Beneficial effects of sleep extension on daily emotion in short-sleeping young adults: An experience sampling study

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ABSTRACT

Objectives: Short sleep duration has been linked to disrupted emotional experiences and poor emotion regulation. Extending sleep opportunity might therefore offer a means to improve emotion functioning. This study used experience sampling to examine the effect of sleep extension on daily emotion experiences and emotion regulation.

Participants: Participants were young adults (n = 72), aged 18-24 years who reported consistently sleeping less than 7 hours in a 24-hour period in the past 2 weeks.

Design and setting: For 14 consecutive days, participants completed experience sampling questions related to sleep, emotion, and emotion regulation via a smartphone application. Procedures were identical for all participants for the first 7 days (“baseline” assessments).

 Intervention: From days 8-14, participants were randomly assigned to either a “sleep extension” condition, in which they were instructed to increase their sleep opportunity by 90 minutes or a “sleep as usual” condition.

Measurements: Duration and quality of the previous night’s sleep were reported each morning and daytime experiences of positive and negative emotion and emotion regulation were measured at pseudorandom timepoints 6 times a day.

Results: Multilevel modeling demonstrated that participants in the sleep extension condition reported significantly longer sleep times and improved sleep quality, as well as higher positive and lower negative daily emotion, compared to those in the sleep as usual condition.

Conclusion: A brief experimental paradigm to extend sleep length has the potential to improve sleep quality and to a minor extent mood, among young adults with short sleep.

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Introduction

Insufficient sleep duration is common in young adults and has been linked to poor health outcomes at this developmental stage and across the lifespan. Estimates from US college students suggest that less than 30% get the typically recommend 8 hours, and 25% sleep less than 6.5 hours per night. Similar estimates are available from European and Asian university students, with 21% identified as short sleepers (6%, <6 hours; 15%, 6-7 hours). There is also evidence that the number of adolescents reporting short sleep duration is increasing. One nationally-representative US study showed that compared with 2009 data, adolescents in 2015 were 16%-17% more likely to sleep less than 7 hours on most nights.

In young adults, insufficient sleep is especially concerning because mood disturbances most commonly emerge during this developmental period, and sleep disturbance may be a contributory factor. Sleep restriction studies provide compelling evidence for a causal relationship between shorter sleep duration and poorer mood (see meta-analysis). Epidemiological studies also suggest the presence of a link between short sleep and mood disruption. For example, in a community-based cohort of over 20,000 Australian young adults, self-reported shorter sleep duration was linearly associated with more severe and persistent psychological distress. In a school-based cohort in China, self-reported sleep of fewer than 8 hours was associated with an increased risk of suicide attempts in adolescents.

Given the prevalence and potential impact of short sleep duration, a number of studies have begun to assess the feasibility and impact of sleep extension procedures. Most of these have been “proof of concept” tests, assessing whether sleep extension can improve sleep-related parameters. A smaller number of studies have also tested the impact of extending sleep on variables of importance for the target...
sample, particularly in athlete and military populations, for example serving accuracy in tennis players (n = 12) or cognitive-motor outcomes in military tactical athletes.

Emerging work has tested the possible impact of sleep extension on emotion functioning. In an early and landmark study of sleep extension, Mah and colleagues, Dement demonstrated significant improvements in mood, measured using the Profile of Mood States, in varsity basketball players as well as improvements in athletic performance. A recent meta-analysis of at-home sleep extension reported on 3 studies with young nonathlete adult samples, where outcomes were mood or attention-related. In the most recent of these 3 studies, Casement et al. compared 11 women assigned to sleep extension and 10 assigned to typical sleep opportunity. The women in the sleep extension group reported reductions in depression symptoms and anhedonia, and higher positive affect, measured in the morning, relative to a baseline week. In 10 young adults with overweight status, extending sleep was associated with an increase in self-reported vigor after the intervention period compared with baseline. Finally, 15 college students encouraged to sleep as much as possible showed significant improvements in their Profile of Mood States-measured vigor at the end of sleep extension compared with baseline.

Need to understand emotion outcomes, and natural variations

While these studies are part of the accumulating evidence for the feasibility of at-home sleep extension procedures in young adults, understanding potential effects on emotional outcomes has been identified as a research priority. Studies to date in small samples have shown promising effects on outcomes such as depressive symptoms and mood, comparing pre- and post-intervention measures, and typically at a single time point. However, mood and emotion-related variables are characterized by fluctuations, both within and across days. For sleep, there is increasing recognition that intraindividual variability is a characteristic component of sleep-wake rhythms, theorized to be especially impactful in adolescence. Intraindividual variability in sleep has been relatively understudied, because of a general tendency to examine sample or individual mean sleep values over time. Measuring naturally occurring fluctuations in both mood and sleep is now feasible with experience sampling methods (ESM), which provide opportunities to obtain data with higher temporal-resolution than traditional questionnaire measures. For example, using experience sampling in free-living young adults, we found that prior night reported sleep quality was associated with positive emotion and emotion regulation strategy use, measured at multiple time points across the day.

In this study, we examined whether a remotely delivered simple sleep extension instruction could improve sleep, emotion experiences and emotion regulation, tested using experience sampling. We tested young adults reporting recent frequent (i.e., more nights than not) sleep of less than 7 hours, randomly assigned to either a 7-day sleep extension or sleep as usual condition. We obtained frequent day-time measures of their emotion experiences and endorsement of strategies considered to be adaptive or maladaptive in regulating positive and negative emotions, as measured via a smartphone application. We expected that young adults assigned to the sleep extension instruction would show improved sleep patterns, in terms of duration and quality. We further expected increased reporting of positive emotion, and adaptive emotion regulation use and decreased negative emotion and maladaptive emotion regulation use in the sleep extension group.

Participants and methods

Participants

Participants were recruited using King’s College London Facebook groups and a student and staff email circular. Both university students and young adults from the nonuniversity population were included. Inclusion criteria for participation were: aged 18-24 years, study-defined short sleep duration, access to an internet-enabled smartphone, self-reported as English speaking, and UK resident. Short sleep duration was defined as reporting sleeping less than 7 hours per 24-hour period, more days than not, over the past 2-week period. The 2-week period was specified because it is the time period referred to as “current” in the commonly used Insomnia Severity Index, and 7 hours because it is widely known as the minimum recommended sleep duration for adults (including young adults). The final sample was comprised of 72 participants, with 38 in the intervention (sleep extension) and 34 in the control (sleep as usual) group. For details on planned sample size and numbers of participants at each screening stage, see the Supplementary Materials.

Compensation for participation was up to a maximum of £35, which comprised £5 for completing the baseline survey, £5 for completion of 20% or more of surveys (the minimum required for analysis) for each week of the ESM procedure, and a bonus of £10 for completing over 70% of surveys also for each week of the ESM procedure. 42.86% of participants completed >70% of surveys on both weeks (see Supplementary Material for more details on bonuses). Participants gave informed consent online prior to completing the baseline assessment. Ethical approval was obtained via the Psychiatry, Nursing and Midwifery Research Ethics Subcommittee, King’s College London (RESCM-20/21-22675).

Study design

Participants first completed a baseline assessment conducted via Qualtrics (Qualtrics International Inc.), followed by a 14-day longitudinal ESM component, carried out using the MetricWire (MetricWire Inc.) smartphone application.

Baseline measures

At baseline, participants completed demographic (gender, age, education level), sleep and emotion-related measures. Sleep measures assessed: insomnia (Insomnia Severity Index, ISI), sleepiness (Epworth Sleepiness Scale, ESS) and sleep-related cognitions (Dysfunctional beliefs about sleep, DBAS). Emotion regulation measures were: the Responses to Positive Affect (RPA) questionnaire, assessing 3 types of positive emotion regulation (adaptive emotion-focused, adaptive self-focused and maladaptive dampening); and the Emotion Regulation Questionnaire (ERQ), assessing 2 additional types of emotion regulation (adaptive cognitive reappraisal and maladaptive expressive suppression). Participants also completed measures of depression (Patient Health Questionnaire, PHQ-9) and anxiety (Generalized Anxiety Disorder 7-item scale; GAD-7) symptoms (see Table 1 for psychometric properties and Supplementary Materials for further details of questionnaire scores). All participants were provided with a “guidance and counselling” information sheet. Additionally, participants who endorsed the PHQ-9 item referring to suicidality were redirected to the information sheet directly after completing the PHQ-9 scale.

ESM measures

Sleep ESM measures were 5 items taken from the Consensus Sleep Diary, a widely-used self-report instrument designed for daily sleep recording. These comprised the sleep quality item, “How would you rate the quality of your sleep?” (5-point Likert scale from “very good” to “very poor”) and numerical values for: “How long did you nap or doze in the last 24 hours?” (referred to as ‘nap’ throughout), “What time did you try and go to sleep?”, “How long did it take you to fall asleep?”, and “What time was your final awakening?”. From these
We calculated sleep opportunity (difference between the time participants tried to go to sleep and the final awakening time), sleep duration (sleep opportunity minus time taken to fall asleep), and total sleep duration (sum of sleep and nap duration).

We also calculated a "quality-adjusted" sleep outcome variable, to consider the potential trade-off in sleep quality by extending sleep duration. Based on the widely-used metric of "quality-adjusted life years" from health economics, which combines metrics of life quality with life expectancy, we computed "quality-adjusted sleep hours." Sleep quality ratings were standardized on a 0–1 scale (“very poor” sleep = 0, “very good” sleep = 1), and then multiplied by sleep duration, in order to weight the hours of sleep by the quality of sleep. For example, a report of 5 hours of "very poor" quality sleep would receive a score of 0 (0*5 = 0), whereas a report of 5 hours of “very good” sleep would receive a score of 5 (1*5 = 5), and a report of "fair" sleep would receive a score of 2.5 (0.5*5 = 2.5).

Emotion ESM measures comprised 7 items: 2 ratings of emotion intensity and 5 emotion regulation items. Emotion intensity ratings separately assess positive and negative emotions (eg, "In the last few hours, how positive have you felt?" and participants responded to each using a 0–100 Visual Analogue Scale (VAS) (0 = not at all positive, 100 = very positive). For emotion regulation items, 3 were based on items from the RPA, examining emotion focus, self-focus, and dampening and 2 were based on the ERQ, examining cognitive reappraisal and suppression (all scored on a 0–100 VAS, see Supplementary Materials).

### ESM

During the 14 study days, participants completed self-report questions via their smartphones, using the app MetricWire. Each morning between 07:00 and 12:00, participants were asked to complete 5 items related to the previous night’s sleep and were asked to answer 5 items related to the previous night’s sleep and were asked to complete this survey within an hour of waking, as in the instructions for the Consensus Sleep Diary. Replicating the time-stratified ESM procedure used elsewhere, we divided the day into 6 intervals of 120 minutes, from 09:00 to 21:00. Within each time interval, surveys were sent at random timepoints. These included 7 emotion-of 120 minutes, from 09:00 to 21:00. Within each time interval, surveys were sent at random timepoints. These included 7 emotion-regulation items, we calculated sleep opportunity (difference between the time participants tried to go to sleep and the final awakening time), sleep duration (sleep opportunity minus time taken to fall asleep), and total sleep duration (sum of sleep and nap duration).

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### Statistical analysis

Data processing and analysis were carried out in RStudio version 4.0.2, and analysis code is available from: https://osf.io/nhdyf/. ESM data were nested in 3 levels: observations (ie, surveys), within days (note sleep parameters were measured just once per day), within participants. Multilevel modeling (MLM) was used to accommodate this hierarchical structure. Three-level linear mixed models were created for each outcome (sleep quality, total sleep time, positive/negative emotion intensity, and each emotion regulation strategy). In each model, week (baseline or intervention), condition (sleep extension or sleep as usual), and the 2-way interaction of week*condition were entered as fixed factors. Random intercepts were included for “participant” and “days within participant,” similar to analytic approaches reported elsewhere. Models were estimated using the lme4 package and were optimized using a quadratic approximation (BOBYQA) with a set maximum of 20,000 iterations. Missing data was handled using listwise deletion for individual assessments (see Supplementary Materials Table A4).

### Results

#### Participant characteristics

Seventy-two individuals (60 female, 12 male) took part (sleep extension: 31 female, 7 male; sleep as usual: 29 female, 5 male), with items, we calculated sleep opportunity (difference between the time participants tried to go to sleep and the final awakening time), sleep duration (sleep opportunity minus time taken to fall asleep), and total sleep duration (sum of sleep and nap duration).

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For days 8–14, participants were randomly assigned (1:1 ratio) to a “sleep extension” or a “sleep as usual” condition (see Supplementary Materials for verbatim instructions). Participants were randomly allocated to alternating groups based on their time of sign up to MetricWire. We anticipated more female than male participation, based on the samples reported in a previous systematic review of experimental sleep extension studies. We therefore stratified based on gender, to minimize potential gender bias in random group allocation. To balance the number of participants in each group, we monitored drop-out rates and group allocations were made accordingly. Individuals were notified on MetricWire and via email at 11 AM on day 7 as to their group allocation.

Participants in the “sleep extension” condition were instructed to give themselves an opportunity to sleep an extra 90 minutes per day. This could include going to bed earlier, waking up later, or having a nap during the day. Those in the “sleep as usual” condition were asked to continue to sleep as they normally would. Participants were given no further details about the experimental aims of the study. To retain participants and encourage an adequate response rate, we sent additional reminder prompts about participation bonuses at 21:00 on day 2 (week 1), and day 9 (week 2).

#### Table 1

<table>
<thead>
<tr>
<th>Scale range</th>
<th>Sample range</th>
<th>Cronbach’s a</th>
<th>Mean (SD) Sleep extension</th>
<th>Mean (SD) Sleep as usual</th>
<th>Group diff (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-</td>
<td>18-24</td>
<td>20.61 (1.81)</td>
<td>20.85 (1.74)</td>
<td>-0.59 (0.56)</td>
</tr>
<tr>
<td>ESS</td>
<td>0-24</td>
<td>0-16</td>
<td>0.73</td>
<td>7.53 (4.23)</td>
<td>6.94 (3.61)</td>
</tr>
<tr>
<td>ISI</td>
<td>0-28</td>
<td>2-25</td>
<td>0.79</td>
<td>14.18 (5.14)</td>
<td>14.71 (4.73)</td>
</tr>
<tr>
<td>DBAS-16</td>
<td>0-10</td>
<td>1.62-10</td>
<td>0.87</td>
<td>5.18 (1.58)</td>
<td>5.28 (1.81)</td>
</tr>
<tr>
<td>RPA: Emotion-focus</td>
<td>5-20</td>
<td>6-20</td>
<td>0.77</td>
<td>13.00 (3.02)</td>
<td>12.94 (3.60)</td>
</tr>
<tr>
<td>RPA: Self-focus</td>
<td>4-16</td>
<td>4-16</td>
<td>0.80</td>
<td>8.42 (2.93)</td>
<td>8.62 (2.80)</td>
</tr>
<tr>
<td>RPA: Dampering</td>
<td>8-32</td>
<td>8-31</td>
<td>0.80</td>
<td>21.08 (5.36)</td>
<td>20.71 (5.14)</td>
</tr>
<tr>
<td>ERQ: Reappraisal</td>
<td>6-42</td>
<td>6-37</td>
<td>0.83</td>
<td>20.26 (7.37)</td>
<td>21.82 (6.74)</td>
</tr>
<tr>
<td>ERQ: Suppression</td>
<td>4-28</td>
<td>4-27</td>
<td>0.80</td>
<td>16.87 (5.97)</td>
<td>14.47 (4.44)</td>
</tr>
<tr>
<td>PHQ-9</td>
<td>0-27</td>
<td>0-24</td>
<td>0.85</td>
<td>10.47 (5.35)</td>
<td>12.32 (6.33)</td>
</tr>
<tr>
<td>GAD-7</td>
<td>0-21</td>
<td>0-21</td>
<td>0.89</td>
<td>8.05 (5.05)</td>
<td>9.29 (5.44)</td>
</tr>
</tbody>
</table>

Note: ESS = Epworth Sleepiness Scale, ISI = Insomnia Severity Index; DBAS = dysfunctional beliefs about sleep, RPA = Responses to Positive Affect scale; ERQ = Emotion Regulation Questionnaire; PHQ = Patient Health Questionnaire-9 for measuring depressive symptoms; GAD-7 = Generalized Anxiety Disorder 7-item scale for measuring anxiety symptoms.
a mean age of 20.72 years (SD = 1.77). Around 60% had completed secondary school level education (59.72%), and the remainder had obtained higher education qualifications (bachelor’s degree: 29.17%, master’s degree: 11.11%). At the time of the study, 62 participants (86.11%) reported being full-time or part-time students. There were no significant differences in gender, age or higher education qualifications between the sleep extension and sleep as usual groups (gender: χ²(1, N = 72) = 0.01, p = .92; education: χ²(2, N = 72) = 0.91, p = 0.63; student status: χ²(1, N = 72) = 3.60, p = .06; for age, see Table 1). There were no significant between-group differences in baseline assessments of sleep and trait-level emotion regulation (Table 1).

Participants’ baseline ESS scores were on average between 6 and 7, indicating higher than ‘normal’ daytime sleepiness.23 Participants’ mean ISI scores fell at the upper end of the cut-off for sub-threshold insomnia. The majority of participants’ PHQ-9 and GAD-7 scores were in the mild to moderate range (for further details, see Supplementary Materials).

Mean sleep ESM survey completion rate was 83.33% (SD = 20.63) and mean emotion ESM survey completion rate was 63.03% (SD = 23.46). Across the first 7 study days, the mean sleep quality score was 2.96 (SD = .96; median = 3, range = 1-5, IQR = 2-4) and mean sleep duration was 6.24 hours (SD = 1.74; median = 6.33 hours, range = 0.00-12.83 hours, IQR: 5.17-7.33 hours; see Supplementary Materials). Mean daily sleep, emotion and regulation ratings are displayed in Table 2. Of the emotion regulation strategies, “suppression” was the most strongly endorsed, whereas “dampening” was the least strongly endorsed during the baseline week. We also examined participants’ baseline questionnaire scores (PHQ-9, GAD-7 and ISI) and emotion and emotion regulation ratings in the baseline week. The only significant effect was related to depression symptoms, where higher PHQ-9 scores were associated with lower positive emotion intensity (B = -0.82, p = .049), higher negative emotion intensity (B = 1.50, p < .001), reduced endorsement of self-focused emotion regulation (B = -1.16, p = .016) and greater endorsement of dampening emotion regulation (B = 1.13, p = .045).

Effects of sleep extension on sleep outcome variables

For sleep quality, there was no significant main effect of condition (sleep extension, sleep as usual), but a small, statistically significant main effect of week, and a small significant interaction of condition*week (Table 3, Fig. 1). Sleep quality ratings were significantly higher during the intervention week compared to the baseline week, for the sleep extension condition but not for the sleep as usual condition (Table 4). For total sleep duration, there were significant main effects of condition, week, and a significant interaction of condition*week. Participants in the sleep extension condition reported sleeping an extra 1 hour and 20 minutes on average in the intervention week, compared to the baseline week, whereas those in the sleep as usual group reported similar mean sleep durations for both weeks (see Supplementary Materials Table A5 for model using “sleep opportunity”).

Combining sleep quality and duration into a single metric

Given that longer sleep duration does not always correlate with higher sleep quality, we carried out an exploratory analysis, examining the relationship between participants’ reported sleep quality and duration. First, we ran MLM analyses to examine associations between sleep quality and sleep duration, for each week (baseline or intervention). During the baseline week, sleep quality and sleep duration were positively associated with a small effect size (B = 0.15 [0.13, 0.18], p < .001, d = 0.17). During the intervention week, these variables were associated with a small-medium effect size for both the sleep extension group (B = 0.32 [0.29, 0.36], p < .001, d = 0.36), and the sleep as usual group (B = 0.26 [0.22, 0.30], p < .001, d = 0.29). Using the “quality-adjusted” sleep outcome variable in an additional MLM, we found significant main effects of condition (B = 1.00 [0.33, 1.68], SE = 0.34, p = .004, d = 0.48) and week (B = 1.19 [0.93, 1.45], SE = 0.13, p < .001, d = 0.57), and a significant interaction of condition*week (B = -1.21 [-1.44, -0.98], SE = 0.12, p < .001, d = -0.58). These MLM results indicate beneficial effects of the sleep extension instruction on quality-adjusted sleep hours.

How did participants change their sleep?

Exploring changes in sleep patterns in the two groups, participants in the sleep extension group appeared to shift their bedtimes and sleep times earlier (mean baseline week: bedtime 01:04, sleep time 01:45; mean intervention week: bedtime 01:00, sleep time 00:50), whereas participants in the sleep as usual group did not substantially change their bed or sleep times (baseline week: bedtime 01:05, sleep time 01:37; mean intervention week: bedtime 00:52, sleep time 01:30). For wake times, participants in the sleep extension group appeared to delay their wake time (mean baseline week: 07:46; mean intervention week: 08:30), whereas participants in the sleep as usual group did not substantially change their wake time (mean baseline week: 07:44; mean intervention week: 07:40).

Napping was reported by participants throughout the study, with a nap reported on 22.64% of all days with available data. Nap duration (in minutes) was significantly positively skewed and was typically short in duration (median: 0.50 hours, IQR: 0.25-1.00 hours). Therefore, we focus our analysis on counts of naps, rather than nap duration. Approximately half of all participants reported napping during the day one or more times during the baseline week (sleep as usual group: 58.82%, sleep extension group: 57.89%) and during the intervention week (sleep as usual group: 45.45%, sleep extension group: 48.65%). There was no significant change from the baseline week to the intervention week in the proportion of individuals reporting naps in either the sleep extension (χ²(1, N = 38) = 0.33, p = .57) or the sleep as usual group (χ²(1, N = 34) = 0.72, p = .40).

Baseline mood and insomnia symptoms’ effects on sleep extension

We ran additional MLMs to examine whether baseline depression, anxiety and insomnia symptom severity moderated the change in sleep duration within the sleep extension group. Results demonstrated a significant main effect of baseline insomnia (ISI) scores on sleep duration (B = -0.08, 95% CI = -0.14, -0.01, p = .017) and a significant interaction of baseline ISI scores and week (B = -0.03, 95% CI = -0.06, -0.00, p = .032), where individuals with lower baseline ISI scores demonstrated greater increases in sleep duration from baseline to intervention weeks. There were no significant main or interaction effects for models examining baseline depression (PHQ-9) or anxiety (GAD-7) scores (all p > .35; see Supplementary Materials Table A6).

Effects of sleep extension on emotion outcome variables

For positive emotion, there were no significant main effects of condition or week, but there was a significant interaction of condition*week (Table 3, Fig. 2). Participants in the sleep extension group gave positive emotion ratings that were on average ~1-point higher during the intervention week compared to the baseline week (Table 4). In contrast, the ratings of the “sleep as usual” group were on average ~1-point lower in the intervention week compared to the baseline week. However, analyzing simple effects for each group, we found no significant effect of week for the sleep extension group, or in the sleep as usual group.

For negative emotion, there was no significant main effect of condition, but there was a significant main effect of week and a
significantly different interaction of condition*week. Negative emotion ratings were significantly lower during the intervention week, compared to the baseline week (Table 3). Interaction effects indicated that the sleep extension group had lower negative emotion ratings in the intervention week compared to the baseline week (Table 4), but there was no change in the sleep as usual group.

Across all emotion regulation models, there was no main effect of condition and no interaction effect of condition*week. Only one model (positive emotion-focused regulation) demonstrated a significant main effect of week, with participants reporting lower endorsement of emotion-focused regulation use during the intervention week (M = 40.91, SD = 23.65), compared to the baseline week (M = 42.59, SD = 24.53). We did not have any specific a priori predictions about main effects of week, and note that this may be a spurious finding, given the number of models tested.

Discussion

In this randomized experiment, we demonstrate the benefits of 7 days of at-home sleep extension on daily emotion experience, measured using experience sampling. We found that young adults with recent sleep of less than 7 hours responded positively to a remotely delivered sleep-extension instruction to increase their sleep duration, with significantly longer reported sleep times, but also improved sleep quality. During the intervention week relative to baseline, participants in the sleep extension group had increased positive and negative emotion ratings, with a significant decrease in negative emotion ratings during the intervention week compared to baseline. These findings suggest that sleep extension can improve daily emotion experience in short-sleeping young adults, with potential benefits for overall mental health and well-being.

Table 2
Descriptive statistics of experience sampling variables across the baseline week and the intervention week for the sleep extension and sleep as usual conditions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline M</th>
<th>Baseline SD</th>
<th>Baseline Intercept</th>
<th>Baseline 95% CI lower</th>
<th>Baseline 95% CI upper</th>
<th>Baseline SD BP</th>
<th>Baseline SD WPr</th>
<th>Baseline ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive emotion intensity</td>
<td>53.84</td>
<td>23.07</td>
<td>54.54</td>
<td>51.06</td>
<td>58.02</td>
<td>14.53</td>
<td>17.53</td>
<td>0.41</td>
</tr>
<tr>
<td>Negative emotion intensity</td>
<td>39.54</td>
<td>25.36</td>
<td>40.65</td>
<td>36.81</td>
<td>44.51</td>
<td>16.05</td>
<td>19.46</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Note: Sleep quality ratings range from 1 ‘Very poor’ to 5 ‘Very good’.
decreased negative daily emotion, relative to the effects seen for the “sleep as usual” group. Our recruitment of short sleeping young adults, and experimental extension of their sleep duration, allows us to make directional conclusions about a positive impact of sleep on daily emotion outcomes.

Overall, we note adequate retention and rates of survey completion among participants. The majority of participants (76%) who were enrolled into the experience sampling (ESM) component of our study completed >20% of surveys over the 14 days of experience sampling, our a priori threshold for including data in analyses. While the studies of young adults previously reviewed had low attrition rates of 10-30%, our completion rates are within reasonable ranges.

Remote delivery: a scalable research intervention, but with self-report only

We tested a simple, experimentally scalable instruction, but our smartphone-based, automated approach comes with both benefits and costs. We used remote data collection, and participants’ sleep reports, which can be extended to large participant groups at minimal cost. However, in the absence of objective measures of sleep, we cannot exclude the possibility that participants are simply reporting compliance with the instructions (ie, socially desirable responding), rather than actual extended sleep time. However, the positive effects on emotion experience here are not clearly attributable to demand characteristics. We also note that participants reported an increase in sleep quality, which again was not directly related to the instructions provided. Finally, our findings of reported “successful” extended sleep duration are in line with studies that did combine objective measures of sleep with participants’ reports of their sleep time, albeit in different study samples.

While we expected that participants would extend their duration of reported sleep based on the instructions, we felt it was important to examine the effects on sleep quality. Increases in sleep duration do not always coincide with improved sleep quality, as for as seen for example during COVID restrictions. We found modest improvements in sleep quality in the sleep extension group, compared to the sleep as usual group, and our metric combining sleep quality and time into a “quality-adjusted” sleep outcome, also indicates beneficial instruction effects. The fact that participants’ sleep quality improved, along with their sleep duration, corroborates the idea that young adults frequently getting less than 7 hours sleep are under-sleeping relative to their sleep need. Given more sleep opportunity, young adults can achieve longer, and better-quality sleep.

We did not provide participants with explicit instructions on how to extend their sleep, contrasting with other studies, where participants were given individualized sleep timetables. While some participants might benefit from individual instructions, thereby leading to greater compliance, our instruction is both highly scalable and provides an opportunity to examine what participants will naturally select themselves. We found that the sleep extension participants both advanced their bedtime and delayed their waketime, with the change to bedtime being the slightly larger change (55-min difference), compared with waketime changes (44-min). For napping, somewhat surprisingly, there was no change in the frequency of naps taken, suggesting that most of the changes made were related to night-time sleep scheduling. The tendency of young adults to self-select bedtime changes, rather than more frequent naps, may be useful information for the design of individualized sleep extension interventions.

Effects sizes on emotion

A strength of the study is the multiple times across multiple days measure of emotion experience, comprising both positive and negative emotions. Effect sizes here were small, when considering the

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Table 3
Results of multilevel model analyses examining week, condition and week*condition interaction effects on daily positive and negative emotion intensity ratings, emotion regulation strategies, and sleep quality/duration

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Std. error</th>
<th>95% CI (lower)</th>
<th>95% CI (upper)</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep quality</td>
<td>Week</td>
<td>0.22</td>
<td>0.06</td>
<td>0.11</td>
<td>0.33</td>
<td>.001</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Condition</td>
<td>0.14</td>
<td>0.16</td>
<td>-0.17</td>
<td>0.45</td>
<td>.376</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Week “condition”</td>
<td>-0.29</td>
<td>0.06</td>
<td>-0.40</td>
<td>-0.18</td>
<td>&lt;.001</td>
<td>-0.30</td>
</tr>
<tr>
<td>Total sleep duration</td>
<td>Week</td>
<td>1.28</td>
<td>0.11</td>
<td>1.07</td>
<td>1.49</td>
<td>&lt;.001</td>
<td>0.71</td>
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<tr>
<td></td>
<td>Condition</td>
<td>1.23</td>
<td>0.31</td>
<td>0.63</td>
<td>1.83</td>
<td>&lt;.001</td>
<td>0.68</td>
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<tr>
<td></td>
<td>Week “condition”</td>
<td>-1.25</td>
<td>0.10</td>
<td>-1.45</td>
<td>-1.05</td>
<td>&lt;.001</td>
<td>-0.69</td>
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<tr>
<td>Positive emotion intensity</td>
<td>Week</td>
<td>1.15</td>
<td>0.87</td>
<td>-0.55</td>
<td>2.86</td>
<td>.194</td>
<td>0.05</td>
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<td>8.16</td>
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<td>Week “condition”</td>
<td>-2.42</td>
<td>1.13</td>
<td>-4.63</td>
<td>-0.21</td>
<td>.032</td>
<td>-0.11</td>
</tr>
<tr>
<td>Negative emotion intensity</td>
<td>Week</td>
<td>-4.70</td>
<td>1.10</td>
<td>-6.87</td>
<td>-2.54</td>
<td>&lt;.001</td>
<td>-0.19</td>
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<tr>
<td></td>
<td>Condition</td>
<td>-3.89</td>
<td>3.98</td>
<td>-11.70</td>
<td>3.92</td>
<td>.330</td>
<td>-0.16</td>
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<tr>
<td></td>
<td>Week “condition”</td>
<td>4.85</td>
<td>1.30</td>
<td>2.31</td>
<td>7.39</td>
<td>&lt;.001</td>
<td>0.20</td>
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<tr>
<td>Self-focused regulation</td>
<td>Week</td>
<td>0.18</td>
<td>0.75</td>
<td>-1.29</td>
<td>1.64</td>
<td>.815</td>
<td>0.01</td>
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<tr>
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<td>Condition</td>
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<td>4.36</td>
<td>-15.34</td>
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<td>-0.29</td>
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<td>1.79</td>
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<td>Emotion-focused regulation</td>
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<td>.427</td>
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<td>Week</td>
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<td>-2.88</td>
<td>2.85</td>
<td>.994</td>
<td>0.00</td>
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<tr>
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<td>Week “condition”</td>
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<td>.318</td>
<td>0.04</td>
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<td>-3.88</td>
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<td>-0.07</td>
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<tr>
<td></td>
<td>Condition</td>
<td>-5.78</td>
<td>4.52</td>
<td>-14.64</td>
<td>3.08</td>
<td>.204</td>
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<tr>
<td></td>
<td>Week “condition”</td>
<td>1.74</td>
<td>1.12</td>
<td>-0.46</td>
<td>3.94</td>
<td>.122</td>
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<tr>
<td>Suppression</td>
<td>Week</td>
<td>-0.62</td>
<td>1.12</td>
<td>-2.82</td>
<td>1.58</td>
<td>.584</td>
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<tr>
<td></td>
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<td>0.30</td>
<td>5.14</td>
<td>-9.77</td>
<td>10.37</td>
<td>.953</td>
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<tr>
<td></td>
<td>Week “condition”</td>
<td>-2.38</td>
<td>1.27</td>
<td>-4.87</td>
<td>0.11</td>
<td>.061</td>
<td>-0.09</td>
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</tbody>
</table>

Note: Total sleep duration = sleep over a 24 period, including nap time (calculated using bed time, time taken to fall asleep, wake time and nap time).
actual changes in ratings on the positive and negative emotion scales and therefore unlikely to be of clinical relevance. Nonetheless, effects were consistent across study days (Fig. 1) and statistically significant, and generally in line with reports from other sleep studies using different instruments. Further, we found no significant effects on participants’ emotion regulation strategy use. Our significant effects for positive and negative emotion, but not for regulation, are actually consistent with findings from a recent meta-analysis examining sleep loss, rather than sleep extension. Effects of sleep loss were moderate-to-large for mood, but were small or nonsignificant for emotion regulation. Considering the plausible effects of sleep loss on mood, we suggest that reducing or eliminating sleep entirely is likely to result in more pronounced effects than extending sleep by relatively small amounts (90-minute target here). We therefore suggest that our findings of modest effect sizes for emotion are within a plausible range. Emotion regulation changes, given the size of the effects reported in the sleep loss literature, might require a larger or more sleep-deprived sample than that recruited here, or a sample showing emotion regulation deficits.

While we did not explicitly recruit participants with depressive symptoms, our sample largely fell within the mild to moderate depressive symptom range. This is broadly comparable with a previous study sample, where women were explicitly recruited with a Center for Epidemiologic Studies Depression Scale score of over 15, above the population average for young people (indicating some depressive symptoms). Effect sizes reported here are similar to the correlations reported for sleep duration, depression severity, anhedonia, and positive morning affect in the study completers of Casement and colleagues. We suggest that our findings contribute to the preliminary evidence for the feasibility of sleep extension in young adults and provide further impetus for targeting sleep opportunity to improve affective functioning.

Limitations and future directions

We note several important study limitations. First, we relied on self-report measures of sleep, and previous studies have demonstrated that actigraphy provides more conservative estimates of sleep time in sleep extension paradigms (eg,14,15). We used nonprobability convenience sampling to recruit participants, and we did not recruit a sample with clinical levels of insomnia, limiting the relevance of our findings to the clinic. We also tested participants over a short time frame, so we do not know whether participants continued to extend their sleep after our incentivized study period. Future studies may combine actigraphy-measurement of sleep with participants’ self-reports, recruit a sample with more pronounced levels of insomnia, and include longer follow-up periods.

There is also considerable promise in obtaining information on the contexts in which participants function, as part of the experience sampling measures. An understanding of participants’ context is necessary to determine whether emotion regulation strategies are adaptive or maladaptive, or indeed to assess the situational drivers of

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**Fig. 1.** Sleep duration and sleep quality increased in the Sleep Extension group compared to the “Sleep as usual group” in the intervention week. Left panels show sleep during the baseline week (by day), and right panels during the intervention week. (A) Total sleep duration in hours, boxes indicate the interquartile range, with central lines denoting the median. Upper and lower whiskers denote 1.5 times the interquartile range, and black dots indicate outlier values; (B) Participants’ sleep quality ratings (sleep extension group only) represented as percentage of total reports, by day.
emotional experiences. Passive mobile sensing of parameters such as activity, proximity to others, and light exposure, together with event-contingent reports from participants (see 43 for a review of designs), will be useful in understanding sleep-emotion relationships. Such context-based measurement would allow us to test, for example, whether sleep extension has an impact on emotion via increases in next-day activity, or social interactions.

Conclusion

Our findings indicate that a brief, at-home sleep extension procedure can yield beneficial effects on sleep duration, quality and daily emotion experience in short sleeping young adults. Using experience sampling, we provide evidence for reductions in negative emotion, and increased positive emotion measured across multiple points per day for multiple days. Given the prevalence of short sleep duration in young adults, and the theorized role for sleep in the emergence of mood disruptions, simple, scalable interventions to improve sleep are of relevance for public health. Finally, our findings of improved sleep quality with longer sleep duration suggest that many young adults sleeping less than 7 hours might benefit from lengthening their sleep.

Declaration of conflict of interest

The authors declare no conflicts of interest.

Table 4

<table>
<thead>
<tr>
<th></th>
<th>Baseline week</th>
<th>Intervention week</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>p</th>
<th>d</th>
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<tbody>
<tr>
<td>Sleep quality</td>
<td>Sleep extension</td>
<td>3.06</td>
<td>0.95</td>
<td>3.32</td>
<td>0.95</td>
<td>0.22</td>
<td>.008</td>
<td>0.23</td>
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<td>2.85</td>
<td>0.96</td>
<td>2.77</td>
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<td>-0.08</td>
<td>.36</td>
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<td>Sleep extension</td>
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<td>1.88</td>
<td>6.34</td>
<td>1.91</td>
<td>0.03</td>
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<td>0.02</td>
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<td>Positive emotion</td>
<td>Sleep extension</td>
<td>54.42</td>
<td>23.69</td>
<td>55.70</td>
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<td>.311</td>
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<td></td>
<td>Sleep as usual</td>
<td>53.17</td>
<td>22.30</td>
<td>52.11</td>
<td>22.31</td>
<td>-1.27</td>
<td>.14</td>
<td>-0.06</td>
</tr>
<tr>
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<td>Sleep extension</td>
<td>38.65</td>
<td>25.50</td>
<td>34.02</td>
<td>23.31</td>
<td>4.70</td>
<td>&lt;.001</td>
<td>-0.19</td>
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<tr>
<td></td>
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<td>40.58</td>
<td>25.16</td>
<td>40.51</td>
<td>24.32</td>
<td>0.12</td>
<td>.91</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Fig. 2. Positive emotion increased and negative emotion decreased in the Sleep Extension group compared to the sleep as usual group in the intervention week. Left panels show emotion ratings (VAS) during the baseline week (by day), and right panels, during the intervention week. (A) Positive emotion ratings, (B) negative emotion ratings. Boxes indicate the interquartile range, with central lines denoting the median. Upper and lower whiskers denote 1.5 times the interquartile range, and black dots indicate outlier values.
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Author contributions

CEP and KSY devised the study concept, all authors contributed to measurement design and analyses. The manuscript was co-written by the authors.

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Supplementary materials

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References