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Cognitive Psychology

Analyzing the Affective Consequences of Normal Sleep Fluctuations: A Multiverse Investigation Using Experience Sampling Data

Stephen L. Murphy[1a], Kyle Van Gaeveren[1], David De Segovia Vicente[1], Mariek Vanden Abeele[1]

[1] imec-mict-UGent, Department of Communication Sciences, Ghent University, Ghent, Belgium

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How much we sleep at night is believed to impact next-day affective experiences. Yet, the existing research is encumbered by methodological limitations. To address this issue we harnessed experience sampling data (68,232 observations across 10,905 days) from 1,415 Belgian participants to examine whether normal variations in sleep duration linearly or nonlinearly influence next-day fatigue, stress, happiness, anxiety, despondence, and calmness. We also tested whether people that sleep less on average benefit more from a standard sleep increase than people that generally sleep more. We tested 10,080 models as part of a multiverse analyses in this non-pre-registered study. Findings indicate even small increases in sleep duration promote (albeit, in a small way) more positive affective experiences, that effects are generally stronger in the period after waking relative to later in the day, and that effect magnitudes differ markedly across affective experiences. We also found some indication that the impact of sleep on fatigue and feelings of despondence soon after waking may be greater for people that sleep less on average, but further research is needed. Little support was gained for sleep effects being nonlinear. In short, our findings advance understanding of whether and to what extent sleep impacts various affective experiences, and reveal important nuances to this relationship.

Anecdotal evidence supports that adequate night-time sleep is important for promoting more positive affective experiences the following day, for instance, increased happiness and calmness, and decreased fatigue and stress. This is buttressed by formal theory maintaining that sleep has a critical restorative function (Assefa et al., 2015), and better enables top-down control of negative affect (Kahn et al., 2013). Moreover, empirical evidence indicates that reduced sleep–whether sleeping slightly less than usual (Bromley et al., 2012), drastically cutting hours (Dagys et al., 2012; Reddy et al., 2017), or total sleep deprivation (Schwarz et al., 2019)–generally deteriorates affective states (Acheson et al., 2007; Baum et al., 2014; Bromley et al., 2012; Schwarz et al., 2019). Observational research, a key approach for investigating this phenomenon, corroborates the link (Barber et al., 2023; Konjarski et al., 2018). A notable systematic review revealed that most analyzed studies reported positive correlations between sleep duration and subsequent day's positive emotions (Konjarski et al., 2018). These findings are reinforced by recent higher-quality studies encompassing extensive datasets and pre-registration of research protocols (e.g., Das-Friebel et al., 2020; Hachenberger et al., 2022).

Despite this support, more research is needed to better grasp the link between sleep amount and next day affective experiences. Anecdotal evidence, while valuable, is not well suited to accurately revealing the nuances of the sleep-affect relationship. *How much* of an impact does sleep duration exert on affective experiences? Does sleep duration exert a greater effect on feeling calm the next day relative to feeling happy? Questions like these concern smaller effects that warrant precise empirical investigation.

The need for more research is also supported given the general absence of strategies by past research to prevent effect overestimation. Pre-registration, which refers to the outlining of hypotheses, methods, and analyses prior to data examination (van 't Veer & Giner-Sorolla, 2016), and prevents researchers from selecting for significance (and thus inflated effects, Brodeur et al., 2022; Munafò et al., 2017), was only conducted by a handful of studies (e.g., Das-Friebel et al., 2020; Hachenberger et al., 2022; Willroth et al., 2022). To our knowledge, multiverse analysis, which

a Correspondence concerning this article should be addressed to Stephen L. Murphy, imec-mict-UGent, Department of Communication Sciences, Ghent University, Ghent, Belgium. E-mail: stephen.murphy@ugent.be

involves testing effects in many ways and can also prevent effect size overestimation (Dragicevic et al., 2019; Steegen et al., 2016), has yet to be harnessed. This presents the very real possibility that many published effects reflect overestimates–particularly amid strong incentives to report significant effects and the difficulties of collecting (sufficient) data (Nelson et al., 2018)–thus justifying the need for rigorous approaches better able to reveal population effects.

Finally, more research is needed since only a few studies have examined whether sleep's influence on affective states is actually *non*-linear (e.g., Barber et al., 2023; Groeger et al., 2022; Palmer et al., 2024; Wrzus et al., 2014). That nonlinearity has not been extensively investigated is highly surprising. First, because it seems implausible that any positive affective influence of increased sleep would not *eventually* level off. Indeed, we seem to know intuitively, from our own experiences and the experiences of others, that one can get *too much* sleep such that it stops conferring clear benefits, and that getting even one or two hours less than usual can render one tense and tired where one would otherwise be relaxed and energized. Second, because theory maintains sleep effects in general are non-linear (e.g., the impact of sleep on recovery and mortality risk, Ferrara & De Gennaro, 2001; Hirshkowitz et al., 2015), thus suggesting (near) perfect linearity should not be expected in the relationship between sleep and affective experiences. Finally, because various theorists claim that there are a core number of hours one must sleep to not accumulate sleep debt (Ferrara & De Gennaro, 2001), implying nonlinear restorative effects of sleep. Concerning the research that tested a nonlinear link between sleep and affective states, most supported an effect (e.g., Palmer et al., 2024; Wrzus et al., 2014). However, this evidence is insufficient for it comes from (a handful of) studies weakened by the methodological issues already noted.

Present Study

Accordingly, the present research investigates whether more sleep at night promotes more positive (and less negative) next day affective experiences, by examining both linear and non-linear effects. While pre-registration of this study is not possible (data was collected for other research purposes), we employ multiverse analyses to test effects and strengthen our empirical contribution. We leverage data from an experience sampling (ESM) study involving 1,415 participants, whereby sleep duration was captured from participant self-reports of their sleep and wake times shortly after waking (10,905 datapoints), and whereby six affective experiences (mental fatigue, stress, happiness, anxiety, despondence, and calmness) were captured from participant self-reports at six random points throughout the day (68,232 datapoints). These experiences were our focus given they all possess a strong affective component. But also given we leverage data collected for other research purposes, thus alternatives were not available.

Informed by anecdotal experiences, formal theory, and empirical research, we hypothesize that getting more sleep at night promotes more positive affective experiences the following day (Hypothesis 1). We also hypothesize that sleep's positive impact is nonlinear, such that an extra hour sleep at higher sleep amounts will exert a lesser impact than an extra hour sleep at lower sleep amounts (Hypothesis 2). If this nonlinear effect does exist, it should follow that people that sleep less on average will be more positively impacted by a set sleep duration increase than people that sleep more on average. Thus, we also hypothesize this cross-level interaction effect (Hypothesis 3).

We should note that the plausibility of nonlinear relations between sleep duration and affective experiences (Ferrara & De Gennaro, 2001; Hirshkowitz et al., 2015) indicates this study is unlikely to reveal how *extreme* sleep deviations/amounts generally impact next day affective experiences. We conclude this given our participants reported only sleeping less than five hours on 119 occasions and more than ten hours on 401 occasions. If very low or high sleep amounts *do* exert a markedly different impact on affective experiences than more moderate sleep amounts–as intuition and theory suggests they may–the high preponderance of data whereby reported sleep duration was 'normal' (e.g., 8 hr) would render our models largely insensitive to this reality. To be clear, then, the present study represents a robust investigation of how *typical* day-to-day sleep deviations impact next day affective experiences only.

Methods

Transparency and Openness

This non-pre-registered study repurposed data originally collected to explore the relationship between digital media use and well-being (see de Segovia Vicente et al., 2024). This article does not detail questionnaire items not directly relevant to the present paper. However, the complete methodology, inclusive of all measures, study materials, and data, is accessible on our OSF page: https://osf.io/9bp53/

Participants

Of the 3,065 Flemish individuals that registered for this study online by providing their name, email address, and age, 1,415 (46.17%) participants completed at least 1 ESM questionnaire. These participants (874 females, 523 males, 13 non-binary, 5 other) were aged between 18 and 82 years (M = 38.80, SD = 11.77), and most (1,278) held at least a degree and were in full-time employment (1,083). The remaining participants were students (114), unemployed (18), on long-term sick leave (29), retired (53), engaged in unpaid care work (14), employed in other capacities (103), or preferred not to disclose their occupation (1). Participants, required to be 18 years or over and to own a smartphone, received a personalized report of their digital media use and well-being, plus access to public dissemination events, as incentives. The Ghent University review board approved the study, conducted from October to December 2022.

Procedure

Data collection involved an initial intake survey that collected demographic information and a subsequent 14-day ESM phase, whereby participants reported on key constructs like sleep duration and stress. A final online survey, conducted post-ESM phase, focused on various personality factors unrelated to this study's objectives. All materials were provided in Dutch, with translations available on our OSF page.

The study, promoted in a major national newspaper, aimed ostensibly to examine digital media use and well-being, thus precluding any bias towards a connection between sleep duration and affective experiences. Participants registered online and then received instructions for downloading the m-Path app (https://m-path.io; Mestdagh et al., 2023) and joining the study, which started with a 10 min intake survey. After completing the intake questionnaire, participants began receiving ESM questionnaires according to a mixed sampling scheme that had semi-random and fixed elements. Participants received six short questionnaires per day, between 07:30 hrs and 22:45 hrs. Each notification was randomly scheduled within one of six 90 min time slots throughout the day: 07:30-09:00 hrs, 10:15-11:45 hrs, 13:00-14:30 hrs, 15:45-17:15 hrs, 18:30-20:00 hrs, 21:15-22:45 hrs. These time slots were separated by a period of at least 1 hr 15 min and at most 4 hr 15 min. On average, ESM responses were separated by 3 hr 4 min (SD = 16.66 min). Following the initial notification, each ESM questionnaire remained available to complete for 45 min. Participants received a reminder notification if the questionnaire had not been responded to 30 min after the initial notification. Participants received ESM questionnaires for 14 full days. They received additional questionnaires depending upon the time they completed the intake questionnaire. For instance, if a participant completed the intake questionnaire at 20:15 hrs, they received the remaining scheduled questionnaire for that day, between 21:15 and 22:45 hrs, and then 14 full days of ESM questionnaires starting the following day. Thus, participants received a minimum of 84 ESM questionnaires and a maximum of 90 ESM questionnaires. Please note that the additional questionnaires sent to participants reflect an app limitation, such that completion of the intake questionnaire 'initiated' the ESM questionnaire schedule. After completing the ESM phase, participants received an outtake questionnaire and were debriefed and thanked for their involvement.

Experience-Sampling Procedure and Protocol

Each ESM questionnaire sent to participants was identical in content, with a few exceptions. First, the initial ESM questionnaire participants received each day contained items with the stem 'Since getting up this morning…', whereas the remaining five questionnaires each day included the stem 'Since the last questionnaire…'. Also, only the initial questionnaire of each day contained items that measured the time participants went to sleep the previous night ('What time did you go to bed last night?), and the time the participant woke up that morning ('At what time did you get up this morning?), on a 24 hr formatted clock face.

Items in each ESM questionnaire were presented to participants in a random order. In each ESM questionnaire participants reported on their mental fatigue ('Since the last questionnaire I felt mentally drained'), stress ('Since the last questionnaire I felt stressed'), happiness ('Since the last questionnaire I felt happy'), anxiety ('Since the last questionnaire I felt anxious'), despondence ('Since the last questionnaire I felt down'), and calmness ('Since the last questionnaire I felt relaxed'), on a Likert scale ranging from 1 ('Not true at all') through 4 ('Neither true nor false') to 7 ('Absolutely True').

Analytical Procedures and Strategy

Multiverse Strategy

Our multiverse strategy (specified in the next paragraph), while somewhat arbitrarily chosen, is nevertheless representative of typical analytic decisions made by domain-relevant research. For instance, research has tested the effect of sleep duration on affective experiences using participants' morning (Newman et al., 2023) or whole-day (de Wild-Hartmann et al., 2013; Hachenberger et al., 2022) affective experiences, and with and without a) a random slope (Das-Friebel et al., 2020; Newman et al., 2023), b) control variables (Hachenberger et al., 2022; Newman et al., 2023), and c) removing participants that contributed only a handful of datapoints (de Wild-Hartmann et al., 2013; Hachenberger et al., 2022; Newman et al., 2023). Moreover, it is plausible that researchers seeking significant effects may remove participants that, for instance, complete 'too few' questionnaires, or that are not employed or within a particular age bracket, because these factors can be justified and may well be influential (e.g., participants that contribute minimal data may be more likely to contribute poor quality data). More multiverse parameters could have been included in our analysis plan. However, we opted against this given the exponential model *N* increase that would result (e.g., adding a few extra parameters could require over 30,000 models), and that our parameter number and type is sufficient to allay concerns that findings were underpinned by selective reporting—which given the study's exploratory nature was a major priority.

First, after removing obvious problematic datapoints (e.g., duplicates), we investigated whether sleep duration associates with each next day affective experience by using all available data in a model with a random intercept and slope. We then tested the same model, but after first removing questionnaires that were completed by participants in less than 45 sec (pilot testing suggested this data was likely to have resulted from inattentive responding). We then tested all prior models while additionally controlling for any weekday/weekend effect on affective experiences. Next, we tested all prior models while additionally controlling for the prior day autoregression effect (e.g., average fatigue from the prior day predicting fatigue the next day). We then tested all prior models with data from each of the six questionnaires participants received each day separately (e.g., testing all models from questionnaire 1 data pertaining to the period soon after waking, then testing all models from questionnaire 2 data pertaining to the period just before lunch), rather than simply across *all* questionnaires. We then tested all prior models but where the model had a random intercept and a *fixed* slope. We then tested all prior models but only after initially removing participants that a) had completed at least 8 questionnaires, b) had completed at least 16 questionnaires, c) were in paid employment, and d) were aged less than 50 years. This multiverse approach was identical for all hypothesis tests. To explore whether the effect of sleep duration on an affective experience differed across questionnaires (e.g., questionnaire 1 vs. questionnaire 6), models could only be tested with data from *all* questionnaires. Overall, we ran 10,080 models to test our three hypotheses. Please see our supplementary materials for details of how many data points and participants were included in each model.

Data Preparation and Analyses

Data was organized and cleaned with R (R Core Team, 2024). The packages devtools (Wickham et al., 2022), esmpack (Viechtbauer & Constantin, 2023), lubridate (Grolemund & Wickham, 2011), magrittr (Bache & Wickham, 2022), misty (Yanagida, 2023), and dplyr (Wickham et al., 2023) were used to clean the data, the packages lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and psych (Revelle & Revelle, 2015) were used to analyse the data, and the packages ggplot2 (Wickham et al., 2016), ggpattern (FC & Davis, 2022), mixedup (Clark, 2023), and broom.mixed (Bolker & Robinson, 2022) were used to present/visualize the results.

All multiverse analyses were conducted with multilevel models given observations often came from the same data collection day and participant and thus lack independence. This took the form of a three-level model, with observations at level 1 (ranging from 1 to 88), day at level 2 (ranging from 1 to 15), and participant at level 3. Given we are primarily interested in the pure within-person effect of sleep duration on affective experiences, continuous (Enders & Tofighi, 2007) level 2 predictors were participant-mean centered. Each participant's average sleep duration, being the sole Level 3 predictor, was grand-mean centered to facilitate interpretation of model coefficients. Dependent variables (next day affective experiences) remained in their original metric. In the following, we detail equations that are particularly helpful for understanding our findings. All remaining equations that underlie our multiverse analyses (e.g., those that include covariates, or contain fixed slopes) are available at our osf page.

We first investigated the degree of variance at each level via an intercept-only model for each affective experience:

$$AffectExp_{ijk} = \gamma_{000} + u_{0k} + u_{0jk} + e_{ijk} \tag{1}$$

where $AffectExp_{ijk}$ represents the affective experience for the ith observation on the jth day for the kth participant, γ_{000} represents the grand mean for the affective experience, u_{0k} represents the participant-level residual for the affective experience, u_{0jk} represents the day-level residual, and e_{ijk} represents the level 1 residual.

Then, representing the first step in our multiverse analyses, we constructed models to investigate whether an increased sleep duration promotes more positive affective experiences the following day (Hypothesis 1):

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + u_{0k} + u_{0jk} \\ &+ \gamma_{110}\text{SleepDuration}_{jk} \\ &+ u_{1k}\text{SleepDuration}_{jk} + e_{ijk} \end{aligned} \tag{2}$$

where sleep duration is included as a day-level predictor ($\text{SleepDuration}_{jk}$) with a random slope across participants (u_{1k}). Sleep duration was calculated from the reported going to sleep and waking up times in the first questionnaire of each day. Sleep duration data was excluded if going to sleep time was reported as between 6am and 6pm (108 datapoints) because we were concerned with night-time sleep effects only. Following, extreme sleep data was found with respect to duration, with 14 and 19 datapoints depicting a sleep duration of greater than 12 hrs and less than 2 hrs, respectively. Given this extreme data represents a small percentage of the overall dataset (0.30% of datapoints), and that it is plausible they yet represent the participant's actual sleep duration, these extreme data were retained for all analyses. Each sleep duration value was copied from the first ESM questionnaire of the day to other rows within that day. To model Equation 2 with the multiverse iteration whereby affective experience autoregression effects were controlled for, we created a variable representing the mean affective experience for a participant within a day (average across each of the six daily questionnaires). This affective experience value was then copied to the next day within each participant.

Next, we constructed models to investigate whether any positive impact of sleep duration on next day affective experiences may actually be more nonlinear than linear, such that an extra hour sleep at higher sleep amounts exerts a lesser impact than an extra hour sleep at lower sleep amounts (Hypothesis 2):

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + u_{0k} + u_{0jk} + \gamma_{110}\text{SleepDuration}_{jk} \\ &+ u_{1k}\text{SleepDuration}_{jk} + \gamma_{210}\text{SleepDuration}^2_{jk} \\ &+ u_{2k}\text{SleepDuration}^2_{jk} + e_{ijk} \end{aligned} \tag{3}$$

where a quadratic term ($\gamma_{210}\text{SleepDuration}^2_{jk}$) is included alongside an associated random slope (u_{2k}). If a model revealed a significant nonlinear effect, we established whether the estimated 'turning point' (i.e., the sleep duration value where the effect was predicted to change direction - which must result when nonlinearity is modelled with a quadratic term) occurred well within the range of sleep duration values reported in our sample. This enabled us to support an effect direction change, or rather, whether the effect just gets stronger or weaker as sleep duration varies but *without* any realistic direction change (Simonsohn, 2018). Approximately 90.64% of sleep duration data within our sample lay within 1.5hr of each participant's mean sleep duration. Hence, we concluded that a significant quadratic effect supported an effect direction change if the turning point was within this range. The turning point was calculated as follows (for more details, see Simonsohn, 2018):

$$-\frac{a}{2b} \tag{4}$$

where *a* refers to the estimated linear effect of sleep duration on an affective experience (γ_{110} specified in Equation 3), and *b* refers to the estimated nonlinear effect (γ_{210} in Equation 3). As a sensitivity check, a two-line test was additionally conducted. According to Simonsohn (2018), using a quadratic term to test for an effect sign change is not ideal for a quadratic term tests a very particular functional form whereby y values are proportional to the square of the x values. Thus, testing for a sign-change with a quadratic term can elevate the false positive rate. In contrast, a two-line test–which here refers to examining sleep duration effects separately on data both sides of the turning point–can support a hypothesized effect direction change if both sleep duration effects are significant and in opposite directions (Simonsohn, 2018).

Three variables were created to conduct the two-line test. 'XLow' was calculated by subtracting the turning point value from each sleep duration value below the turning point. If sleep duration was above the turning point it was given the value '0'. 'XHigh' was calculated by subtracting the turning point value from each sleep duration value above the turning point. If sleep duration was below the turning point, it was given the value '0'. Finally, 'High' was allocated the value '1' if sleep duration was greater than the turning point, otherwise it was given the value '0'. These predictors were then added to our model:

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + u_{0k} + u_{0jk} + \gamma_{110}\text{XLow}_{jk} \\ &+ u_{1k}\text{XLow}_{jk} + \gamma_{210}\text{XHigh}_{jk} + u_{2k}\text{XHigh}_{jk} \\ &+ \gamma_{310}\text{High}_{jk} + u_{3k}\text{High}_{jk} + e_{ijk} \end{aligned} \tag{5}$$

where linear and quadratic sleep duration variables were replaced with these variables (XLow_{jk}, XHigh_{jk} and High_{jk}). Significant effects in opposite directions for variables XLow and XHigh effects were considered supportive of a sleep duration effect on an affective experience that changes direction.

Following, we investigated whether the *linear* impact of sleep duration on next day affective experiences is stronger for people that get less sleep on average, which is plausible if the relation between sleep duration and an affective experience is determined to be nonlinear in the theorized direction (Hypothesis 3):

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + \gamma_{100}\text{MeanSleepDuration}_{k} + u_{00k} \\ &+ u_{0jk} + \gamma_{210}\text{SleepDuration}_{jk} \\ &+ u_{2k}\text{SleepDuration}_{jk} \\ &+ \gamma_{310}\text{MeanSleepDuration}_{k} \\ &\cdot \text{SleepDuration}_{jk} + e_{ijk} \end{aligned} \tag{6}$$

where a participant's mean sleep duration is included as a predictor of their mean affective experience ($\text{Mean SleepDuration}_k$), and an interaction term is included to test whether a within-person relation between sleep duration and an affective experience varies across people in relation to their mean sleep duration ($\gamma_{310}\text{MeanSleepDuration}_k \cdot \text{SleepDuration}_{jk}$).

Following these formal hypothesis tests, we explored whether the linear relation between sleep duration and the affective experience differs on weekend days relative to weekdays:

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + u_{0k} + u_{0jk} + \gamma_{110}\text{SleepDuration}_{jk} \\ &+ u_{1k}\text{SleepDuration}_{jk} + \gamma_{210}\text{Weekend}_{jk} \\ &+ u_{2k}\text{Weekend}_{jk} + \gamma_{310}\text{Weekend}_{jk} \\ &\cdot \text{SleepDuration}_{jk} + e_{ijk} \end{aligned} \tag{7}$$

where γ_{000} represents the expected affective experiences on weekdays, $\text{SleepDuration}_{jk}$ represents the effect of sleep on an affective experience on weekdays, $\gamma_{210}\text{Weekend}_{jk}$ represents the change in a person's affective experience from a weekday to a weekend day when sleep duration was at a person's mean, and $\gamma_{310}\text{Weekend}_{jk} \cdot \text{SleepDuration}_{jk}$ represents the change in the impact of sleep on an affective experience from a weekday to a weekend day.

Finally, we explored whether the effect of sleep duration on next day affective experiences is greater in the period soon after waking, relative to later in the day:

$$\begin{aligned} AffectExp_{ijk} = &\gamma_{000} + u_{0k} + u_{0jk} + \gamma_{110}\text{SleepDuration}_{jk} \\ &+ u_{1k}\text{SleepDuration}_{jk} \\ &+ \gamma_{220}\text{QNum}_{ijk} + u_{2k}\text{QNum}_{ijk} \\ &+ \gamma_{310}\text{QNum}_{ijk} \cdot \text{SleepDuration}_{jk} \\ &+ e_{ijk} \end{aligned} \tag{8}$$

where γ_{000} represents the expected affective experience soon after waking, $\gamma_{110}\text{SleepDuration}_{jk}$ represents the effect of sleep on an affective experience soon after waking, $\gamma_{200}\text{QNum}_{ijk}$ represents the change in a person's affective experience from the period soon after waking to later in the day when sleep duration was at a person's mean (to manage our equation length, QNum represents five dummy variables reflecting how the affective experience changes from soon after waking to late morning, early afternoon, etc.), and $\gamma_{310}\text{QNum}_{ijk} \cdot \text{SleepDuration}_{jk}$ represents the change in the impact of sleep on an affective experience from soon after waking to later in the day.

All reported effect sizes are unstandardized. Two-tailed tests were used for all analyses, with alpha set at .05. However, given this study's exploratory nature, and the use of multiverse analyses, effects were only considered supported after careful and nuanced examination of effects from all analyses. In instances where nonsignificant effects are identified, we do not consider the effect absent, but rather to have simply not been found (see Bakan, 1966 for details).

Results

Descriptive Findings and Preliminary Analyses

For the 1,415 participants included in formal analyses, 68,232 questionnaires were completed in full, which equates to 48.22 questionnaires completed on average per participant (57.72% of questionnaires received). The compliance rate across questionnaires one to six that participants received each day was 58.61%, 58.79%, 58.34%, 58.55%, 58.96%, and 52.91% questionnaires completed, respectively. Of note, 102 (7.21%) and 202 (14.28%) participants completed less than 8 and 16 ESM questionnaires, respectively. Also, each questionnaire took a median of 93 sec to complete, with 2,821 questionnaires completed in less than 45 sec.

Table 1 presents a descriptive summary and correlation analysis of key study variables from all data available. This table depicts participants on average reported sleeping a typical number of hours (approximately 8 hr), and that they were not mentally fatigued, stressed, anxious, or despondent. They also reported, on average, that it was neither true or untrue that they were happy or calm.

Intercept-only models support the data's hierarchical structure, with variance across affective experiences ranging between 43% and 70% at the observation level (level 1), 0% and 1% at the day level (level 2), and 30% and 57% at the participant level (level 3).

Main Analyses

Does Sleeping More at Night Promote More Positive Next Day Affective Experiences?

See Figure 1 for multiverse analyses results (see Supplementary Materials Tables 1 to 6 for more detailed overview). Overall across affective experiences, 79.55% of 3,360 models concluded that sleep duration significantly promotes a more positive next-day affective experience, with the mean (unstandardized) b of these significant effects being $\pm$ 0.06. No models revealed a significant effect in the opposite direction.

This effect was particularly robust when the focal affective experience was mental fatigue (86.43% of models revealed significant effect in theorized direction, mean b = -0.07), stress (93.21% of models, mean b = -0.07), happiness (84.46% of models, mean b = 0.04), and calmness (95.71% of models, mean b = 0.09), with the effect being more fragile for anxiety (53.21% of models, mean b = -0.03) and despondence (64.29% of models, mean b = -0.03). The effect was also particularly robust when the affective experience was measured in the brief period after waking (questionnaire 1; 96.46% of models revealed significant effect, mean b = $\pm$ 0.07), late afternoon (questionnaire 4; 86.67% of models, mean b = $\pm$ 0.07), early evening (questionnaire 5; 82.08% of models, mean b = $\pm$ 0.06), and late evening (questionnaire 6; 90.21% of models, mean b = $\pm$ 0.05), with the effect being more fragile when the affective experience was measured at late morning (questionnaire 2; 56.25% of models, mean b = $\pm$ 0.06) and early afternoon (questionnaire 3; 51.67% of models, mean b = $\pm$ 0.06). See Figure 2 for a visual depiction of how the average effect of sleep differed across the day for each affective experience.

Finally, the effect was particularly robust across models that did *not* control for a potential confound–whether the day in question was a weekday or a weekend day (90.83% of 1,680 models demonstrated a significant effect, vs. 68.27% when weekday/weekend was controlled for, mean b = 0.07 vs. 0.05). A similar pattern was revealed when considering only fatigue (100% vs. 72.86% of models demonstrated significant effect, mean b = -0.08 vs. -0.06), stress (100% vs. 86.43%, mean b = -0.09 vs. -0.06) happiness (100% vs. 68.93%, mean b = 0.05 vs. 0.03), anxiety (68.57% vs. 37.86%, mean b = -0.03 vs. -0.02), despondence (76.43% vs. 52.14%, mean b = -0.04 vs. -0.03), calmness (100% vs. 91.43%, mean b = 0.11 vs. 0.07), the period soon after waking (100% vs. 92.92% of 240 models, mean b = $\pm$ 0.08 vs. 0.06), late morning (87.50% vs. 25%, mean b = $\pm$ 0.06 vs. 0.05), early afternoon (66.67% vs. 36.67%, mean b = $\pm$ 0.07 vs. 0.05), late afternoon (92.50% vs. 80.83%, mean b = $\pm$ 0.08 vs. 0.05), early evening (89.17% vs. 75%, mean b = $\pm$ 0.07 vs. 0.05), and late evening (100% vs. 80.42%, mean b = $\pm$ 0.06 vs. 0.04).

Collectively, our results support Hypothesis 1: that getting more sleep at night promotes more positive next day affective experiences. They also reveal that the effect of sleep on next day affective experiences is most robust in the period soon after waking (although robust evidence also exists for an effect later in the day), for the affective experiences fatigue, stress, happiness, and calmness (relative to anxiety and despondence), and when weekday/weekend was not controlled for. Another broad theme is that getting an extra hour sleep likely only exerts a small effect on next day affective experiences, with a one hour increase in sleep duration predicted to promote an effect ($\pm$) generally ranging between 0.01 and 0.16.

The noted descriptive differences in the effect between sleep duration and affective experiences in relation to when the affective experience was reported–a finding highlighted visually in Figure 1–suggest that the effect of sleep on next day affective experiences may be *stronger* in the brief period after waking relative to other periods of the day. We thus modelled this interaction possibility to investigate further (see Supplementary Materials Tables 7 to 36 for more detailed overview). Overall, in 31.83% of models the relationship between sleep and an affective experience was predicted to be significantly different when the affective experience was reported in the brief period after waking relative to later in the day. Most important, 100% of these significant interaction effects indicated a stronger sleep duration effect in the brief period after waking relative to later in the day, with a mean b = $\pm$ 0.05. Stronger evidence for this effect was found when mental fatigue (59.25% of models revealed significant effect in theorized direction, mean b = 0.06), stress (53.25% of models, mean b = 0.05), and calmness (56.25% of models, mean b = 0.06) were the focal affective experiences, with less support for happiness (0% of models), anxiety (20.50% of models, mean b = 0.03), and despondence (1.75% of models, mean b = 0.04). Evidence for this effect was more robust when considering the in-

Table 1. Within- and Between-Person Correlations of Key Study Variables Based Upon All Available Data

Variable	Mean	SD	Min	Max	ICC	1	2	3	4	5	6	7
Sleep Duration (hrs)	8.05	0.91	6.77	9.27	0.30	-	0.01	-0.01	-0.02	0.02	0.04	0.03
Mental Fatigue	2.81	0.75	1.96	3.88	0.49	-0.1***	-	0.79***	-0.66***	0.69***	0.82***	-0.72***
Stress	2.86	0.79	1.94	3.98	0.41	-0.11***	0.62***	-	-0.62***	0.72***	0.74***	-0.76***
Happiness	4.86	0.62	3.97	5.63	0.40	0.08***	-0.59***	-0.57***	-	-0.54***	-0.68***	0.78***
Anxiety	1.98	0.44	1.53	2.66	0.57	-0.05***	0.46***	0.51***	-0.43***	-	0.77***	-0.59***
Despondance	2.29	0.59	1.67	3.21	0.50	-0.05***	0.66***	0.55***	-0.63***	0.55***	-	-0.67***
Calmness	4.69	0.76	3.63	5.66	0.30	0.14***	-0.6***	-0.71***	0.69***	-0.44***	-0.54***	-

Note. *** $p < 0.001$. Within- and between-person correlation coefficients depicted below and above the diagonal, respectively. 'Within' refers to the day-level rather than the observation-level. All affective experience variables have a possible range of 1 to 7. 'Mean', 'SD', 'Min', and 'Max' refer to the mean of the participants' Mean, SD, Min, and Max, respectively. ICC refers to variance explained at participant level, with remainder explained at observation-level (variance explained at day level generally less than 1 percent for each variable). Within- and between-person correlations calculated from 10,872 and 1,343 datapoints, respectively.

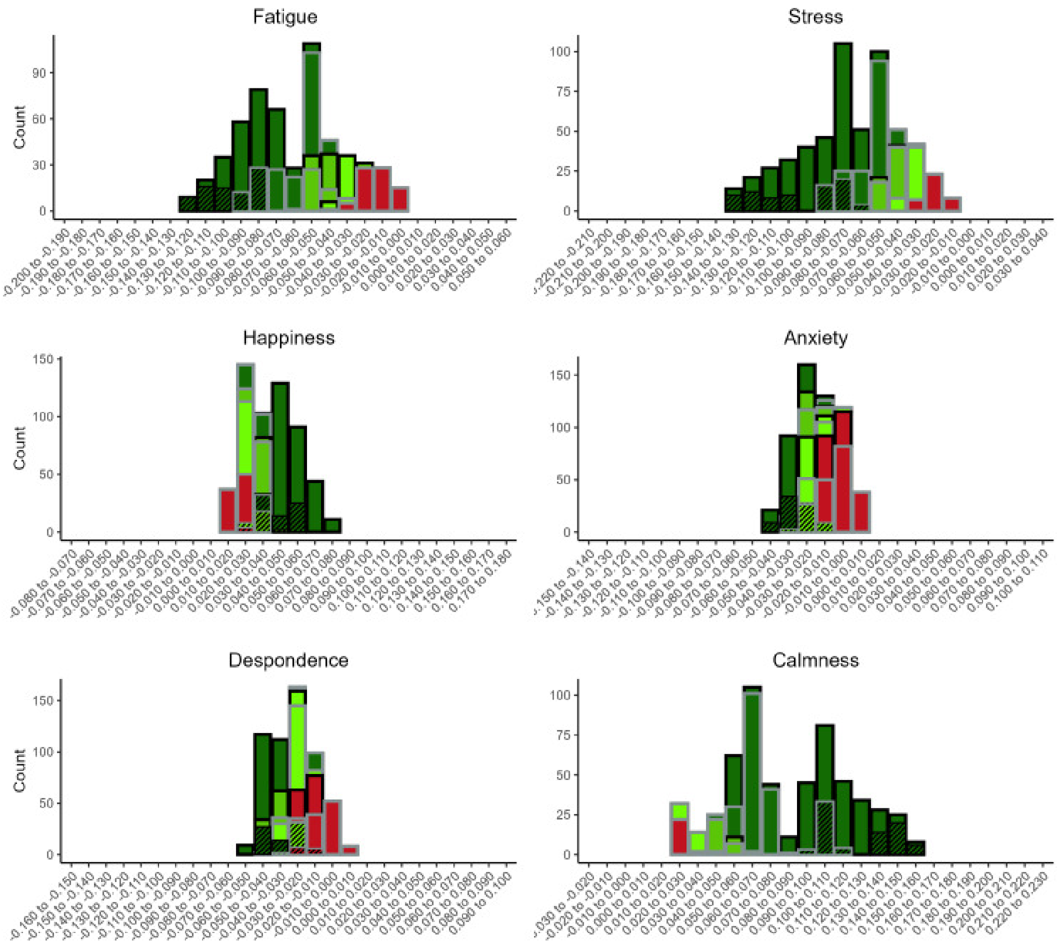

Figure 1. Multiverse Analyses of the Linear Relationship Between Sleep Duration and Next Day Affective Experiences

Note. The x-axis depicts the unstandardized b for the relation between sleep duration and the focal affective experience. The y-axis depicts the number of models that had an effect within the specified parameter. Where bars are dark, normal, and light green, they indicate the effect from the model had a significance value that was less than or equal to .001, .01, and .05, respectively. Where the bars are red the model indicates nonsignificance at .05 level. A grey and black border depict that the influence of weekday/weekend was/was not controlled for. Bars that are/are not striped depict data that was/was not from the first questionnaire after waking.

teraction between effects from the brief period after waking to early afternoon (49.38% of models revealed significant effect in theorized direction, mean $b = \pm 0.05$) and late evening (48.96% of models, mean $b = \pm 0.06$) relative to late morning (32.08% of models, mean $b = \pm 0.06$), late afternoon (0.83% of models, mean $b = \pm 0.04$), and early evening (27.92% of models, mean $b = \pm 0.05$). Finally, more robust evidence for this interaction effect was not found in models that did not control for whether the day in question was a weekday or a weekend day (31.50% of models, mean $b = \pm 0.05$, vs. 32.17% of models where weekday/weekend was controlled for, mean $b = \pm 0.05$).

Our data suggested that the relationship between sleep duration and an affective experience may be partially explained by whether or not sleep and affective experience data is provided on a weekday instead of a weekend day (we also depict this visually in Figure 1). We thus investigated this possibility inferentially (see Supplementary Materials Tables 37 to 42 for more detailed overview). Overall, 6.13% of models indicate that weekday/weekend day significantly moderates the effect of sleep duration on an affective experience. Of these significant interaction effects, 39.81% in-

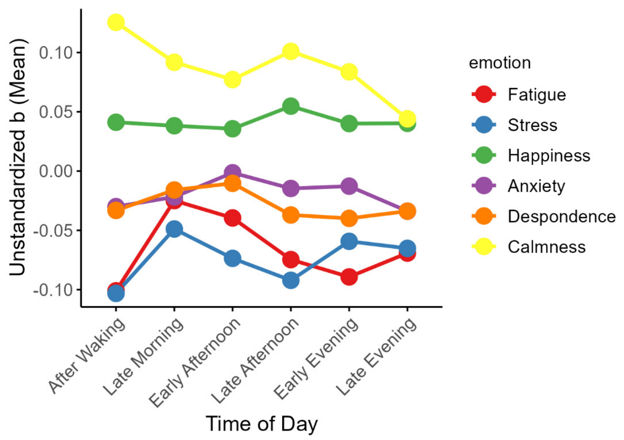

Figure 2. Mean Sleep Duration Effects on Affective Experiences Throughout Day

Note. Mean unstandardized b values from all models investigating the linear effect of sleep duration on next day affective experiences. X-axis labels refer to questionnaire 1 to 6 received each day, respectively.

dicated that the effect of sleep duration on affective experiences is stronger at the weekend relative to weekdays (mean $b = \pm 0.05$), and 60.19% indicated an effect in the opposite direction (mean $b = \pm 0.06$).

Finally, descriptively across affective experiences there is no clear evidence of effect magnitude differences due to any of the other analytic choices taken (e.g., after excluding non-workers, or questionnaires completed in less than 45 seconds, etc.).

Is the Positive Impact of Sleep on Affective Experiences Stronger/Weaker at Higher/Lower Sleep Durations, and May the Effect Change Direction?

See Figure 3 for multiverse results (see Supplementary Materials Tables 43 to 48 for more detailed overview). Overall across affective experiences, 25.39% of 3,360 models concluded that sleep duration *nonlinearly* promotes a more positive next-day affective experience, with the mean b of these significant nonlinear effects being 0.02. No models revealed that sleep duration nonlinearly promotes a more *negative* next-day affective experience. Concerning the significant nonlinear effects, all translated as sleep exerting a more adaptive affective response at higher sleep amounts, such that, for instance, getting 9 instead of 8hr sleep will reduce stress more than getting 7 instead of 6hr sleep. Interestingly, only 7.20% of models revealed a significant nonlinear effect with a turning point within sleep data range (i.e., within 1.5hrs of each participant's mean sleep duration), thus giving less support to the idea that sleep duration effects change direction at higher absolute sleep amounts. This conclusion is supported following two-line test sensitivity analyses, whereby only 0.21% of significant within-range quadratic effects gained this additional support.

Upon closer inspection, the most robust evidence for a nonlinear relationship is revealed when the focal affective experience is stress (46.07% of models found significant nonlinear effect, mean b = -0.02) and calmness (42.68% of models, mean b = 0.02), with 22.09% and 27.20% of these effects within sleep duration data range. More fragile evidence exists for the affective experiences fatigue (12.50% of models, mean b = -0.02), happiness (20.71% of models, mean b = 0.02), anxiety (21.43% of models, mean b = -0.01), and despondence (8.93% of models, mean b = -0.02), with 30%, 30.17%, 21.67%, and 76% of these effects within sleep duration data range. The most robust evidence for a nonlinear relationship is also revealed when the affective experience was reported in early afternoon (22.86% of models, mean b = 0.02) and late evening (34.82% of models, mean b = 0.01), with 51.56% and 13.33% of these effects within sleep duration data range. A nonlinearity effect was more fragile when a relationship was reported in the brief period after waking (5.18% of models, mean b = 0.03), late morning (13.39% of models, mean b = 0.02), late afternoon (15% of models, mean b = 0.03), and early evening (15.36% of models, mean b = 0.02), with 0%, 1.33%, 8.33%, and 4.65% of these effects within sleep duration data range.

Finally, the most robust evidence for a nonlinear relationship is also revealed in models that did not control for whether the day in question was a weekday or a weekend day (41.25% of 1680 models demonstrated a significant effect, vs. 9.52% when weekday/weekend was controlled for). A similar pattern was revealed when considering only fatigue (24.64% vs. 0.36% of models demonstrated significant effect), stress (70% vs. 22.14%) happiness (38.57% vs. 2.86%), anxiety (28.93% vs. 13.93%), despondence (17.14% vs. 0.71%), calmness (68.21% vs. 17.14%), the period soon after waking (9.58% vs. 2.50% of 240 models), late morning (31.25% vs. 0%), early afternoon (38.75% vs. 14.58%), late afternoon (35% vs. 0%), early evening (35.83% vs. 0%), and late evening (58.75% vs. 22.50%).

Collectively, our findings do not support Hypothesis 2, which maintains that the positive effect of increased sleep on next day affective experiences is less at higher (relative to lower) absolute sleep amounts. They also offer little support for an effect in the opposite direction, particularly given most significant nonlinear effects are revealed in models that do not control for a possible confounder–whether the day in question was a weekday or a weekend day.

Is the Positive Impact of Sleep Duration on Next Day Affective Experiences Weaker for People that Get More Sleep on Average?

See Figure 4 for multiverse analyses results (see Supplementary Materials Tables 49 to 54 for more detailed overview). Overall across affective experiences, 19.76% of 3,360 models estimated that a person's average sleep duration significantly moderates the within-person relation between sleep duration and their next day affective experience. Of these significant effects, 69.58% were 'just' significant (i.e., p value between .01 and .05). Interestingly, 93.37% of these significant effects indicated that sleep exerts a more positive affective impact the next day for people that sleep *less* on average.

Investigating these significant interaction effects further, our findings reveal that evidence for an interaction effect was most robust when the focal emotion is mental fatigue (45.18% of models found significant effect, with 100% of these indicating effects are stronger for people that generally sleep less) and despondence (39.46% of models found significant effect, with 100% of these indicating effects are stronger for people that generally sleep less). Evidence for an interaction effect was much more fragile when the focal emotion is stress (4.46% of models found significant effect), happiness (13.93% of models found significant effect), anxiety (5.54% of models found significant effect), and calmness (10% of models found significant effect). Our findings also demonstrate that a sleep-affective experience interaction effect was most robust when the affective experience was reported in the period after waking (25.21% of models found a significant effect), early afternoon (36.46%), and late evening (21.25% of models found a significant effect), with the interaction effect being more fragile when the affective experience was reported in late morning, late afternoon, and early evening (13.33%, 4.58%, and 1.25% of models found a significant effect).

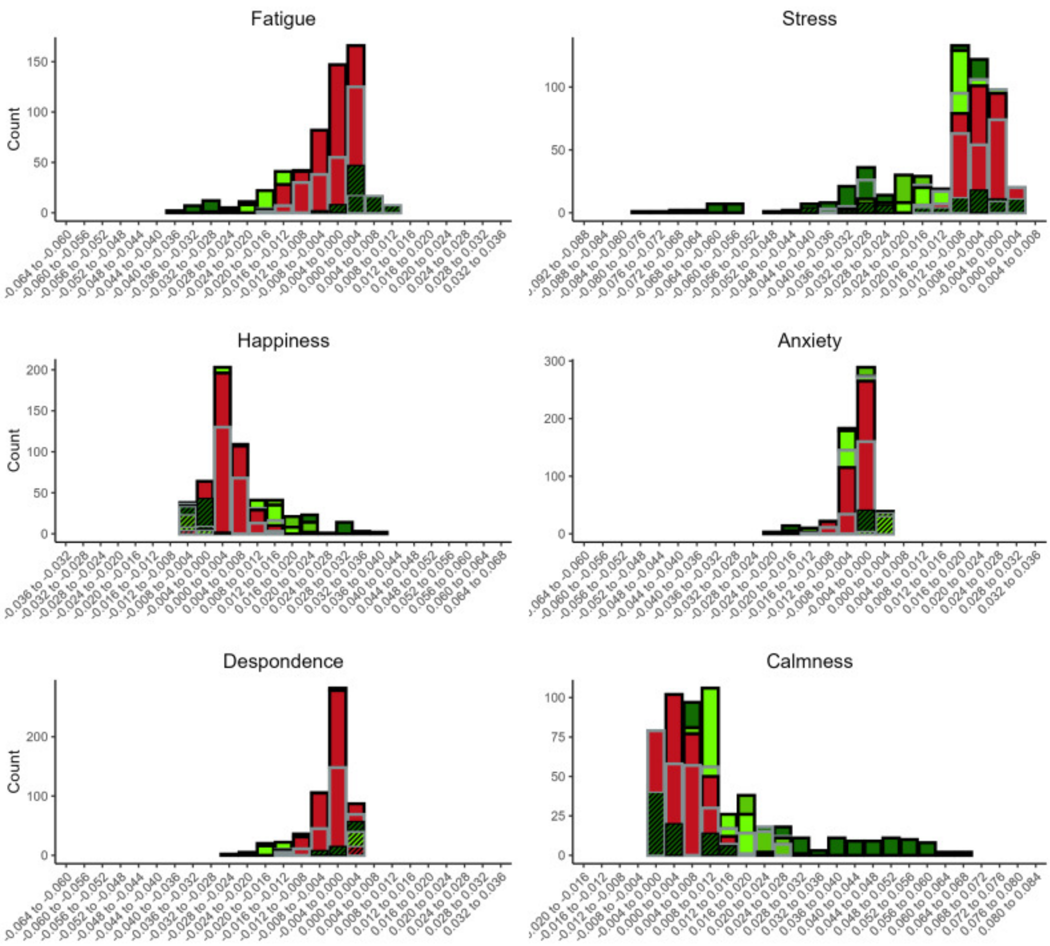

Figure 3. Multiverse Analyses Investigating Whether the Relationship Between Sleep Duration and Next Day Affective Experiences is Nonlinear

Note. The x-axis depicts the unstandardized b nonlinear (quadratic) effect, with positive and negative effects reflecting a u- and inverted u-shape, respectively. The y-axis depicts the number of models that had an effect within the specified parameter. Where bars are dark, normal, and light green, they indicate the effect from the model had a significance value that was less than or equal to .001, .01, and .05, respectively. Where the bars are red the model indicates nonsignificance at .05 level. A grey and black border depict that the influence of weekday/weekend was/was not controlled for. Bars that are/are not striped depict data that was/was not from the first questionnaire after waking.

Finally, the interaction effect was not more robust from models that did not control for whether the day in question was a weekday or a weekend day. Rather, the interaction effect was slightly more robust when weekday/weekend *is* controlled for (14.94% of 1680 models demonstrated a significant effect, vs. 24.58% when weekday/weekend was controlled for). A similar pattern was revealed when considering only fatigue (29.29% vs. 61.07% of models demonstrated significant effect), stress (6.07% vs. 2.86%) happiness (11.43% vs. 16.43%), anxiety (6.07% vs. 5%), despondence (30.71% vs. 48.21%), calmness (6.07% vs. 13.93%), the period soon after waking (14.17% vs. 36.25% of 240 models), late morning (7.92% vs. 18.75%), early afternoon (30.42% vs. 42.50%), late afternoon (8.75% vs. 0.42%), early evening (0% vs. 2.50%), and late evening (15.83% vs. 26.67%).

Collectively, our findings provide minimal support for Hypothesis 3, in that they give some support to the idea that an increase in sleep for people that generally sleep less will promote a greater reduction in both fatigue and despondence the following day, relative to their counterparts that generally sleep for longer. The large number of effects that were ‘just’ significant, and the lack of model support for other affective experiences, or these affective experiences at particular timepoints the next day, prevents our claiming of stronger support for Hypothesis 3.

Discussion

The effect of sleep duration on next day affective experience is a topic that has garnered significant attention in everyday discussions and academic inquiries (Callahan, 2023; Walker, 2009). However, a solid understanding of this relationship is still lacking. Accordingly, the present study leveraged a large ecologically valid dataset–well placed to provide accurate insights into the affective effects of *normal* sleep deviations–to conduct a high-quality investigation of the effects of sleep duration on next day affective experiences. Overall, our findings strongly support that increased sleep at night promotes more positive affective experiences the next day. Also, analyses identified various important and novel nuances to this relationship, which we elaborate on in the next section. Interestingly, we also found some evidence (very tentatively) suggesting that a set sleep in-

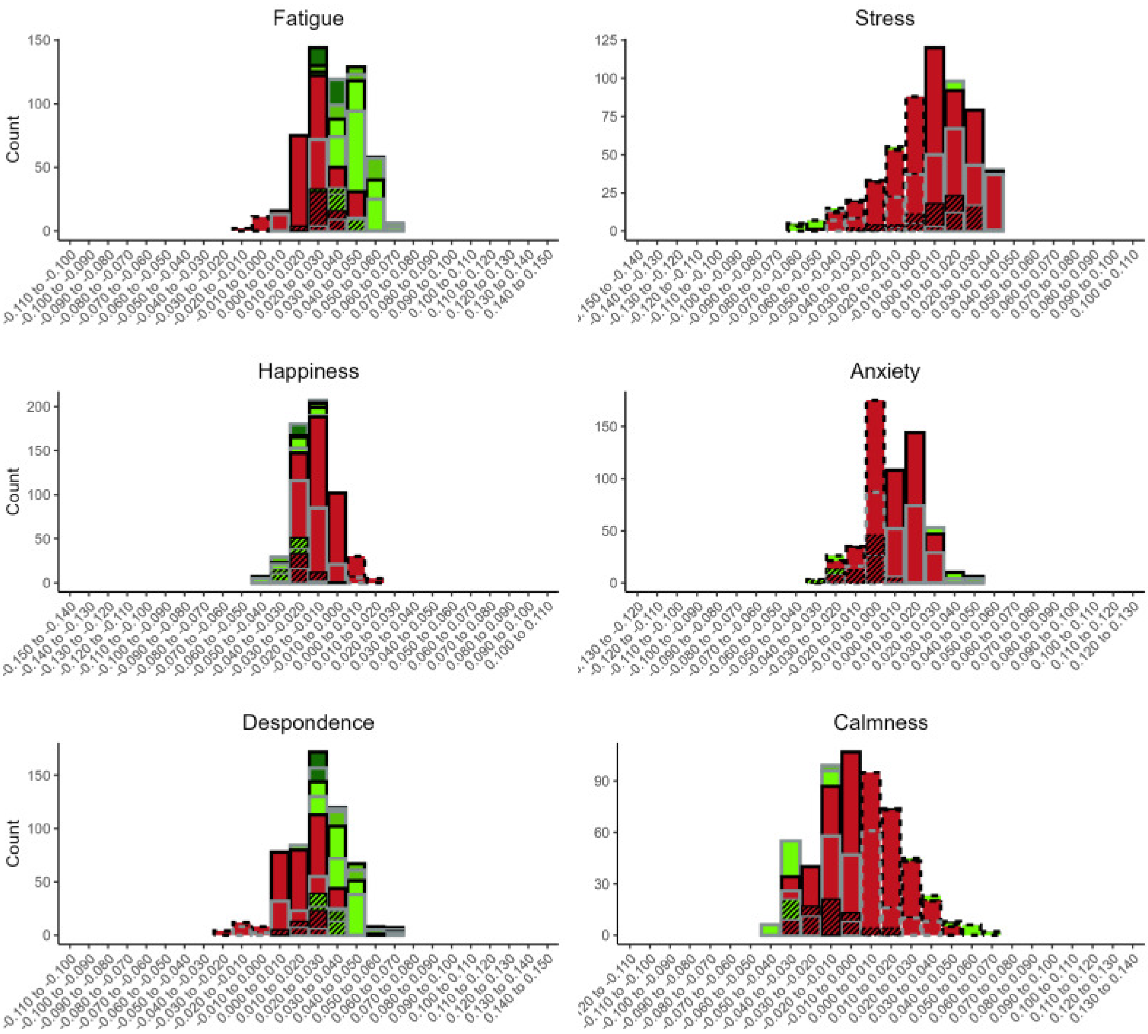

Figure 4. Multiverse Analyses Investigating Whether Person-Average Sleep Duration Moderates the Relationship Between Sleep Duration and Next Day Affective Experiences

Note. The x-axis depicts the unstandardized b for the relation between sleep duration and the focal affective experience. The y-axis depicts the number of models that had an effect within the specified parameter. Where bars are dark, normal, and light green, they indicate the effect from the model had a significance value that was less than or equal to .001, .01, and .05, respectively. Where the bars are red the model indicates nonsignificance at .05 level. A grey and black border depict that the influence of weekday/weekend was/was not controlled for. Bars that are/are not striped depict data that was/was not from the first questionnaire after waking. Bars with borders that are dashed instead of solid indicate models that predict an interaction effect in the opposite direction to hypothesized. E.g., that the negative sleep-stress relationship was predicted to be stronger for people with a greater typical sleep duration.

crease may reduce fatigue and despondence more in people that *generally* sleep less (partial support for Hypothesis 3). Surprisingly, however, analyses did not reveal convincing evidence that the sleep-affect relationship is nonlinear (Hypothesis 2), thus contrasting with prior literature that has supported this effect (Barber et al., 2023).

Theoretical and Applied Implications

Given a comprehensive understanding of the link between sleep and affective experiences does not exist, our findings indicating that even small increases in sleep at night (i.e., sleep increases within a normal range) promote more positive affective experiences the following day represents a valuable empirical contribution. This is evident considering our rigorous methodology (e.g., multiverse analyses, alleviation of recall bias concerns, large sample size), which is arguably better placed to capture true population effect magnitudes than prior research that leveraged small (Konjarski et al., 2018) and student (Das-Friebel et al., 2020) samples, and that did not implement safeguards (e.g., preregistration, multiverse/sensitivity analyses) to prevent false positives and effect overestimation (e.g., Barber et al., 2023; Newman et al., 2023). It is also evident given effects in most instances were supported regardless of multiverse iteration (e.g., testing for effects after modelling/not modelling possible confounds, random slopes, etc.). On this point, while sleep was found to impact mental fatigue, stress, happiness, and calmness at most timepoints the following day, our findings are clear that sleep very likely impacts *all* affective experiences of interest in this study in the brief period after waking (92.92% of models supported across affective experiences, and after controlling for the likely confound weekday/weekend). Collectively, our findings broadly accord with extant research, both for the effects' direction (Barber et al., 2023; Konjarski et al., 2018; Tomaso et al., 2020), and magnitude (which on the whole are likely small, Newman et al., 2023), thus giving them additional weight. Our findings also broadly signal that getting a reduced–but still typical–amount of sleep at night will generally not be so impactful (e.g., a 1 hour reduction in sleep predicted to increase stress on average soon after waking by 0.10, in relation to the item 'Since waking up, I felt stressed' and a response scale ranging from 1 'Not true at all' to 7 'Absolutely true').

Zooming in, our findings reveal some nuances to the linear link between sleep and next-day affective experiences that had yet to be convincingly uncovered by prior literature. First, our results make clear that the magnitude of the impact sleep has is inextricably tied to the affective experience in question. For instance, models based upon the period soon after waking estimate that a 1-hour sleep duration increase likely impacts mental fatigue, stress, and calmness approximately two to three times as much as happiness, anxiety, and despondence. Moreover, while the impact of sleep on mental fatigue and stress reduces substantially from soon after waking until later in the morning (see Figure 2), the reduction in the impact of sleep on other affective experiences is less discernible.

Effect magnitude differences across affective experiences can be assumed *without* empirical evidence, for perfect parity in effect magnitudes is rare in nature (Tukey, 1991). However, evidence is needed to support claims about the specific nature of these differences, and these are the novel insights our research provides. What can explain the effect magnitude differences across affective experiences? The most likely reason sleep deviations affect mental fatigue, stress, and calmness more than happiness, anxiety, and despondence is that the latter are arguably less determined by the core affective response theorized to result from sleep deviations (Kahn et al., 2013). Much research demonstrates that when people report on their happiness, in addition to how they feel affectively in that moment, they often take into account their wellbeing or satisfaction with life more broadly (Diener et al., 2018; Oishi & Westgate, 2022). Similarly, anxiety may be more trait-like than some of the other affective experiences considered (e.g., Pawluk et al., 2021 supported that people without generalized anxiety disorder experience relative stability in their anxiety levels throughout the day), while despondence is a particularly complex affective state additionally influenced by social, cognitive, and personality factors. It is these more complex facets of happiness, anxiety, and despondence that likely limits the impact sleep has, and underpins the smaller effect sizes and stability in effect sizes that seem apparent across the day (Figure 2).

Second, models that examined linear effects suggest sleep duration exerts a stronger affective response in the brief period after waking relative to later in the day, for 100% of models that found a significant interaction effect indicated this. While we did not strictly hypothesize this effect, it is one that aligns with anecdotal evidence of when sleep is particularly influential to how we feel. Moreover, it seems clear that as people move through their day they have more opportunities to regulate the affective consequences of reduced sleep, for instance, by drinking coffee, engaging in more affectively pleasant activities, or taking a nap. Empirical evidence also supports this finding of sleep being more affectively impactful soon after waking (Das-Friebel et al., 2020; Könen et al., 2016). Nevertheless, there is important detail with this identified effect that should be considered. Although many models supported this interaction effect for mental fatigue (59.25% of models), stress (53.25% of models), and calmness (56.25% of models), very few (or no models) supported this effect for happiness (0% of models), anxiety (20.50% of models), and despondence (1.75% of models). Also, while many models supported this interaction effect when the comparator was the period early afternoon (49.38% of models) and late evening (48.96% of models), few models supported this effect in relation to the period late morning (32.08% of models), late afternoon (0.83% of models), and early evening (27.92% of models). It is very possible this lack of support simply represents a statistical power issue (i.e., we need more data to find effects that accord with the direction of our significant findings. After all, 100% of significant interaction effects are in the expected direction). However, it cannot be discounted that with more data we may identify effects in the opposite direction.

Third, some models supported that the impact of sleep on affective experiences is greater in people that *generally* sleep less (of 19.76% of models that identified a significant effect, 93.37% were in the stated direction). We hypothesized this effect given anecdotal evidence, theory (Ferrara & De Gennaro, 2001), and empirical research (Barber et al., 2023; Palmer et al., 2024) highlights that the benefits of sleep should eventually attenuate, and that human beings need a minimal sleep amount to not accumulate sleep debt (Ferrara & De Gennaro, 2001). However, given approximately 70% of significant interaction effects were only 'just' significant, and that very many models found no support for this effect, considerable caution should be taken when interpreting these findings. Moreover, this effect is most robust in relation to fatigue (45.18% of models), despondence (39.46% of models), and the periods soon after waking (25.21% of models), early afternoon (36.46% of models), and late evening (21.25% of models), with the effect being much more fragile for stress (4.46% of models), happiness (13.93% of models), anxiety (5.54% of models), calmness (10% of models), and the periods late morning (13.33% of models), late afternoon (4.58% of models), and early evening (1.25% of models). It should also be kept in mind that we failed to gain sufficient support for Hypothesis 2–that the link between sleep duration and next day affective experiences is nonlinear (models that controlled for a likely confound–whether the measurement day was a weekday or weekend day–found support to be very fragile across affective experiences). If true that the absolute sleep amount determines how impactful a set sleep increase is, then one would also expect to identify nonlinear relations between sleep duration and affective experiences, which we do not. As per our explanation for the instances where our other interaction effect was not supported (i.e., sleep effect being greater soon after waking relative to later in the day), this may be a statistical power issue. However, this explanation is less plausible for nonlinear effects, for all models that found a significant nonlinear effect found it in the *opposite* direction to that theorized (e.g., the positive impact that increased sleep has on calmness the next day estimated to get *stronger* at higher sleep amounts).

The final major insight our study revealed is methodological in nature. That is, our results highlight clearly the value of leveraging multiverse analyses when investigating not just sleep effects, but psychological or other effects more broadly. By employing this approach, we found we could quickly uncover whether an effect was very likely spurious or not, by cross-checking the finding with other multiverse models that should similarly provide support. It is through this approach that we could arrive at more conservative conclusions as to the existence of any cross-level interaction effect, appraise more accurately the small percent of models that supported the existence of a nonlinear effect, and claim strong support for the idea that failing to control for whether or not the day in question is a weekday or weekend day will generally lead to inflated effect magnitudes. Concerning the latter point, this phenomenon very likely results due to people sleeping more and feeling better at the weekend (*M* sleep duration: 7.95 vs. 8.36; *M* stress: 2.96 vs. 2.4; *M* happiness: 4.81 vs. 5.17), for this reality will bias/strengthen the slope to minimize error variance. Although some prior literature also controlled for this confound when investigating the affective impact of sleep (e.g., Hachenberger et al., 2022), other studies have not (e.g., Newman et al., 2023).

Strengths and Limitations

The present study represents a high-quality test of the influence of sleep on next-day affective experiences for various reasons. First, participants' ability to accurately recall their affective experiences was not heavily hindered given the average recall requirement was the past two to three hours. Second, participants reported their sleep duration and how they felt many times over a 14-day period. This enabled investigating within-person effects. Third, our data was not collected to test a sleep effect, thus limiting demand effects (Orne, 2017). Fourth, we arguably leverage higher quality data than the typical study in this area, for participants were not recruited with financial incentives (these may encourage inattentive responding, see Shamon & Berning, 2019).

Fifth, we investigate sleep effects on various affective experiences, thus enabling better scrutiny of theory proposing a broad connection via core affect. Finally–and perhaps the present study's most notable strength–we used a multiverse approach whereby we run 10,080 models to investigate effects (e.g., with/without covariates/random slope, etc.). Although multiverse analyses is no replacement for study pre-registration (we could not pre-register this study as we had explored data for other research purposes), it is a strength for it helps allay concerns that results may have arisen from selective reporting (Steegen et al., 2016), and given it can enable a more robust test of theory (Clayson, 2024; Richter & Gendolla, 2024). For instance, by testing the link between sleep and affective experiences using only the first questionnaire participants received each day, then the second, then the third, etc–analytic choices that are plausibly defendable–we could hypothetically challenge a claim suggesting that it does not really matter *when* the next day the affective experience is reported.

Concerning limitations, this study's observational nature means it could not robustly test the proposed causal direction of effects. Indeed, it is likely some participants a) chose to sleep longer because they knew the next day would be easier (this would render sleep effects overestimated), and b) chose to sleep less to better prepare for what they knew would otherwise be a stressful day (this would render sleep effects *under*estimated - preparation can reduce stress). High-quality research able to statistically control for or avoid likely confounds (e.g., ecological momentary interventions, Heron & Smyth, 2010), is thus sorely needed. Another limitation is the imperfect validity of measured constructs. Happiness and anxiety are relatively complex affective experiences unable to be perfectly captured with our single items, and sleep duration captured from self-reported going-to-sleep and getting-up times lacks validity in light of the possibility of participant recall errors, and periods of awake time during formal 'sleep time' unknown. We thus welcome similar research able to overcome these issues (sleep duration measured with wearable sensors, e.g., Das-Friebel et al., 2020). Another issue beyond that related to measurement for the affective experiences is that we cannot discount sleep duration may exert markedly different effects on affective experiences not examined (for instance, anger, frustration, cheerfulness). Thus, effect magnitudes in this study that were estimated across affective experiences, or in relation to particular multiverse set-ups, should be interpreted relative to the experiences examined, with caution in interpretations advised beyond this.

Another limitation is that our participant sample contained citizens from a WEIRD (white, educated, industrialized, rich, democratic, Henrich et al., 2010) region - Flanders, Belgium. It is possible our findings (particularly effect magnitudes) do not generalize to individuals from non-WEIRD regions. A further study limitation is that our multiverse may incorrectly convey to readers that our findings are *much* stronger than they actually are. This possible default interpretation may result in light of the sheer number of models that supported effects in our study, and perhaps a tendency to assume that each of our multiverse model iterations differed markedly. The reality, however, is that differences across many (but not all) multiverse models were small (e.g., testing model with and without participants that completed less than 16 questionnaires). We thus caution readers to keep in mind the exact nature of our multiverse parameters when appraising our results. A final limitation is that our findings are unlikely to effectively inform about the effects of extreme sleep deviations, because our data contains minimal extreme sleep data and it is conceivable that effect magnitudes differ as a function of absolute sleep duration. This limitation plagues all observational research investigating this effect, hence, we welcome experimental approaches–particularly that which maximizes ecological validity–to better understand the effects of extreme sleep deviations.

Conclusion

In the present research, our findings reveal that even small increases in sleep duration at night promote more positive affective experiences the following day. Our findings also indicate that sleep exerts its greatest affective impact in the brief period following waking, and for mental fatigue, stress, and calmness, (relative to happiness, anxiety, and despondence).

Author Contributions

Methodology: Stephen L. Murphy (Lead), Kyle Van Gaeveren (Supporting), David De Segovia Vicente (Supporting). Funding acquisition: Stephen L. Murphy (Supporting), Mariek Vanden Abeele (Lead). Conceptualization: Stephen L. Murphy (Lead). Writing – original draft: Stephen L. Murphy (Lead). Writing – review & editing: Stephen L. Murphy (Equal), Kyle Van Gaeveren (Equal), David De Segovia Vicente (Equal), Mariek Vanden Abeele (Equal). Formal Analysis: Stephen L. Murphy (Lead). Visualization: Stephen L. Murphy (Lead), Kyle Van Gaeveren (Supporting). Investigation: Stephen L. Murphy (Equal), Kyle Van Gaeveren (Equal), David De Segovia Vicente (Equal), Mariek Vanden Abeele (Equal). Project administration: Stephen L. Murphy (Supporting), Kyle Van Gaeveren (Supporting), David De Segovia Vicente (Supporting), Mariek Vanden Abeele (Lead). Data curation: Kyle Van Gaeveren (Lead).

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Competing Interests

The authors have no competing interests to declare.

Data Accessibility Statement

All materials, participant data, and analysis scripts can be found on this articles OSF page: https://osf.io/9bp53/

Correspondence

Correspondence concerning this article should be addressed to Stephen L. Murphy, imec-mict-UGent, Department of Communication Sciences, Ghent University, Ghent, Belgium. E-mail: stephen.murphy@ugent.be

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