes of calculating effect sizes with the above equation. Effect sizes were interpreted using the guidelines: small: $f^2 \geq 0.02$, medium: $f^2 \geq 0.15$, large: $f^2 \geq 0.35$) [47].

To correct for multiple comparisons, adjusted p-values were calculated using the Benjamini-Hochberg procedure [48].

3.3. Time-lagged (n+1) mixed linear models

Time-lagged models were computed to examine whether day-to-day effects of sleep extended to MMS ratings measured on the second day after the sleep period (i.e. day *n*+1, where day *n* refers to the index day). When referring to these time-lagged models, the main models described in the above section will be referred to no-lag. Age, sex, BMI, weekday/weekend day type and days in study were adjusted for. For consistency, previous day nap duration (relative to the morning of each sleep episode) was also adjusted for in models examining associations with post-wake MMS ratings, while same day nap duration was adjusted for in models examining associations with pre-bedtime MMS ratings. The full model equations can be found in supplementary materials.

3.4. Linear regression models

Aggregated multiple linear regression models were used to examine the effects of intraindividual sleep variability (TST SD) on each separate component of MMS. Models were adjusted for age, sex, BMI, study, and mean TST. In this part of the analyses, the 11 participants who participated in both studies were grouped under Study 1. The model equation used for each component of MMS was:

$$Y = \beta_0+\beta_1(study)+\beta_2(female)+\beta_3(age)+\beta_4(BMI)+\beta_5(Mean\ TST)+\beta_6(TST\ SD)+\varepsilon$$

3.5. Sensitivity analyses

To account for potential external influences of approaching examinations on MMS ratings, we repeated our models, excluding data that was collected during the university reading and examination weeks (Study 1: 19 Apr – 9 May 2021; Study 2: 19 Sep – 2 Oct 2022). The results are presented in Suppl Table 1.

4. Results

4.1. Participant characteristics

Age, sex ratio, and BMI were comparable across the two study samples (see Table 1). Participants in Study 1 (39 female) had a mean age of 22.16 (SD = 1.72) years, while participants in Study 2 (25 female) had a mean age of 23.12 (SD = 1.58) years. Many participants reported napping for more than half an hour at least once per week (76.4% in Study 1, 53.2% in Study 2) and may be considered to be "habitual nappers" [49,50]. Across all participants, the average bedtime was 1:42 a.m. (SD = 1:09), average TIB was 7.12 h (SD = 0.69), and average TST was 6.03 h (SD = 0.71). Only 56% of participants were found to have an average TIB of at least 7 h, and 50% had an average TST of at least 6 h. Independent t-tests suggested that average weekend wake times were later, average TIBs were longer on weekdays and weekends, and WASO was longer on weekdays and weekends in Study 2 compared to Study 1 (all *P*s < 0.05; see Table 2 for comparisons). However, these differences were not significant after controlling for multiple comparisons. The latter finding justified our combining unique participants across both samples in our analyses.

4.2. Multilevel models: Associations between sleep and next-day mood, motivation, and sleepiness ratings

Nights with relatively longer sleep durations for that individual (TST_{within}) were associated with better mood scores on both the following day's post-wake (β = 2.21, *P* < 0.001) and pre-bedtime

Table 1
Participant demographics.

	Study 1 (n = 72)	Study 2 (n = 47)
Female	39 (54.2%)	25 (53.19%)
Age (years)	22.16 (1.74)	23.12 (1.59)
BMI (kg/m^2)	20.94 (2.35)	21.35 (2.17)
Residing on-campus	72 (100.0%)	12 (25.5%)
BAI sum score (0-63)	5.53 (4.49)	3.09 (3.85)
BDI-Y sum score (0-60)	6.49 (4.91)	4.02 (4.48)
Pittsburgh sleep quality index (0-21)	4.47 (1.96)	5.43 (1.35)
Morningness-Eveningness questionnaire (16–86)	48.50 (7.63)	47.85 (7.48)
Chronic sleep reduction questionnaire		
Shortness of sleep (6-18)	12.15 (2.06)	11.66 (2.23)
Irritation (5-15)	6.11 (1.32)	5.94 (1.28)
Loss of energy (5-15)	7.60 (1.68)	7.11 (1.78)
Sleepiness (4-12)	7.22 (1.54)	7.04 (1.43)
Proportion of days with naps (%)	46.1 (25.9)	33.0 (22.1)
Proportion of days with nap (>30min) (%)	32.6 (24.3)	20.1 (19.8)
Habitual nappers (≥1 nap per week of >30mins)	55 (76.4%)	25 (53.2%)
Average nap duration (h; excluding days when nap duration = 0)	1.04 (0.39)	0.92 (0.51)

Note that the 11 participants who participated in both Study 1 and Study 2 are included under Study 1 in this table.

Table 2
Participant's average sleep characteristics measured via Oura Ring.

	Study 1(n = 72)			Study 2(n = 47)		
	Overall	Weekday	Weekend	Overall	Weekday	Weekend
Bedtime	1:43 ± 1:06	1:39 ± 1:05	1:52 ± 1:13	1:41 ± 1:05	1:37 ± 1:04	1:51 ± 1:18
Wake time	8:43 ± 0:48	8:36 ± 0:49	9:02 ± 0:55*	9:01 ± 1:08	8:49 ± 1:11	9:29 ± 1:23*
Mid-sleep time	5:13 ± 0:54	5:07 ± 0:54	5:27 ± 0:59	5:20 ± 1:03	5:13 ± 1:04	5:40 ± 1:15
TIB (h)	6.99 ± 0.69[a]	6.93 ± 0.70[a]	7.15 ± 0.81[b]	7.32 ± 0.67[a]	7.20 ± 0.73[a]	7.62 ± 0.96[b]
TST (h)	5.96 ± 0.72	5.90 ± 0.72	6.10 ± 0.81	6.15 ± 0.68	6.05 ± 0.72	6.42 ± 0.87
SE (%)	85.29 ± 5.22	85.20 ± 5.17	85.52 ± 5.94	84.10 ± 4.05	84.07 ± 3.99	84.28 ± 4.81
SOL (min)	10.00 ± 2.81	9.90 ± 2.97	10.31 ± 3.28	10.04 ± 3.10	10.31 ± 3.55	9.31 ± 4.14
WASO (min)	42.72 ± 20.68*	42.27 ± 20.30	43.90 ± 24.24*	50.16 ± 17.47*	48.75 ± 16.86	53.32 ± 23.95*
Bedtime SD (min)	58.3 ± 26.0	–	–	57.8 ± 25.6	–	–
Wake time SD (min)	53.2 ± 29.7**	–	–	68.4 ± 34.8**	–	–
MST SD (min)	47.3 ± 22.7	–	–	52.8 ± 25.3	–	–
TST SD (min)	54.2 ± 18.0	–	–	60.0 ± 22.0	–	–

Note that the 11 participants who participated in both Study 1 and Study 2 are included under Study 1 in this table.
[a] Unadjusted p-value <0.05
[b] Unadjusted p-value <0.01

Table 3
Associations between sleep and next-day mood, motivation, and sleepiness ratings (adjusted for previous day outcome, age, sex, BMI, study, weekends, days in study, previous day nap duration (for post-wake ratings) and index day nap duration (for pre-bedtime ratings)).

		Mood (post-wake) β ± SE (P-value) (Cohen's f^2)	Mood (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Motivation (post-wake) β ± SE (P-value) (Cohen's f^2)	Motivation (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Sleepiness (post-wake) β ± SE (P-value) (Cohen's f^2)	Sleepiness (pre-bedtime) β ± SE (P-value) (Cohen's f^2)
TST	*Between*	1.04 ± 1.42 (0.468)	1.20 ± 1.64 (0.465)	−1.47 ± 1.61 (0.362)	−2.88 ± 1.74 (0.098)	−3.83 ± 1.79 (0.034)	−1.19 ± 1.76 (0.499)
	Within	**2.21 ± 0.39 (<0.001)[a] (0.02)**	**1.27 ± 0.38 (<0.001)[a] (0.01)**	**2.91 ± 0.54 (<0.001)[a] (0.03)**	0.72 ± 0.44 (0.106) (0.00)	**−4.48 ± 0.54 (<0.001)[a] (0.06)**	**−2.40 ± 0.49 (<0.001)[a] (0.01)**
MST	*Between*	−1.82 ± 0.93 (0.051)	−0.21 ± 1.07 (0.843)	−1.44 ± 1.05 (0.172)	0.81 ± 1.15 (0.481)	2.99 ± 1.20 (0.014)	−1.67 ± 1.19 (0.161)
	Within	−0.73 ± 0.49 (0.141) (0.00)	−0.38 ± 0.55 (0.486) (0.00)	−0.34 ± 0.55 (0.544) (0.00)	0.45 ± 0.58 (0.433) (0.00)	−0.06 ± 0.64 (0.928) (0.00)	−0.25 ± 0.62 (0.696) (0.00)
SE	*Between*	−0.02 ± 0.21 (0.908)	−0.02 ± 0.24 (0.943)	0.04 ± 0.23 (0.879)	0.02 ± 0.26 (0.944)	−0.06 ± 0.27 (0.819)	0.07 ± 0.26 (0.783)
	Within	0.06 ± 0.08 (0.418) (0.00)	−0.02 ± 0.08 (0.782) (0.00)	0.07 ± 0.10 (0.492) (0.00)	−0.02 ± 0.11 (0.866) (0.00)	−0.00 ± 0.12 (0.986) (0.00)	0.01 ± 0.11 (0.941) (0.00)

Note that the Cohen's f effect sizes shown were calculated using models without random effects of the within-subject predictor.
[a] Adjusted p-value <0.05 using the Benjamini Hochberg method.

assessments (β = 1.27, $P < 0.001$). Interestingly, mood ratings were not affected by that person's average sleep duration ($TST_{between}$) relative to other persons in the sample. (Table 3 contains the results of all the multi-level models run).

Nights with longer sleep durations for a given person (TST_{within}) also significantly predicted higher motivation scores after waking the next day (β = 2.91, $P < 0.001$), but not by the pre-bedtime assessment (P = 0.11). Midsleep time and sleep efficiency were not significantly associated with motivation scores in the post-wake and pre-bedtime assessments.

Nights with longer sleep duration for a given person (TST_{within}) were also found to be associated with lower sleepiness scores both in the post-wake (β = −4.48, $P < 0.001$) and pre-bedtime assessments (β = −2.40, $P < 0.001$) of the next day. At the between-subject level, participants with longer average sleep durations were found to have lower sleepiness scores after waking (β = −3.83, P = 0.03). Participants with later average midsleep times also reported feeling sleepier after waking (β = 2.99, P = 0.01). However, after correcting for multiple comparisons, these between-subject effects were not significant.

Controlling for nocturnal sleep duration, a longer nap taken the previous day significantly predicted lower sleepiness scores after waking (β = −0.06, $P < 0.001$), while a longer nap taken on the same day significantly predicted better mood (β = 0.03, P = 0.005) and less sleepiness in the pre-bedtime window (β = −0.10, $P < 0.001$). Corresponding coefficients and p-values of nap duration covariates for each model can be found in Suppl Table 2.

In sensitivity analyses, significant associations between the within-subject predictor (TST_{within}) and MMS ratings measured in the post-wake and pre-bedtime windows remained significant even after excluding data that was collected during the university reading and examination weeks, suggesting that these associations were not attributable external influence of exam-related stressors (Suppl Table 1; all *P*s < .005). Later average midsleep times were also found to be significantly associated with more sleepiness in the post-wake window (β = 3.65, P = 0.005).

Analyzing Study 1 and Study 2 separately found that the significant associations of sleep duration on post-wake mood and motivation, and on post-wake and pre-bedtime sleepiness were identical to those of the combined analysis in which participants were combined for greater power (Suppl Tables 3 and 4; all *P*s < .05). As a result of reduced power, significant effects of sleep duration on pre-bedtime mood did not survive correction for multiple comparisons in either study. Additionally, in Study 1 only, a shorter average sleep duration and later average mid-sleep time were significantly associated with greater sleepiness in the post-wake window at the between subject level (both *P*s < .01). These latter effects were not observed when participants in the original analysis where participants were combined.

4.3. *Time-lagged associations between daily sleep and mood, motivation, and sleepiness ratings*

No significant associations were found between sleep and MMS ratings measured in the post-wake or pre-bedtime assessments of the second day after the sleep episode (n+1; see Table 4). Hence, associations between sleep and MMS ratings were confined to the immediately following day only.

Table 4
No-lag and n+1 associations between sleep and mood, motivation, and sleepiness ratings (within-subject associations only).

	Day	Mood (post-wake) β ± SE (P-value) (Cohen's f^2)	Mood (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Motivation (post-wake) β ± SE (P-value) (Cohen's f^2)	Motivation (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Sleepiness (post-wake) β ± SE (P-value) (Cohen's f^2)	Sleepiness (pre-bedtime) β ± SE (P-value) (Cohen's f^2)
TST	*No-lag (n)*	2.21 ± 0.39 (<0.001)[a] (0.02)	1.27 ± 0.38 (<0.001)[a] (0.01)	2.91 ± 0.54 (<0.001)[a] (0.03)	0.72 ± 0.44 (0.106) (0.00)	−4.48 ± 0.54 (<0.001)[a] (0.06)	−2.40 ± 0.49 (<0.001)[a] (0.01)
	n+1	−0.45 ± 0.45 (0.318) (0.00)	−0.76 ± 0.40 (0.059) (0.00)	−0.65 ± 0.45 (0.150) (0.00)	−0.14 ± 0.49 (0.781) (0.00)	0.32 ± 0.54 (0.555) (0.00)	−0.15 ± 0.51 (0.776) (0.00)
MST	*No-lag (n)*	−0.73 ± 0.49 (0.141) (0.00)	−0.38 ± 0.55 (0.486) (0.00)	−0.34 ± 0.55 (0.544) (0.00)	0.45 ± 0.58 (0.433) (0.00)	−0.06 ± 0.64 (0.928) (0.00)	−0.25 ± 0.62 (0.696) (0.00)
	n+1	0.66 ± 0.50 (0.187) (0.00)	1.28 ± 0.48 (0.009) (0.00)	0.65 ± 0.51 (0.208) (0.00)	0.53 ± 0.56 (0.341) (0.00)	−0.92 ± 0.62 (0.138) (0.00)	−0.94 ± 0.58 (0.105) (0.00)
SE	*No-lag (n)*	0.06 ± 0.08 (0.418) (0.00)	−0.02 ± 0.08 (0.782) (0.00)	0.07 ± 0.10 (0.492) (0.00)	−0.02 ± 0.11 (0.866) (0.00)	−0.00 ± 0.12 (0.986) (0.00)	0.01 ± 0.11 (0.941) (0.00)
	n+1	−0.08 ± 0.08 (0.309) (0.00)	0.06 ± 0.08 (0.495) (0.00)	−0.08 ± 0.10 (0.456) (0.00)	−0.01 ± 0.10 (0.930) (0.00)	−0.00 ± 0.12 (0.995) (0.00)	0.03 ± 0.12 (0.783) (0.00)

Note that the Cohen's f effect sizes shown were calculated using models without random effects of the within-subject predictor.
[a] Adjusted p-value <0.05 using the Benjamini Hochberg method.

Table 5
Associations between mean TST and TST variability and daily mood, motivation, and sleepiness ratings (adjusted for age, sex, BMI, study).

Predictor	Mood (post-wake) β ± SE (P-value) (Cohen's f^2)	Mood (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Motivation (post-wake) β ± SE (P-value) (Cohen's f^2)	Motivation (pre-bedtime) β ± SE (P-value) (Cohen's f^2)	Sleepiness (post-wake) β ± SE (P-value) (Cohen's f^2)	Sleepiness (pre-bedtime) β ± SE (P-value) (Cohen's f^2)
TST SD (h)	**−10.91 ± 3.88 (0.006)[a] (0.07)**	−3.41 ± 4.02 (0.398) (0.01)	**−13.66 ± 4.07 (0.001)[a] (0.10)**	−7.74 ± 4.31 (0.075) (0.03)	8.64 ± 4.24 (0.044) (0.02)	0.10 ± 4.46 (0.982) (0.00)
TST mean (h)	2.65 ± 1.93 (0.173) (0.02)	0.99 ± 2.00 (0.621) (0.00)	−0.81 ± 2.03 (0.689) (0.00)	−5.05 ± 2.14 (0.020) (0.05)	−5.28 ± 2.11 (0.014) (0.06)	−0.16 ± 2.22 (0.941) (0.00)

[a] Adjusted p-value <0.05 using the Benjamini Hochberg method.

4.4. Linear regression models: Associations between sleep variability and mood, motivation, and sleepiness ratings

Significant effects of sleep variability on MMS ratings were found using linear regression models (see Table 5). An increase in sleep duration variability by 1 h was found to be associated a decrease in average mood by 10.91 points ($P = 0.006$) and a decrease in average motivation by 13.66 points ($P = 0.001$) after waking. No significant associations between sleep variability and MMS ratings in the pre-bedtime assessment were found.

Adjusting for TST variability, a higher mean TST was associated with less sleepiness after waking ($\beta = -5.28$, $P = 0.01$), as well as lower motivation before bedtime ($\beta = -5.05$, $P = 0.02$). However, these associations were not significant after adjusting for multiple comparisons.

5. Discussion

5.1. Night-to-night changes in sleep duration influence mood, motivation, and sleepiness

In a sample of healthy but relatively sleep restricted university students, our results showed that nights when sleep was longer than the participant's average were associated with better mood, higher motivation, and lower sleepiness in the post-wake window of the following day. Better scores in mood and sleepiness but not motivation persisted into the evening pre-bedtime period. Time-lagged analyses demonstrated that associations between nocturnal sleep and MMS were temporally circumscribed, being strongly linked to MMS on the day after the index nocturnal sleep episode, but not for the subsequent day. Significant associations between MMS and nap duration suggest that daytime naps may alleviate the effects of inadequate nocturnal sleep.

Our results are consistent with existing studies that have identified links between shorter sleep duration and more negative next-day mood [36,51–54]. Notably, significant within-subject effects of sleep duration in existing studies have been shown when sleep duration was measured using self-report, but not when sleep duration was objectively measured [38,52–54]. It is possible that the relatively long monitoring period (2–6 weeks) in the current study allowed for sufficient within-subject observations to reveal effects sleep duration. An alternative explanation could be that these findings emerged, studying a sample whose habitual sleep duration is below the recommended 7-9 h for this age group [55]. Only 56% of participants had an average TIB of ≥7, and only 50% obtained TST ≥6 h, comparable to what has been observed for other Asian samples [56,57]. A 1.5 h increment in sleep opportunity from a lower baseline (5–6.5 h) has been shown to have greater benefit on vigilance compared to when starting from a higher baseline (6.5–8 h) [1,58]. Additionally, a larger cumulative sleep debt has been linked to greater negative affect on the next-day [59,60]. Extending the present work to incorporate sleep extension in a less sleep-restricted population could shed light on how much sleep is needed for a given individual [61], and clarify the value of short-term sleep-banking [62,63] as a potential 'life hack' to improve mental wellbeing and performance.

We did not find significant within-subject effects of sleep timing on next-day MMS ratings. On the other hand, effects at the between-subject level (significant only prior to correcting for multiple comparisons) suggested that individuals with later mid-sleep times tended to be sleepier after waking, and less sleepy in the following pre-bedtime window. This could point towards influences of trait-like circadian preference on sleepiness.

The absence of significant within-subject associations suggests that daily fluctuations in sleep timing did not impact MMS. However, it must be noted that most participants had already late bedtimes and relatively late wake times (Mean MST = 5:16 a.m., SD = 0:58). Moreover, university students, particularly in the era of hybrid learning, have greater flexibility to wake up later to compensate for nights when they sleep late, leading to less reduction in sleep durations obtained [64]. In contrast, most working adults and school students need to wake up early [65]. Wake time flexibility in our sample could have mitigated some of the negative effects of sleeping late documented elsewhere [43].

When taken, longer naps had favorable effects on mood and sleepiness in the post-nap, pre-bedtime assessment, as well as on following day post-waking sleepiness, even after controlling for nocturnal sleep duration. This finding sharpens the message delivered in reviews on the value of napping [66,67] and adds to recent work examining within-participant benefits of napping on mood, memory, and vigilance [68].

The finding that greater intraindividual sleep variability has negative impact on MMS ratings extends previous work showing that across participants, more variable sleep can result in higher subjective sleepiness [69], more severe depressive symptoms [70], as well reduced positive affect [71,72]. In turn, these could have negative impact on cognitive performance and productivity [73,74].

Finally, in contrast to our within-subject findings, our linear regression models and multilevel models indicated that a person's average sleep duration *did not* significantly predict between-subjects differences in average mood or motivation ratings in the post-wake window. This suggests that there are significant interindividual differences in the amount of sleep necessary to maintain mental well-being. Although different health domains have been posited to require different sleep durations [75], the evidence to support this arises only from cross sectional epidemiologic studies [43] largely based on less reliable self-reports [76,77]. A new generation of studies like ours using objective sleep data and long-term sleep and behavior tracking can help materialize the dream of a personalized sleep prescription.

Overall, our study found tight associations between daily fluctuations in nocturnal sleep, naps, as well as intraindividual sleep variability, with three indicators of mental readiness – mood, motivation, and sleepiness. Although readiness to perform is subject to different interpretations, we demonstrate the feasibility of using a simple daily diary approach to gauge the influence of sleep on subjective mental readiness. Our work could have broader implications regarding the importance of sleep to our ability to perform in the classroom, workplace, or while driving. Many consumer wearables currently provide daily "readiness scores" based on prior day's activity, sleep, and heart rate measures, but these are primarily oriented to one's fitness to engage in physical activity. Our findings should encourage more ecological studies to expand the scope of what constitutes 'readiness' [78].

5.2. Strengths

Compared to previous longitudinal actigraphy studies, where sleep is typically recorded over a few days to 2 weeks [36,51–53,79], we collected data over a longer period of 2–6 weeks. This approach yields more accurate estimations of sleep variability and the effects associated with it [80].

As college students typically have more freedom to flexibly determine their sleep-wake schedules compared to working adults or school-age children; we were able to examine a good range of sleep timings and regularity in a wide variety of sleep-wake schedules. The high temporal resolution (daily sleep and twice daily EMA) of the data collected in this study also enabled us to examine finer grained within-subject associations between sleep and mood, MMS ratings. By examining the temporal order of sleep and EMA events in the multi-week time series data, we were able to focus on the window of time when the associations between sleep parameters and mood, motivation and sleepiness were most relevant. Uniquely, naps were logged and accounted for in our models.

5.3. Limitations

A limitation of the present study is that we only examined a college student population which might be more sleep-restricted compared to persons in other age groups [81], and hence, it is uncertain whether these findings extend to other less sleep-restricted populations. However, our exclusion of individuals with moderate to severe symptoms of depression or anxiety could have attenuated the negative effects of more varied and shorter sleep on MMS that might be found in a less selected population [54].

Finally, the requirement for having meals in set time windows for the purpose of studying blood glucose levels may have affected sleep-wake timings for some individuals in Study 1 in the first two of four weeks of study (see Supplementary Information for protocol details). For example, habitually late sleepers might have needed to adhere to an earlier and more regular wake-up schedule in order to accommodate the breakfast collection window (0730–0900 h). However, the consistent results when Study 1 and 2 were examined separately indicates that this did not affect out main conclusions.

6. Conclusions

Using unobtrusive multi-week sleep and behavioral tracking of mood, motivation, and sleepiness (MMS), we found that in healthy persons who are not getting adequate nocturnal sleep, intraindividual fluctuation in nocturnal sleep duration and napping affect MMS in a temporally circumscribed manner. This lends credibility to issuance of a daily 'readiness' score based on measurements of nocturnal sleep duration.

CRediT authorship contribution statement

Alyssa S.C. Ng: Conceptualization, designed the study, coordinated the recruitment of participants, data collection, Formal analysis, wrote the first draft of the paper, Writing – original draft. **Stijn A.A. Massar:** provided critical input for analysis, Writing – review & editing. **Bei Bei:** provided critical input for analysis, Writing – review & editing. **Michael W.L. Chee:** Conceptualization, designed the study, provided critical input for analysis, Writing – review & editing, Writing – original draft, All authors have approved the final submitted version of the paper.

Declaration of competing interest

Authors declare none.

Acknowledgements

We are grateful to Gizem Yilmaz, Shamsul Azrin Jamaluddin, Chua Xin Yu, Pu Zhenghao, Nicole Yu and Nicha Turton for their assistance in data collection. This work was supported by grants from the Yong Loo Lin School of Medicine, Lee Foundation, and the National Medical Research Council Singapore (STaRMay2019–001) awarded to Dr Michael W.L. Chee.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2023.09.028.

References

[1] Leong RLF, Chee MWL. Understanding the need for sleep to improve cognition. Annu Rev Psychol 2022;74(1):27–57.
[2] CDC. Effect of short sleep duration on daily activities–United States, 2005-2008. MMWR Morb Mortal Wkly Rep: Centers for Disease Control and Prevention (CDC); Mar 4 2011.

[3] Schmidt C, Collette F, Cajochen C, Peigneux P. A time to think: circadian rhythms in human cognition. Cogn Neuropsychol 2007;24(7):755–89.
[4] Dinges DF, Powell JW. Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. Behav Res Methods Instrum Comput 1985;17(6):652–5.
[5] Gillberg M, Kecklund G, Åkerstedt T. Relations between performance and subjective ratings of sleepiness during a night awake. Sleep 1994;17(3):236–41.
[6] Åkerstedt T, Anund A, Axelsson J, Kecklund G. Subjective sleepiness is a sensitive indicator of insufficient sleep and impaired waking function. J Sleep Res 2014;23 (3):242–54.
[7] Axelsson J, Ingre M, Kecklund G, Lekander M, Wright KP, Sundelin T. Sleepiness as motivation: a potential mechanism for how sleep deprivation affects behavior. Sleep 2020;43(6).
[8] Kaplan S, Bradley JC, Luchman JN, Haynes D. On the role of positive and negative affectivity in job performance: a meta-analytic investigation. J Appl Psychol 2009; 94(1):162–76.
[9] Valiente C, Swanson J, Eisenberg N. Linking students' emotions and academic achievement: when and why emotions matter. Child Development Perspectives 2012;6(2):129–35.
[10] Hogenelst K, Schelvis R, Krone T, et al. A within-person approach to the relation between quality of task motivation, performance and job satisfaction in everyday working life. Motiv Emot 2022;46(5):588–600.
[11] Robbins S, Lauver K, Le H, Davis D, Langley R, Carlstrom A. Do psychosocial and study skill factors predict college outcomes? A meta-analysis. Psychol Bull 2004; 130:261–88.
[12] Borbély AA. A two process model of sleep regulation. Hum Neurobiol 1982;1(3): 195–204.
[13] Van Dongen HPA, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 2003;26(2):117–26.
[14] Lo JC, Ong JL, Leong RLF, Gooley JJ, Chee MWL. Cognitive performance, sleepiness, and mood in partially sleep deprived adolescents: the need for sleep study. Sleep 2016;39(3):687–98.
[15] Short MA, Booth SA, Omar O, Ostlundh L, Arora T. The relationship between sleep duration and mood in adolescents: a systematic review and meta-analysis. Sleep Med Rev 2020;52:101311.
[16] Konjarski M, Murray G, Lee VV, Jackson ML. Reciprocal relationships between daily sleep and mood: a systematic review of naturalistic prospective studies. Sleep Med Rev 2018;42:47–58.
[17] Kahn M, Sheppes G, Sadeh A. Sleep and emotions: bidirectional links and underlying mechanisms. Int J Psychophysiol 2013;89(2):218–28.
[18] Vandekerckhove M, Wang Y-L. Emotion, emotion regulation and sleep: an intimate relationship. AIMS Neuroscience 2018;5(1):1–17.
[19] Baglioni C, Spiegelhalder K, Lombardo C, Riemann D. Sleep and emotions: a focus on insomnia. Sleep Med Rev 2010;14(4):227–38.
[20] Ben Simon E, Vallat R, Barnes CM, Walker MP. Sleep loss and the socio-emotional brain. Trends Cognit Sci 2020;24(6):435–50.
[21] Palmer CA, Alfano CA. Sleep and emotion regulation: an organizing, integrative review. Sleep Med Rev 2017;31:6–16.
[22] Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. Sleep 1997;20(4):267–77.
[23] Talbot LS, McGlinchey EL, Kaplan KA, Dahl RE, Harvey AG. Sleep deprivation in adolescents and adults: changes in affect. Emotion 2010;10(6):831–41.
[24] Finan PH, Quartana PJ, Smith MT. The effects of sleep continuity disruption on positive mood and sleep architecture in healthy adults. Sleep 2015;38(11): 1735–42.
[25] Tempesta D, Salfi F, De Gennaro L, Ferrara M. The impact of five nights of sleep restriction on emotional reactivity. J Sleep Res 2020;29(5):e13022.
[26] Yeo SC, Jos AM, Erwin C, et al. Associations of sleep duration on school nights with self-rated health, overweight, and depression symptoms in adolescents: problems and possible solutions. Sleep Med 2019;60:96–108.
[27] Kamphuis J, Meerlo P, Koolhaas JM, Lancel M. Poor sleep as a potential causal factor in aggression and violence. Sleep Med 2012;13(4):327–34.
[28] Massar SAA, Lim J, Huettel SA. Chapter 1 - sleep deprivation, effort allocation and performance. In: Van Dongen HPA, Whitney P, Hinson JM, Honn KA, Chee MWL, editors. Progress in brain research, vol. 246. Elsevier; 2019. p. 1–26.
[29] Engle-Friedman M. The effects of sleep loss on capacity and effort. Sleep Science 2014;7(4):213–24.
[30] Boland EM, Goldschmied JR, Wakschal E, Nusslock R, Gehrman PR. An integrated sleep and reward processing model of major depressive disorder. Behav Ther 2020; 51(4):572–87.
[31] Palmer CA, John-Henderson NA, Bawden H, et al. Sleep restriction reduces positive social emotions and desire to connect with others. Sleep 2023;46(6):zsac265.
[32] Boland EM, Kelley NJ, Chat IK-Y, et al. Poor sleep quality is significantly associated with effort but not temporal discounting of monetary rewards. Motivation Science 2022;8(1):70–6.
[33] Jurgelis M, Boardman JM, Coxon JP, Drummond SPA, Chong TTJ. Sleep restriction reduces cognitive but not physical motivation. Nat Sci Sleep 2022;14:2001–12.
[34] Libedinsky C, Massar SA, Ling A, Chee W, Huettel SA, Chee MW. Sleep deprivation alters effort discounting but not delay discounting of monetary rewards. Sleep 2013;36(6):899–904.
[35] Massar SAA, Lim J, Sasmita K, Chee MWL. Sleep deprivation increases the costs of attentional effort: performance, preference and pupil size. Neuropsychologia 2019; 123:169–77.
[36] Master L, Nahmod NG, Mathew GM, Hale L, Chang A-M, Buxton OM. Why so slangry (sleepy and angry)? Shorter sleep duration and lower sleep efficiency predict worse next-day mood in adolescents. J Adolesc 2023. n/a(n/a).
[37] McCrae CS, McNamara JPH, Rowe MA, et al. Sleep and affect in older adults: using multilevel modeling to examine daily associations. J Sleep Res 2008;17(1):42–53.
[38] Shen L, Wiley JF, Bei B. Sleep and affect in adolescents: Bi-directional relationships over 28 days of constrained and unconstrained sleep. J Sleep Res 2019;28(S1):e21_12912.
[39] Bustamante V, Rodman CM, Dennison AM, et al. Within-person fluctuations in stressful life events, sleep, and anxiety and depression symptoms during adolescence: a multiwave prospective study. JCPP (J Child Psychol Psychiatry) 2020;61(10):1116–25.
[40] Menghini L, Yuksel D, Prouty D, Baker FC, King C, de Zambotti M. Wearable and mobile technology to characterize daily patterns of sleep, stress, presleep worry, and mood in adolescent insomnia. Sleep Health 2023;9(1):108–16.
[41] Buysse DJ. Sleep health: can we define it? Does it matter? Sleep 2014;37(1):9–17.
[42] Bei B, Wiley JF, Trinder J, Manber R. Beyond the mean: a systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. Sleep Med Rev 2016;28:108–24.
[43] Chaput J-P, Dutil C, Featherstone R, et al. Sleep timing, sleep consistency, and health in adults: a systematic review. Appl Physiol Nutr Metabol 2020;45(10): S232–47.
[44] Lee S, Buxton OM, Andel R, Almeida DM. Bidirectional associations of sleep with cognitive interference in employees' work days. Sleep Health 2019;5(3):298–308.
[45] Altini M, Kinnunen H. The promise of sleep: a multi-sensor approach for accurate sleep stage detection using the Oura ring. Sensors 2021;21(13):4302.
[46] Selya AS, Rose JS, Dierker LC, Hedeker D, Mermelstein RJ. A practical guide to calculating cohen's f(2), a measure of local effect size, from PROC MIXED. Front Psychol 2012;3:111.
[47] Cohen J. Statistical power analysis for the behavioral sciences. second ed. ed. New York: Routledge; 1988.
[48] Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J Roy Stat Soc B 1995;57(1):289–300.
[49] Leong RLF, Yu N, Ong JL, et al. Memory performance following napping in habitual and non-habitual nappers. Sleep 2021;44(6):zsaa277.
[50] Milner CE, Cote KA. Benefits of napping in healthy adults: impact of nap length, time of day, age, and experience with napping. J Sleep Res 2009;18(2):272–81.
[51] Rea EM, DeCarlo Santiago C, Nicholson L, Heard Egbert A, Bohnert AM. Sleep, affect, and emotion reactivity in first-year college students: a daily diary study. Int J Behav Med 2022.
[52] Kouros CD, Keller PS, Martín-Piñón O, El-Sheikh M. Bidirectional associations between nightly sleep and daily happiness and negative mood in adolescents. Child Dev 2022;93(5):e547–62.
[53] Messman BA, Slavish DC, Dietch JR, Jenkins BN, ten Brink M, Taylor DJ. Associations between daily affect and sleep vary by sleep assessment type: what can ambulatory EEG add to the picture? Sleep Health 2021;7(2):219–28.
[54] Difrancesco S, Penninx BWJH, Antypa N, van Hemert AM, Riese H, Lamers F. The day-to-day bidirectional longitudinal association between objective and self-reported sleep and affect: an ambulatory assessment study. J Affect Disord 2021; 283:165–71.
[55] Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health 2015; 1(1):40–3.
[56] Ong JL, Tandi J, Patanaik A, Lo JC, Chee MWL. Large-scale data from wearables reveal regional disparities in sleep patterns that persist across age and sex. Sci Rep 2019;9(1):3415.
[57] Chee MWL, Willoughby AR. The value of large-scale studies of sleep and cognition. Trends Neurosci 2023;46(4):255–6.
[58] Lo JC, Chee MWL. Cognitive effects of multi-night adolescent sleep restriction: current data and future possibilities. Curr Opin Behav Sci 2020;33:34–41.
[59] Shen L, Wiley JF, Bei B. Perceived daily sleep need and sleep debt in adolescents: associations with daily affect over school and vacation periods. Sleep 2021;44(12): zsab190.
[60] Lee S. Naturally occurring consecutive sleep loss and day-to-day trajectories of affective and physical well-being. Ann Behav Med 2022;56(4):393–404.
[61] Kitamura S, Katayose Y, Nakazaki K, et al. Estimating individual optimal sleep duration and potential sleep debt. Sci Rep 2016;6(1):35812.
[62] Arnal PJ, Sauvet F, Leger D, et al. Benefits of sleep extension on sustained attention and sleep pressure before and during total sleep deprivation and recovery. Sleep 2015;38(12):1935–43.
[63] Rupp TL, Wesensten NJ, Bliese PD, Balkin TJ. Banking sleep: realization of benefits during subsequent sleep restriction and recovery. Sleep 2009;32(3):311–21.
[64] Massar SAA, Chua XY, Soon CS, et al. Trait-like nocturnal sleep behavior identified by combining wearable, phone-use, and self-report data. npj Digital Medicine 2021;4(1):90.
[65] Pu Z, Leong RLF, Chee MWL, Massar SAA. Bedtime procrastination and chronotype differentially predict adolescent sleep on school nights and non-school nights. Sleep Health 2022;8(6):640–7.
[66] Ficca G, Axelsson J, Mollicone DJ, Muto V, Vitiello MV. Naps, cognition and performance. Sleep Med Rev 2010;14(4):249–58.
[67] Faraut B, Andrillon T, Vecchierini MF, Leger D. Napping: a public health issue. From epidemiological to laboratory studies. Sleep Med Rev 2017;35:85–100.
[68] Leong RLF, Lau T, Dicom AR, Teo TB, Ong JL, Chee MWL. Influence of mid-afternoon nap duration and sleep parameters on memory encoding, mood, processing speed, and vigilance. Sleep 2023;46(4):zsad025.

[69] Valdez P, Ramírez C, García A. Delaying and extending sleep during weekends: sleep recovery or circadian effect? Chronobiol Int 1996;13(3):191–8.
[70] Vanderlind WM, Beevers CG, Sherman SM, et al. Sleep and sadness: exploring the relation among sleep, cognitive control, and depressive symptoms in young adults. Sleep Med 2014;15(1):144–9.
[71] Ying F, Wen JH, Klaiber P, DeLongis A, Slavish DC, Sin NL. Associations between intraindividual variability in sleep and daily positive affect. Affect Sci 2022;3(2): 330–40.
[72] Lemola S, Ledermann T, Friedman EM. Variability of sleep duration is related to subjective sleep quality and subjective well-being: an actigraphy study. PLoS One 2013;8(8):e71292.
[73] Bono TJ, Hill PL. Sleep quantity and variability during the first semester at university: implications for well-being and academic performance. Psychol Health Med 2022;27(4):931–6.
[74] Okano K, Kaczmarzyk JR, Dave N, Gabrieli JDE, Grossman JC. Sleep quality, duration, and consistency are associated with better academic performance in college students. npj Sci Learn 2019;4(1):16.
[75] Watson NF, Badr MS, Belenky G, et al. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American academy of sleep medicine and sleep research society. Sleep 2015;38(6):843–4.
[76] Girschik J, Fritschi L, Heyworth J, Waters F. Validation of self-reported sleep against actigraphy. J Epidemiol 2012;22(5):462–8.
[77] Short MA, Gradisar M, Lack LC, Wright H, Carskadon MA. The discrepancy between actigraphic and sleep diary measures of sleep in adolescents. Sleep Med 2012;13(4):378–84.
[78] LaGoy AD, Kubala AG, Deering S, Germain A, Markwald RR. Dawn of a new dawn: advances in sleep health to optimize performance. Sleep Medicine Clinics..
[79] Yap Y, Slavish DC, Taylor DJ, Bei B, Wiley JF. Bi-directional relations between stress and self-reported and actigraphy-assessed sleep: a daily intensive longitudinal study. Sleep 2020;43(3):zsz250.
[80] Lau T, Ong JL, Ng BKL, et al. Minimum number of nights for reliable estimation of habitual sleep using a consumer sleep tracker. SLEEP Advances 2022;3(1):zpac026.
[81] Schlarb AA, Claßen M, Grünwald J, Vögele C. Sleep disturbances and mental strain in university students: results from an online survey in Luxembourg and Germany. Int J Ment Health Syst 2017;11(1):24.