A Longitudinal Study of Sleep in University Freshmen: Facilitating and Impeding Factors

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Abstract

Study Objectives: Establishing healthy sleeping habits is a challenge for many college students. We determined how academic schedule influenced sleep patterns across the semester, and if these are modulated by place of residence and class start times.

Methods: A longitudinal cohort study evaluated 638 freshmen over their first 20-week semester involving instructional, reading, examination and vacation weeks. Sleep duration and timing were measured daily with sleep trackers (Oura Ring 3). Time-use was reported through a smartphone app.

Results: 638 participants (mean [SD] age, 20.3 [1.3] years; females, 51.7%) provided 64,642 nights of sleep data. Bedtimes were late (mean [SD], 01:53 [71.76min]). Weekday sleep duration increased after the midterm break ($\beta=2.74$, $p<.0001$), arising from delayed waketimes ($\beta=5.81$, $p<.0001$). Pre-midterm, students woke up after class started on 37.1% of days with early 08:00 classes, likely arriving late or skipping class. This percentage increased to 49.9% post mid-term. Participants living on-campus (n=357) had later bedtime and shorter weekday sleep than those off-campus (n=281, bedtime: +37.26min; $t_{629}=6.62$; $p<.0001$; duration: −19.03min; $t_{629}=6.36$; $p<.0001$). They reported substantial in-person social and co-curricular activities on weekday nights (60min in the 4h before bedtime), and compositional data analysis indicated that spending more time on such activities would further delay their bedtime. Additional screen time showed the same effect for off-campus students.

Conclusions: Through unobtrusive longitudinal monitoring of sleep and relevant behaviors in freshmen, we found that the positive change of extending sleep emerged unexpectedly from delaying weekday waketimes, rather than sleeping earlier.

Keywords: Sleep timing, freshmen, wellbeing, time-use

Trial Registration: Sleep, Learning and Wellbeing in NUS Undergraduates: The NUS1000 Study (NUS1000), NCT05977517, https://clinicaltrials.gov/study/NCT05977517.

Statement of Significance

How does the structure of the academic term influence sleep patterns in college freshmen? Unobtrusive longitudinal monitoring revealed that despite competing time pressures, an expected early decline in weekday sleep duration was reversed in the latter half of the semester by students' electing to wake up later, skipping early morning classes. In contrast, factors expected to facilitate sleep, such as living on-campus, did not result in increased sleep duration. How freshmen exercise autonomy over their sleep is surprising; positive changes like extending sleep can emerge from unexpected avenues (e.g., delaying weekday waketimes), while more obvious opportunities (e.g., sleeping earlier) are not taken.

Introduction

Starting college is a major milestone in a young adult's life. The disruptive nature of this transition[1-5] creates opportunities to establish habits that could have lasting health consequences. Adequate sleep supports better mood, mental wellbeing, and learning[6-8], while poor sleep is a risk factor for multiple chronic health conditions[9,10], including anxiety and depression[11] which have increasingly high prevalence in college populations[12]. In many countries, sleep in college students is of lower quality or shorter duration than recommended[13-15]. Unique to this group is the combination of newfound autonomy to balance sleep with academic and social demands, more flexible schedules compared to high school students or working adults and the ability to access pre-recorded study material, allowing them to learn at their own pace.

The advent of reliable[16,17], continuous long-term monitoring of sleep patterns[18] through widely available consumer health trackers has made it possible to collect large-scale sleep data cost-effectively. When combined with information on academic load[19,20], screen time[21], and mood[22], such tracking, demonstrated in smaller studies, has provided valuable time-course insights, surpassing the capabilities of conventional, episodic surveys[23-25]. This approach, adopted in the present study, offers a detailed and dynamic understanding of sleep patterns and their associated factors.

For example, tracking 49 freshmen across their first year of college, Bustamante and colleagues found that sleep duration fluctuated with academic demand, wherein students slept longer during vacation periods compared to instructional and examination periods[19]. On a day-to-day level, sleep is also affected by each day's schedule. When college activities end late, sleep onset is delayed, and students obtain shorter sleep that night[26]. Over time, irregular school event schedules are associated with irregular sleep schedules[27]. Other socio-demographic or individual factors may also influence sleep and well-being, for example, female undergraduates sleep earlier and longer than males[28], and on-campus residence is associated with later bedtimes and rise times[29]. With larger samples, using multiple streams of sleep and well-being data tracked over longer periods, structural and individual barriers and facilitators of sleep during transitional periods may be identified to help universities refine strategies to support healthy student life.

We tracked 638 freshmen across their first 20 weeks of college using validated sleep trackers, daily smartphone reports of sleep and well-being, and periodic time-use assessments (Fig. 1). These data were integrated with information on students' residence location, with the aim of understanding the barriers and facilitators of sleep during this critical period. We expected starting college to erode sleep time, but that time saved from not having to commute while staying on campus would be associated with longer sleep duration.

Methods

Participants

Freshmen enrolled into the National University of Singapore (NUS) in the 2023-2024 academic year were recruited prior to their first semester using flyers, posters, emails and orientation camp announcements. Eligibility was assessed via an online demographic survey before obtaining consent. The NUS Institutional Review Board approved the protocols which were compliant with the Declaration of Helsinki. This report follows Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cohort studies. Participants were compensated up to SGD 355 (~USD 263), depending on the number of study components completed each day (see below).

Protocol

Oura Ring

Participants were required to wear an Oura Ring 3 (Oura Health Oy, Oulu, Finland) for at least 20h daily to track sleep. For each day, the longest sleep period between 18:00 the previous day to 17:59 the current day was considered the main sleep episode, and other sleep periods were considered naps. Further filtering based on Oura Ring wear time ensured accurate characterization of the broad range of sleep patterns under free-living conditions, particularly nights with irregular, short sleep or absent sleep (Supplementary Methods & Table S1). No imputation was performed for missing data. Days with overseas travel were excluded from all analyses.

Daily EMA: Questionnaires and Audio Diary

Participants completed ecological momentary assessments (EMA) daily between 2000-2359h on our proprietary Z4IP app. Each assessment consisted of a questionnaire that contained questions that were repeated daily or weekly (Supplementary Methods).

Time-use Diaries

In addition to daily measures, surveys and time-use diaries were completed during three fortnights at the beginning, middle and end of the semester (Fig. 1). Participants completed time-use diaries (Z4IP app) by selecting from a list of 20 activities (e.g., Sleep, Classes, Transport, Meals, Others) for each 15min window. In addition, each activity could be tagged as a “Group” activity, e.g., having a meal with other people. Each day’s activities were editable for up to three days. Only days with at least 75% completion and 3 or more activity types were included for analyses (Massar et al., 2024; Ng et al., 2023).

Data Analysis

Weekly averages of weekday and weekend sleep parameters were obtained for each participant (minimum of one weekday and one weekend for a given week) from curated Oura Ring data. A linear mixed-effects model was specified to examine how weekday sleep timing and duration were affected by the fixed effects of Instructional period (before vs. after the midterm break), week within each period, and their interaction, accounting for random intercepts for individual participants. 500 participants with at least 4 weeks of data in each Instructional period were included in this analysis.

To examine the association between class schedule and waketime, day-by-day wake times were stratified based on the time of the participants’ first class of the day. For each participant, the first class timing for each day of the week was determined by their official timetable (individual class schedules were largely similar across weeks). For each stratum, percentages of days with waketime occurring before and after each first class start time were computed.

For weekday vs weekend comparisons within the same participant group, paired Student's t-tests (two-tailed) were performed. Independent (two-tailed) t-tests were used to assess between-group comparisons for On- vs Off-campus residence.

Time-use behaviors in the 4-hour period preceding individual weekday bedtimes were modeled using a compositional data analysis (CoDA) framework (R package 'epicoda'[30]). This approach accounted for the co-dependent nature of time-use data by analyzing relative, rather than absolute, time spent in each activity[30,31]. Taking into consideration that some activities had a low probability of occurring close to bedtime, the reported activities were grouped as follows:

1) Social (activities labelled as Social, Co-curricular, or tagged as "Group");
2) Digital Leisure;
3) Self-study;
4) Other (any other activities).

Only nights with at least 75% filled entries in the 4-hour period were included. Missing time periods were assigned to Other. Changes in bedtime associated with hypothetical reallocations of time (adding 1 hour of social activities while proportionally reducing time spent on other activities), were modelled separately for the On-campus and Off-campus groups. All effects were interpreted relative to the mean composition of the sample, representing the expected bedtime change for an average individual when reallocating time between activities (see Supplementary Methods for details).

Results

Sample Characteristics

The mean [SD] age of the 638 participants was 20.3 [1.3] years; 330 were female (51.7%); and 357 (56.0%) lived on campus (Table 1). 69 participants withdrew over the course of the study. Study participants provided a total of 64,642 days (72.4%) of Oura sleep recordings, and 38,209 days (42.8%) of Z4IP EMA. 17,726 days (66.2%) of time-use diaries were recorded during the three fortnights required by protocol, and 8005 days outside these periods. Weekly participation rates are shown in Fig. 2.

Sleep patterns across the semester

Weekly averages for weekday waketime ranged from 08:37 to 09:53 across the semester, while weekend waketimes were relatively stable, ranging from 09:25 to 09:55 (Fig. 3 & Table S2). Bedtimes were more consistent than waketimes across the semester, with weekly averages ranging from 01:24 to 02:04 on weekdays, and 01:47 to 02:16 on weekends.

A linear mixed-effects model revealed a significant interaction between Instructional period and week (β = 5.56, 95% CI 4.50 to 6.62, $p < .0001$), indicating that the change in Total Sleep Time (TST) across weeks differed before and after the midterm break (Fig. 3). TST decreased over time before the midterm break (β = −2.82, 95% CI −3.58 to −2.07, $p < .0001$), but increased after (β = 2.74, 95% CI 1.99 to 2.49, $p < .0001$). A similar interaction was found for waketime (β = 5.81, 95% CI 4.37 to 7.26, $p < .0001$), but not for bedtime (β = −0.95, 95% CI −2.35 to 0.45, $p = .183$). Importantly, this upward trend was present independent of participant completion rates (see

Fig. S1). These fluctuations in weekday sleep duration were not present for weekend sleep (Fig. 3).

Inspection of trends in sleep efficiency and sleep onset latency showed minimal differences across the semester, while fluctuations in wake after sleep onset (WASO) largely reflected differences in TIB (Fig. S2).

Association between class start time and weekday waketime

Waketimes were closer to class start time for earlier classes and were further delayed after the midterm break (Fig. 4). In particular, median waketime for 08:00 classes, was 07:31 before the midterm break, but 07:59 after, just 1 min before class start, with 49.9% waketimes occurring *after* class started[32]. In contrast, for 10:00 first class the median waketimes were 08:33 before and 08:49 after the midterm break, i.e., most students were awake prior to class (before midterm, 87.4%; after midterm, 81.4%). When classes started at noon or later, waketimes were similar to those observed on weekends. Similar trends were observed when the analysis was repeated using time-use diaries to determine first class of the day (Fig. S3).

Association between campus residence and sleep

On-campus residence minimized commuting, thereby potentially increasing TST (Fig. 3D–F, 5 and S4). However, while On-campus residents woke up later on weekdays by 16.37min (95% CI, 6.04 to 26.70; $t_{629} = 3.11$; $p < .005$), bedtimes were delayed by 37.26min (95% CI, 26.20 to 48.31; $t_{629} = 6.62$; $p < .0001$), resulting in weekday TST being 19.03min shorter than for those living off-campus (95% CI, −24.91 to −13.15; $t_{629} = -6.36$; $p < .0001$). This finding remained even after naps were taken into consideration (−15.69min; 95% CI, −21.55 to −9.83; $t_{629} = -5.26$; $p < .0001$). Despite the greater opportunity for On-campus residents to nap in their dormitories, they did so for just 3.34min more than Off-campus students (95% CI, 1.12 to 5.57; $t_{629} = 2.95$; $p < .005$) on weekdays, and 5.37min more on weekends (95% CI, 2.59 to 8.15; $t_{629} = 3.80$; $p < .0005$; Fig. S4).

Although the weekday-weekend difference in TST for those living on-campus (mean [SD], −34.87min [44.27min]) was greater (10.44min; 95% CI, 3.53 to 17.36; $t_{618} = 2.97$; $p < .005$) than those living off-campus (mean [SD], −24.54min [40.85min]), there was no difference in weekend sleep, even when naps ($t_{619} = -1.10$; $p = .28$) or Vacation periods ($t_{381} < 1$) were factored in. Thus, group differences in weekday sleep duration and timing are unlikely to represent different sleep needs (Fig. 3F).

Time-use diaries showed that On-campus residents engaged in social and co-curricular activities late into the night, whereas Off-campus students engaged in substantial digital leisure activities (Fig. 5). During the 4 hours preceding individual weekday bedtimes, the On-campus group (Fig. 6A) spent similar amounts of time on Social (60 min), Digital Leisure (52 min), Self-study (66 min) and Other (62 min), whereas the Off-campus group (Fig. 6B) spent the most time on Digital Leisure (86 min), compared to Self-study (73 min) and Other (63 min), and the least time on Social (17 min). CoDA showed that bedtime would be delayed for On-campus students if Social activities were increased by 1 hour (with proportional reductions in other activity types). For the Off-campus group, the same effect would be seen with an increase in Digital Leisure. Reallocating 1 hour to social activity was associated with earlier bedtime, presumably due to the concomitant reduction in screen time. These results indicated that On-campus students with more social activities at night tended to sleep later, whereas Off-campus students who spent more time on their digital devices slept later.

Discussion

Sleep patterns in freshmen evolved during the semester: following an expected diminution in the first half of the semester[20,33], weekday sleep duration increased in the second half. We also found that situations expected to result in more sleep, for example, not having to commute by staying on campus, were not associated with longer sleep. Unexpectedly, students appeared to skip classes – particularly those early in the morning – in order to catch up on sleep.

The uptrend in sleep duration in the latter part of the semester is surprising as freshmen might be expected to increasingly prioritize academic and social commitments, reducing sleep on weekdays and catching up on weekends[34,35]. Accordingly, the intention to improve health has motivated recent studies that incentivized college students to sleep longer[36,37]. However, contrary to expectation, our students showed a gradual extension of sleep duration on weekdays in the second half of the semester. This appears to be due to delayed wake times, afforded by students skipping early morning classes. Obtaining consistently adequate or nearly adequate sleep across weekdays and weekends supports optimal health outcomes for university students facing diverse demands[38].

Our findings are also contrarian because sleep improvement interventions typically focus on sleeping earlier[39]. In our study, students did not change their bedtimes over the course of the semester. Instead, they extended their sleep by waking up later. This pattern may reflect the propensity toward more eveningness in this age group in general[40-42], and also bears resemblance to the shifts observed during COVID-19 pandemic lockdowns, where the relative flexibility in schedules resulted in longer sleep, obtained by delaying wake times[43,44]. In a similar manner, these shifts in waketime were often observed despite participants reporting an aspiration to sleep earlier[45].

While the shift to later wake times resulted in longer sleep, other factors expected to relate to longer sleep did not show this association. Despite not having to commute and spending less late-night leisure time on digital devices (Fig. 5), students living on campus still averaged about 20 minutes less weekday sleep than their off-campus counterparts. This resulted from later bedtimes and not taking enhanced opportunities to take more frequent or longer daytime naps. Later bedtimes and rise times are common with on-campus living and are associated with participation in nocturnal social activities[26,29]. Digital time-use diary information revealed that co-curricular and social activities delayed their weekday bedtimes. Scheduled weekday co-curricular and social engagements are integral to the incentive structure for retaining hostel residency, and these activities likely contribute to occupying weekday evening to late night hours. In contrast, digital leisure activities delayed the bedtimes of those staying off-campus.

Strengths and Limitations

Broad and sustained adoption of the digital phenotyping tools used in this study (>70% of participants providing Oura data over 20 weeks) underscores their acceptance by today's digitally savvy students. The lack of seasonal effects[41] eliminates a common confound in extended longitudinal studies that focus on sleep duration and timing[23,46-48].

The unobtrusive, large-scale longitudinal study of sleep patterns and relevant factors influencing them provided insights that challenge common assumptions about how college students sleep. Increased sleep duration is favorable for health and wellbeing, but as illustrated here, may be achieved in unexpected ways. This can guide fresh practicable interventions. For example, the scheduling of nighttime co-curricular activities to satisfy eligibility demands for on-campus residency could be avoided to allow students to get more sleep on-campus. Additionally, early morning classes should be shifted later.

Although we did not prompt any behavioral change, we cannot exclude the possibility that participation heightened valuation of sleep through creation of awareness of unhealthy sleep habits as students viewed their sleep data and reflected on their use of time in the course of providing data. In addition, lower completion rates were observed on the more time-consuming, self-report channels (e.g., EMA, time-use diaries) that were delivered later in the semester (Supplementary Methods). In theory, the reduced numbers contributing to this data could bias results. However, the overall trends in sleep timing were similarly observed in both high and low compliance participants (Fig. S1), i.e., not likely to have been affected by missing data. The long-term health and wellbeing benefits of stabilizing weekday sleep duration remain to be determined. Finally, the study would have been enriched by collection of light and meal-timing data as these influence sleep.

Conclusions

During university freshmen year, a situation of relative autonomy to determine one's sleep timing, students slept more by waking up later, often past early morning classes start times.

Seemingly available opportunities to lengthen sleep were not taken. Our work highlights the utility of integrating contextual information obtained through smartphones with sleep tracking data to uncover which of several routes to enabling adequate sleep are actually adopted enabling a true 'data-driven' approach to tailoring sleep improvement strategies.

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Data availability: The data in this article are available upon reasonable request from the authors.

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Figure Captions

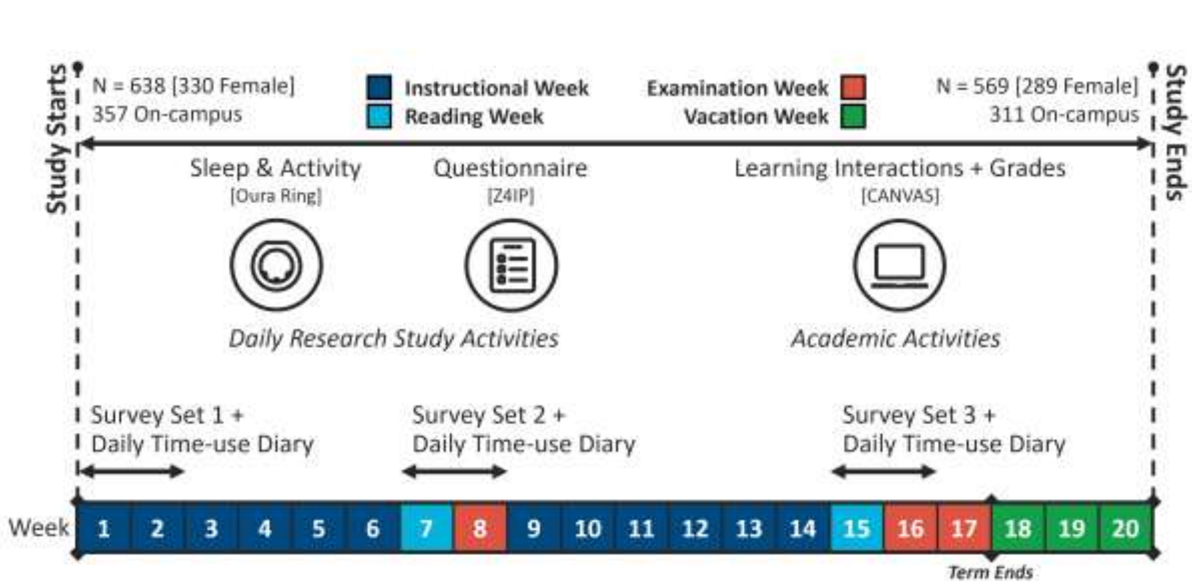


Fig. 1. Schematic of study protocol. A multi-factor protocol was designed to maximize collection of objective and subjective data related to sleep, time-use, emotional fluctuation and academic performance of freshmen through their first semester while minimizing inconvenience to participants.

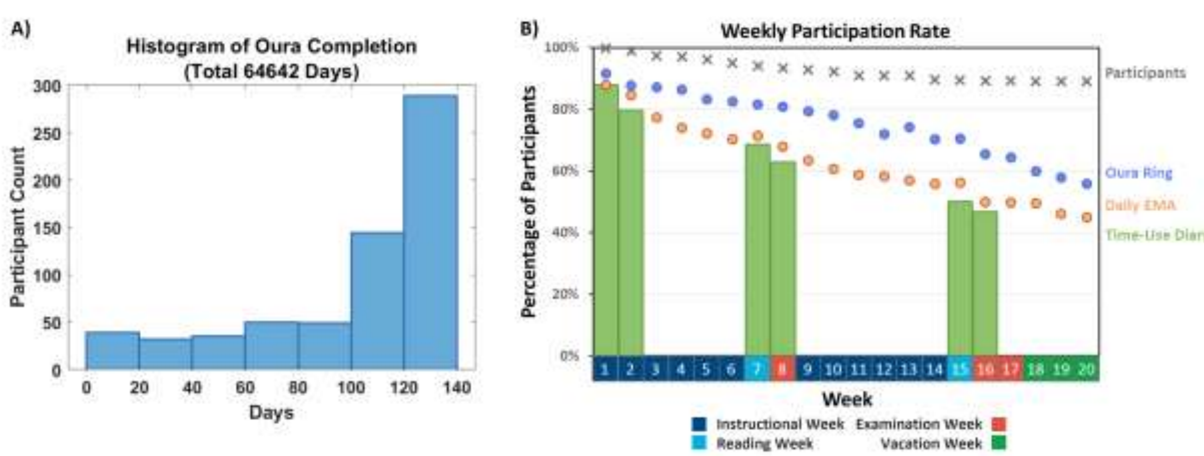


Fig. 2. Participation rates for different data streams. (A) Histogram of Oura Ring completion rate across participants. 433 (67.9%) of participants provided 100 or more days of Oura data. (B) Weekly participation rate for different data streams (minimum of 1 weekday and 1 weekend per week). Despite a gradual decrease in participation rate as the semester progressed, all Instruction weeks had Oura data from more than 450 participants.

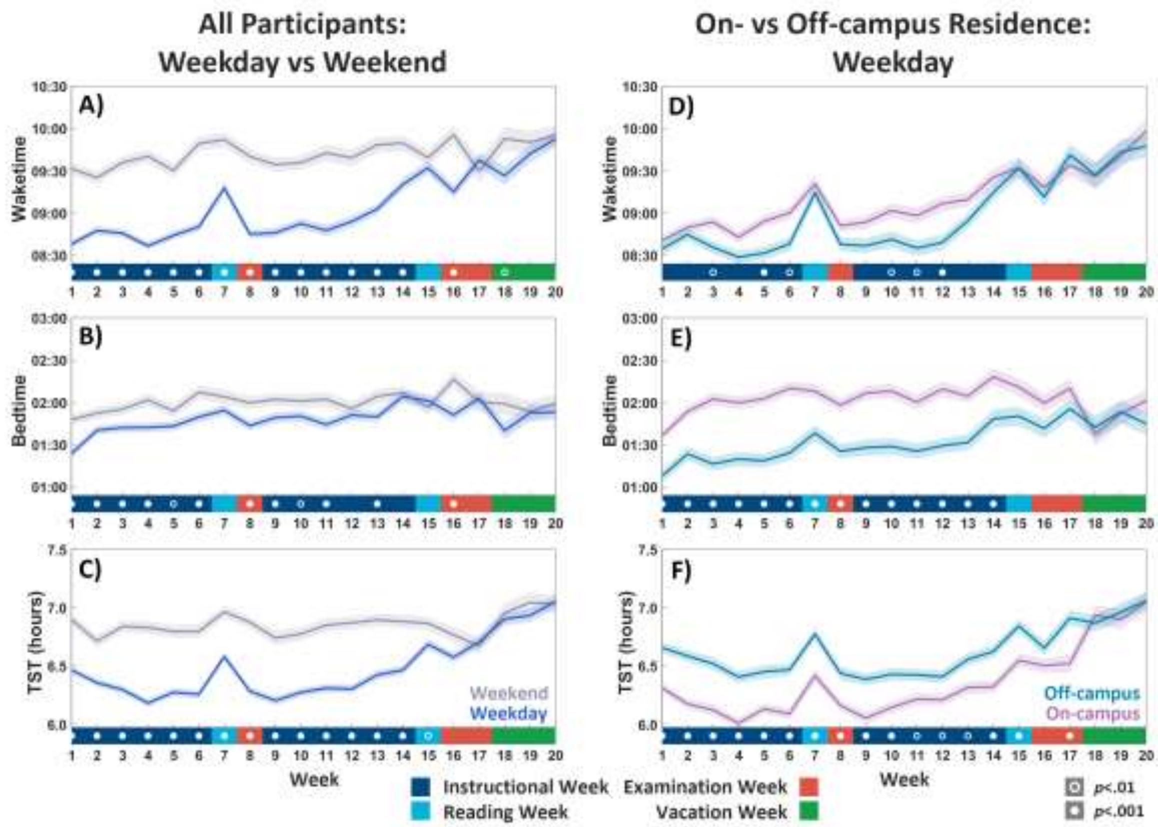


Fig. 3. Weekly sleep trends of freshmen across their first semester. (A – C) Freshmen woke up earlier on weekdays but kept to a consistent late bedtime, resulting in weekday sleep curtailment. (D – F) Despite waking up later, those living on-campus obtained less sleep due to relatively later bedtimes compared to those living off-campus. Note equalization of On- and Off-campus groups during vacation as students return home in the latter case. Error bands represent

standard error of the mean (SEM). Open (p<.01) and closed (p<.001) circles indicate significant differences (t-tests, uncorrected) for each week.

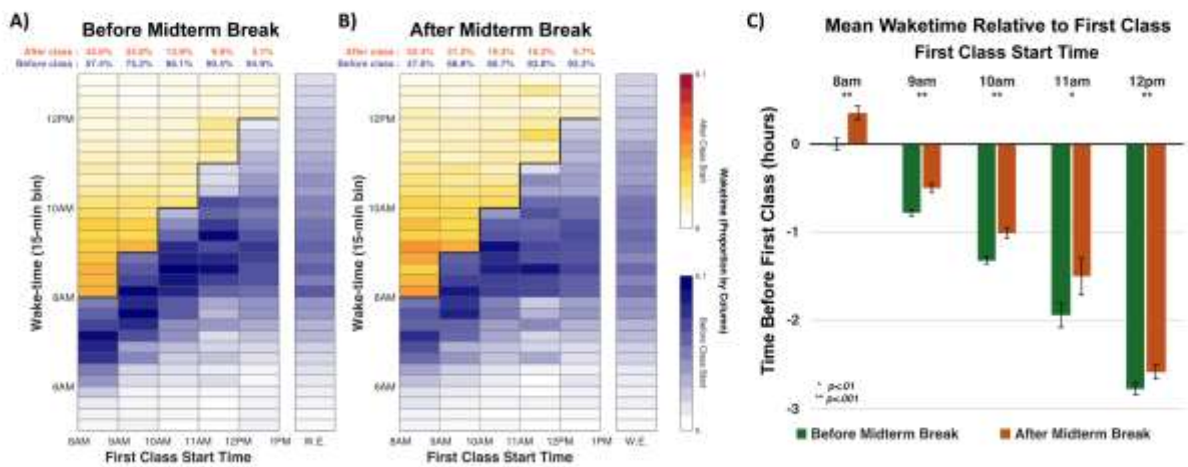


Fig. 4. Waketime in relation to first class of the day before and after midterm break. (A, B) Heatmaps show the proportion of days when freshmen woke up before (blue) or after (orange) their first class of the day. The respective percentage of days with waketimes before and after class start are shown above the heatmaps. Waketime distributions when classes started after noon resembled those on weekends (W.E.). After the midterm break, freshmen woke up later, likely skipping early classes more than before. (C) Bar chart shows mean (SEM) waketime before the first class start time. Asterisks indicate significant differences before vs after midterm break (paired t-tests, uncorrected).

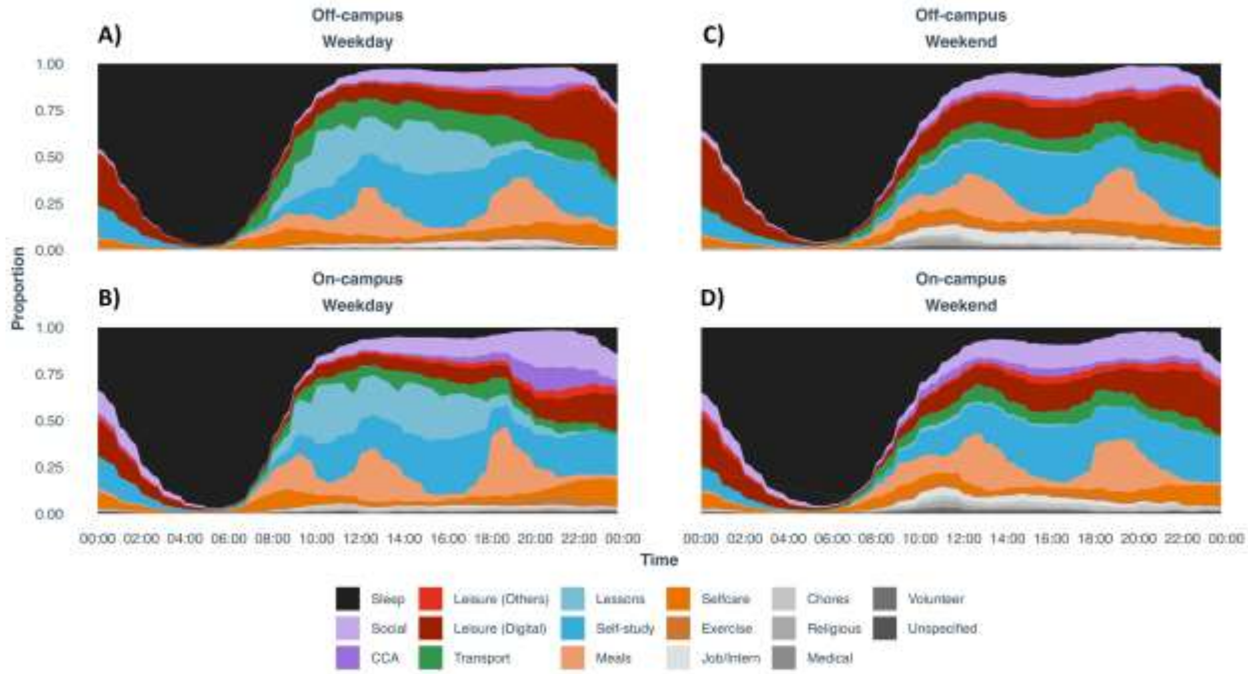


Fig. 5. How freshmen living on- and off-campus spent their day during Instructional weeks. (A) On weekdays, social (lavender) and co-curricular activities (CCA, purple) lasted late into the night for On-campus residents. (B) In contrast, Off-campus students spent a substantial amount of time on digital leisure activities (dark red) late in the night. (C, D) These weekday differences were muted on weekends.

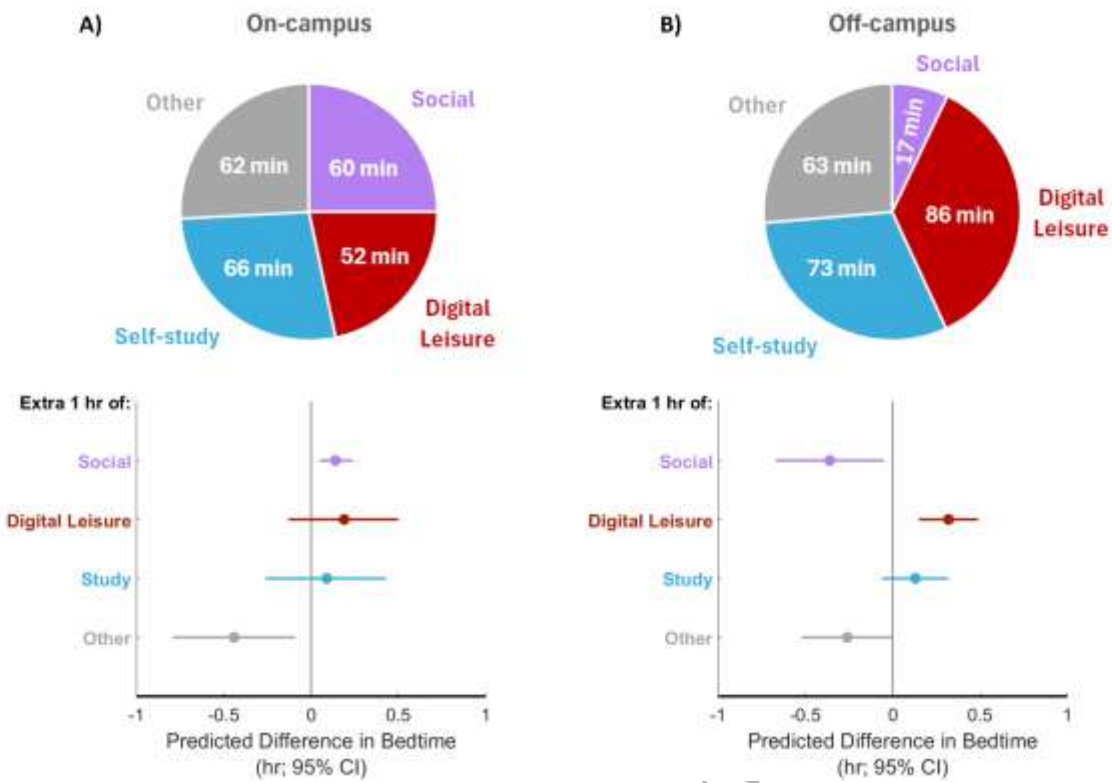
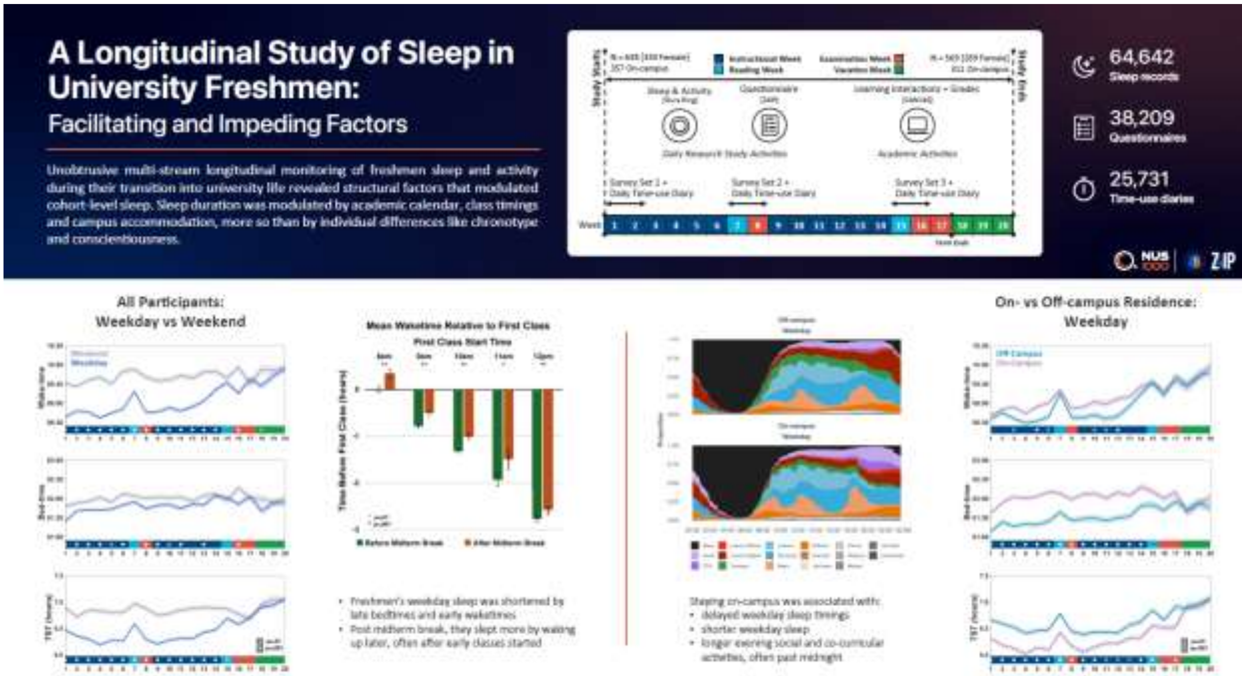


Fig. 6. Late activities affect weekday bedtime differentially for On-campus and Off-campus students. (A) Compositional data analyses showed that an extra hour of Social activities (with proportional reduction in duration of other activities) would delay the bedtime of On-campus residents. (B) For the Off-campus group, the same effect was seen with an increase in Digital Leisure. Reallocating 1 hour to social activity was associated with earlier bedtime, presumably due to the concomitant reduction in screen time.



Graphical abstract

Table 1. Sample Demographics and Sleep Characteristics Grouped by Residence

	Overall N = 638	On-Campus N = 357 (56.0)	Off-Campus N = 281 (44.0)
Age, mean (SD), y	20.4 (1.3)	20.1 (1.2)	20.7 (1.4)
Sex			
Female	330 (51.7)	200 (56.0)	130 (46.3)
Male	308 (48.3)	157 (44.0)	151 (53.7)
Ethnicity			
Chinese	546 (85.6)	302 (84.6)	244 (86.8)
Malay	19 (3.0)	6 (1.7)	13 (4.6)
Indian	46 (7.2)	29 (8.1)	17 (6.1)
Others	27 (4.2)	20 (5.6)	7 (2.5)
Chronotype (MEQ)			
Score	44.7 (8.6)	44.9 (8.6)	44.6 (8.6)
Morning	14 (3.9)	9 (4.9)	5 (2.8)
Intermediate	217 (59.6)	108 (58.7)	109 (60.6)
Evening	133 (36.5)	67 (36.4)	66 (36.7)
Sleep, mean (SD)			
Days of data	101.3 (38.6)	96.9 (39.0)	106.9 (37.5)

Bedtime	01:53 (01:12)	02:04 (01:08)	01:38 (01:14)
Waketime	09:11 (01:09)	09:15 (01:08)	09:05 (01:09)
TST, h	6.5 (0.6)	6.4 (0.6)	6.6 (0.6)
Nap, h	0.3 (0.2)	0.3 (0.2)	0.2 (0.2)
Time-use			
Days	40.4 (31.2)	36.3 (28.4)	45.6 (33.7)
EMA			
Days	59.9 (42.1)	54.2 (39.7)	67.1 (43.9)

SD, Standard deviation; MEQ, Morningness-Eveningness Questionnaire; TST, Total sleep time, EMA, Ecological momentary assessment