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RESEARCH ARTICLE

Sleep quality is associated with emotion experience and adaptive regulation of positive emotion: An experience sampling study

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Abstract

Poor sleep patterns have been strongly linked to disrupted emotional experiences. Emotion regulation, defined as the capacity to manage one's own emotional responses, comprises strategies to increase, maintain, or decrease the intensity, duration, and trajectory of positive and negative emotions. Poor sleep has been identified as a risk factor for emotional dysregulation, but most of the focus has been on *negative* emotion regulation. We therefore asked whether natural variations in sleep are associated with the experience and regulation of both positive and negative emotion. Young adults, aged between 18–24 years (N = 101), completed 7 days of ecological momentary assessments using a smartphone application. Duration and quality of the previous night's sleep was reported each morning. Levels of positive and negative emotions, and strategies used to regulate emotions, were measured at pseudorandom timepoints four times a day. Multilevel modelling indicated that higher self-reported sleep quality was significantly associated with increased intensity and duration of positive emotion, and decreased intensity of negative emotion. There were no statistically significant associations between sleep duration and emotion intensity or duration. Sleep quality, and not sleep duration, was also associated with the reported use of positive emotion regulation strategies. For negative emotion regulation strategy use, we found no associations with sleep quality or duration. Naturally occurring fluctuations in daily sleep quality may be important for the experience and regulation of positive emotion in young adults. These findings emphasise the need to examine both positive and negative emotion, and emotion regulation to understand the links between sleep and mood.

KEYWORD
ecological momentary assessment, emotion regulation, negative emotion, positive emotion, sleep,

1 | INTRODUCTION

Sleep loss and poor sleep quality disrupt how the brain processes emotions (Walker & van der Helm, 2009). Much of the evidence on the impact of sleep loss on emotion, be it the processing of emotions, the recognition of emotional stimuli, or the capacity to regulate emotion, is derived from studies of full or partial sleep restriction (for review, see Beattie et al., 2015). Experimentally reducing sleep to a maximum of 2 h total has been associated with decreased positive affect, measured using the Positive and Negative Affect Schedule (PANAS), in adolescents and adults (Talbot et al., 2010). Even partial sleep restriction, such as reducing sleep by 2 h per night for 3 nights, has been associated with linear reductions in positive affect across study days (Saksvik-Lehouillier et al., 2020). Recent meta-analytic evidence from seven unique studies suggests that experimentally induced sleep loss has a modest, but significant, negative effect on emotion ratings (Hedge's $g = -0.11$). Combining studies in which participants were presented with positive and negative emotion stimuli (e.g., videoclips, or IAPS images), the authors reported no moderating effects of stimulus emotion (Tomaso et al., 2021).

While experimentally limiting sleep has disruptive effects on self-reported mood and emotion ratings (e.g., Haack & Mullington, 2005), less is known about the affective experiences associated with natural fluctuations in sleep patterns, particularly in young people. In adult samples (18–61 years), poorer self-reported sleep, both duration and quality, has been associated with reduced positive and increased negative self-reported emotion (de Wild-Hartmann et al., 2013b), and there is some evidence for similar effects in 13- to 16-year-olds (van Zundert et al., 2015). A 14-day diary study of 30 adults aged between 20 and 59 found that self-reported sleep quality was a small, but significant predictor of more positive next-day mood. Sleep quality was, in fact, the best predictor of mood from a range of additional sleep variables (e.g., awakenings, timing; Totterdell et al., 1994). However, as noted in a recent systematic review assessing the association between positive affect and sleep, the majority of studies have been cross-sectional, and have methodological challenges such as inadequate measurement of negative affect, or small heterogenous sample sizes (Ong et al., 2017).

1.1 | What about emotion regulation?

Another issue in the burgeoning field of emotion-based sleep research is that most studies have focused on the experience of affect that occurs after sleep loss, rather than on the regulatory processes that may alter emotional experiences (Palmer & Alfano, 2017). Emotion regulation impairments are central to clinical models of anxiety and depression pathogenesis (Hofmann et al., 2012), and the role of disrupted negative emotion regulation is especially emphasised. As for studies examining emotion experience, the majority have used experimental reductions in sleep and then assessed negative emotion regulation at a single time point (e.g., Reddy et al., 2017; Tamm et al., 2019; Zhang et al., 2019).

Emotion regulation strategies can be broadly categorised as "adaptive", when associated with long-term beneficial outcomes for mental wellbeing, or "maladaptive", when associated with long-term negative outcomes (Schäfer et al., 2017). The habitual use of negative emotion regulation strategies has been associated with the likelihood of developing psychopathology in several meta-analyses. Among commonly assessed strategies for negative emotions, reappraisal can be considered an "adaptive" strategy (associated with reduced likelihood of psychopathology), whereas suppression is considered a "maladaptive" strategy (associated with increased likelihood of psychopathology; Aldao et al., 2010; Schäfer et al., 2017). Although investigated less, discussions of positive emotion regulation differentiate between strategies that either "enhance" or "dampen" positive emotions (Gilbert, 2012; Young et al., 2019), which are considered adaptive and maladaptive, respectively (Feldman et al., 2008). One recent study restricting sleep to 3 h in young adults found reduced self-reported emotion regulation success, specifically cognitive reappraisal, to negative stimuli (Tamm et al., 2019). In a study of partial sleep reduction to 6.5 h over 5 nights, Baum et al. (2014) reported emotion reaction difficulties in adolescents, as indicated by self-reported "easily upset" and unprovoked or disproportionate emotional reactions (interpreted as emotion regulation difficulties), relative to after 5 nights of typical sleep. Again, with a focus on negative emotion, an analysis of university students reported that more self-reported sleep difficulties at baseline were associated with reduced self-reported regulation effectiveness one year later (Tavernier & Willoughby, 2015). However, emotion regulation is not only dependent on the ability to manage responses to negative emotions, or negative feelings. Being able to notice, savour and reflect on positive emotions, is also important for affective functioning and mood, and may plausibly be disrupted with poor sleep, as for positive mood.

In the present study, we aimed to address the gaps in knowledge around the role of sleep in positive emotion regulation, while simultaneously recording negative affect and negative emotion regulation. We focused on young adults (aged 18–24 years) because late adolescence to early adulthood is a developmental period where there are changes in emotion regulation capacities (Young et al., 2019), and striking shifts in sleep patterns (Roenneberg et al., 2004). Young adults are estimated to have a greater sleep need compared with older adults (Short et al., 2018), and from the onset of puberty, show a preference for a delayed sleep onset timing, leading to the characteristic "owl"-like behaviour of adolescents that persists into the early 20s (Skeldon et al., 2016). Furthermore, younger adults face different daily affective challenges compared with adults, such as the pursuit of autonomy (Weinstein & Mermelstein, 2007), and the neural architecture to support emotion regulation is still maturing in this period (Blakemore & Choudhury, 2006; Guyer et al., 2016). Finally, adolescence and young adulthood is the developmental window where mood disorders most typically emerge, underscoring the importance of this period for understanding sleep and emotion regulation (Paus et al., 2008).

We used experience sampling to obtain more frequent measurements of young adults' emotional experiences and regulation strategies than afforded by traditional questionnaire measures. Experience sampling also allowed us to measure naturally occurring fluctuations in participants' sleep in their normal environments. We expected that higher ratings of sleep quality and longer sleep duration would be associated with *increased* levels of positive affect, and *decreased* negative affect, consistent with previous studies (de Wild-Hartmann et al., 2013b; Reddy et al., 2017). We also expected that higher ratings of sleep quality and longer sleep would be associated with increased use of adaptive regulation of positive and negative emotions and decreased use of maladaptive strategies, in line with previous studies of negative emotion regulation (Mauss et al., 2013; Palmer et al., 2018).

2 | METHODS

2.1 | Participants

Participants were recruited using a research volunteer system at the Institute of Psychiatry, Psychology and Neuroscience, King's College London, which includes both university students and volunteers signing up to the database who are not university students. We also used additional convenience sampling methods, via internal departmental webpages, and social media. Inclusion criteria for participation were: aged 18–24 years, access to an internet-enabled smartphone, self-reported as English speaking, and UK residence. Compensation for participation was monetary vouchers (£8), with an additional £2 reward for completion of over 70% of EMA surveys (67% of participants completed >70% of surveys). Ethical approval was obtained via the Research Ethics Minimal Risk Self-Registration protocol (Daily Emotional Experiences Study, MRA-19/20-19272, Psychiatry, Nursing and Midwifery Research Ethics Subcommittee, King's College London). Participants gave informed consent online via Qualtrics (Qualtrics International Inc.) prior to completing the baseline assessment.

We aimed to collect data from at least 100 participants, based on the sample size reported in a previous daily diary study ($N = 98$), taking measures of emotion intensity and duration over the course of 1 week (Verduyn & Brans, 2012). One hundred and forty individuals completed the baseline questionnaire, of whom 15 were excluded for not meeting the eligibility criteria (wrong age, $n = 10$; incorrect email, $n = 2$; not resident in the UK, $n = 3$). Of the remaining 125 participants at baseline, 115 individuals registered for the EMA component of the study. Eight of these participants were later excluded because their residence was subsequently reported as outside the UK, and six participants provided insufficient data, resulting in a final sample of 101 individuals.

2.2 | Study design

Figure 1 presents the study design, which consisted of a baseline assessment and a longitudinal EMA component, carried out using the MetricWire (MetricWire Inc.) smartphone application.

2.3 | Baseline measures

At baseline, participants completed sleep and emotion-related measures via Qualtrics (see Table 1 for psychometric properties of each scale). Demographic data were also obtained at baseline (gender, age, and education level).

2.3.1 | Sleep

The Insomnia Severity Index (ISI; Morin et al., 2011) is a 7-item instrument, widely used to measure the severity of sleep difficulties and to assess the impact these have on an individual's everyday functioning. Participants responded to seven questions using a 5-point Likert scale (0 = no issues, 4 = very severe issues).

2.3.2 | Emotion regulation

Positive emotion regulation was assessed using the Responses to Positive Affect questionnaire (RPA; Feldman et al., 2008), which comprises 17 items evaluating the degree to which participants habitually engage in three different types of positive emotion regulation: (i) adaptive emotion-focused regulation (5 items); (ii) adaptive self-focused regulation (4 items); (iii) and maladaptive dampening (8 items). Each of these regulation types are reported on a 4-point Likert scale (1 = almost never, 4 = almost always) and as separate subscales within the RPA.

Negative emotion regulation was assessed using the 10-item Emotion Regulation Questionnaire (ERQ, Gross & John, 2003) which evaluates individual differences in the habitual use of two emotion regulation strategies: (i) adaptive cognitive reappraisal and (ii) maladaptive expressive suppression. Each of these regulation types are reported on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

2.4 | EMA measures

Questionnaire items administered during the daily EMA surveys were: (i) one item on sleep quality from the Consensus Sleep Diary (Carney et al., 2012), a widely used self-report instrument designed for daily sleep recording, and two items asking about sleep schedule (sleep time, awakening time); (ii) five items assessing positive emotion regulation adapted from the RPA and one novel item ("I have been thinking that I deserve these feelings"); and (iii) six items assessing negative emotion regulation, including four items adapted from the ERQ, assessing cognitive reappraisal (2 items) and suppression (2 items) and two additional items to measure distraction ("I have been trying to feel less negative by doing something unrelated"; "I have been trying to feel less negative by thinking about something unrelated"), where the first item measured activity-related distraction, derived from Stone et al. (2019), and the second item measured thought-related distraction (see Figure 2, Table S1). The RPA and ERQ items were modified so that the present perfect tense was used instead of the present tense

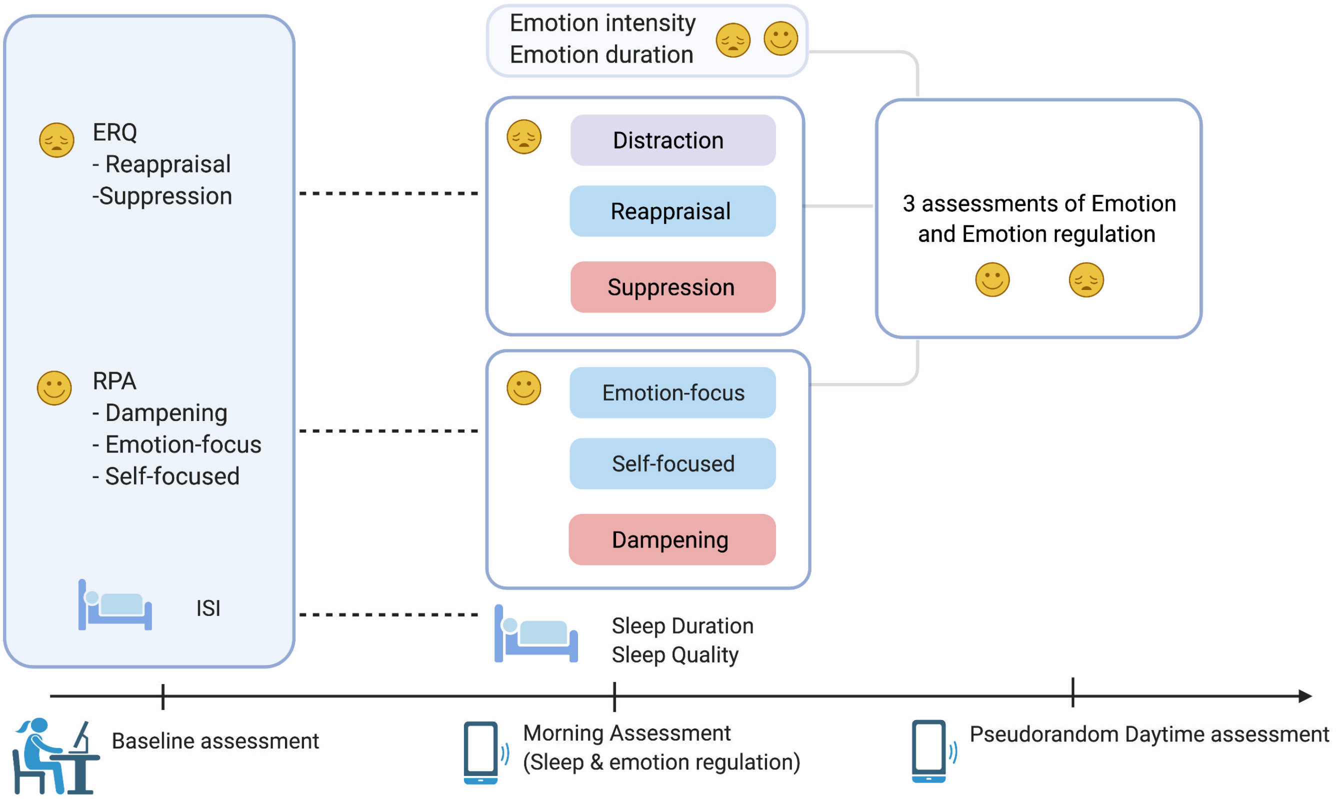

FIGURE 1 Study design. At baseline, participants completed the Emotion Regulation Questionnaire (ERQ), the Responses to Positive Affect questionnaire (RPA), and the Insomnia Severity Index (ISI). The experience sampling component of the study consisted of daily measures of emotion intensity, emotion duration, and emotion regulation strategy use (middle panel). For the emotion regulation strategies (middle panel), adaptive strategies are in blue, maladaptive in red, and neutral in purple. The first survey of each day contained both the sleep assessment and emotion regulation questions, and the other three surveys (final panel) measured emotion levels and regulation only (created using Biorender)

TABLE 1 Descriptive statistics for baseline measures of sleep and trait-level emotion regulation ($N = 101$)

	Mean (SD)	Scale range	Sample range	Cronbach's α
ISI	9.40 (5.46)	0–28	0–24	0.86
RPA: emotion-focused	12.65 (2.85)	5–20	5–20	0.73
RPA: self-focused	8.22 (2.69)	4–16	4–16	0.80
RPA: dampening	18.61 (4.93)	8–32	9–29	0.82
ERQ: cognitive reappraisal	27.40 (6.31)	6–42	11–38	0.84
ERQ: expressive suppression	14.75 (5.62)	4–28	4–25	0.84

Abbreviation: ERQ, emotion regulation questionnaire; ISI, insomnia severity index; RPA, responses to positive affect scale.

or the imperative. Participants could therefore answer the instruction, “think about your experiences in the last few hours or since the last survey” (see Table S1 for all the items). However, this modification, along with the other minor language simplifications detailed in Table S1 should be considered as non-validated changes.

2.4.1 | Sleep parameters

Measures of sleep quality and duration were obtained each morning (10 am–12 pm) with the items (i) “How would you rate the quality of your sleep?” (5-point Likert scale, 1 = very poor, 5 = very good) and (ii) “What time did you go to sleep?” and “What time did you wake up?”, with duration calculated from the participant-estimated sleep and wake times.

2.4.2 | Emotion and emotion regulation

Positive and negative emotion intensity were assessed using the two ratings: “How positive have you been feeling?” and “How negative have you been feeling?” on a sliding scale between 0–100. Positive

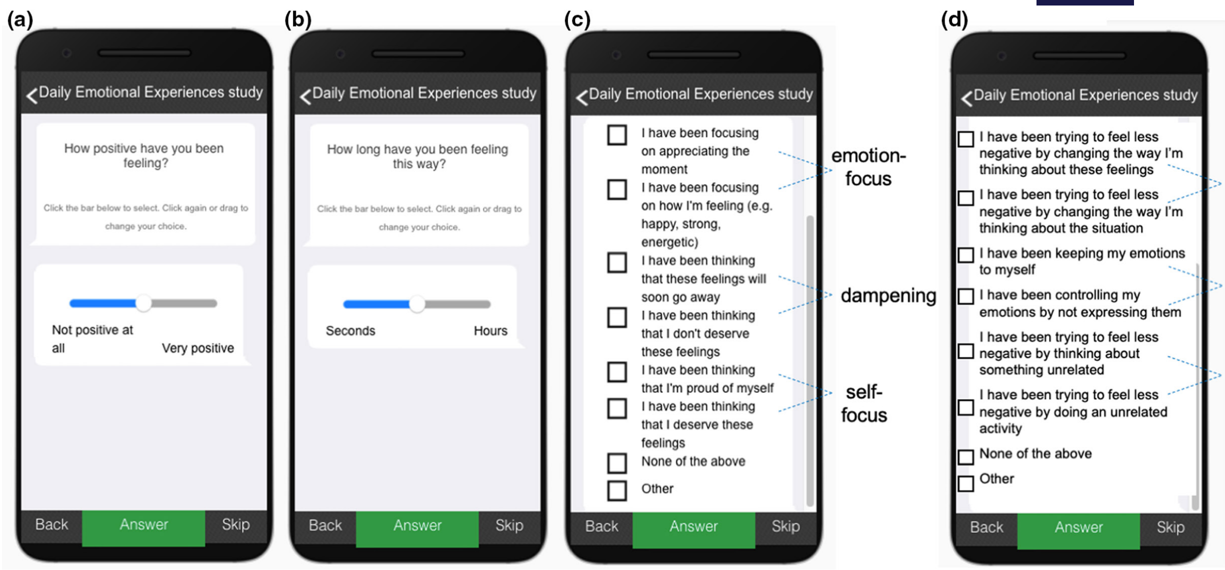

FIGURE 2 Smartphone EMA measurement: (a) Assessing emotion intensity using a sliding visual analogue scale (VAS; prompts asked "how positive" or "how negative"). (b) Assessing emotion duration using a sliding VAS. (c–d) Assessing strategies used for regulating emotions using a tick box format, for both positive (c) and negative (d) emotion regulation strategies

and negative emotion duration were assessed using the item "How long has this feeling been going on?", on a sliding scale ranging from "Seconds" to "Hours", for ease of participant interpretability. We then converted duration-based responding (seconds-hours) to a score between 0–100, noting that this mapping is conceptually imperfect. The order of the positive and negative items was the same across days and participants. Regardless of the answer provided to the emotion intensity or duration question, the use of regulation strategies was then assessed using the question, "What types of thoughts have you been having about these feelings?" for each emotion type. Participants were able to select as many strategies as applicable (see Figure 2).

2.5 | Procedure

After completion of the initial baseline measures, the participants were contacted by a researcher by email and familiarised with the EMA procedures. After registration within the MetricWire application, participants received four questionnaires each day for 7 consecutive days (28 questionnaires in total, see Figure 1). A notification for the first survey of each day was sent to participants at a random timepoint between 10 am and 12 pm, while notifications for the following three surveys were sent at pseudo-random times (at least 2 h apart) between 1 pm and 10 pm. Links to surveys expired after 20 min and were recorded as missed if not returned within this period. A threshold of 20% of completed surveys was required in order for data to be incorporated into subsequent analyses, as per recommendations for EMA procedures to ensure sufficient power (Edwards et al., 2016). Finally, to encourage engagement over the duration of the experiment, participants whose responses dropped below 40% by the third day of surveys were contacted by email and reminded of the participation bonus.

2.6 | Statistical analysis

Data processing and analysis was carried out in RStudio version 4.0.2 (The R Development Core Team, 2020). Data collected within the EMA portion of the study were nested in three levels: observations (i.e., surveys), within days (note sleep parameters were measured just once per day), within participants. Multilevel modelling was used because it can accommodate the hierarchical structure of EMA data. All R code is available from: https://osf.io/urjsf/.

For each of the outcomes (EMA measures of emotion intensity, emotion duration, and emotion regulation strategies), three-level, random-intercept models were created, with each of the day-level sleep parameters (sleep duration, sleep quality) added as predictors (10 models in total, 4 for emotion intensity and duration, 6 for regulation strategies). We used baseline participant-level ISI scores, RPA scores, and ERQ scores as covariates. "Participant" and "Days within participant" were added as random intercepts to account for between-person and between-day differences, respectively, throughout these analyses, as per previous three-level EMA procedures (Geyer et al., 2018). For multilevel models, we used the lme4 package within R, and an optimisation by quadratic approximation (BOBYQA) with a set maximum of 20,000 iterations. Missing data were handled using listwise deletion for individual assessments (i.e., a missing item on a single ESM questionnaire resulted in removal of that assessment point for that individual, see Table S2 for details on rates of missing data).

We first tested whether the daily EMA measures of sleep (duration and quality) were associated with emotion intensity (positive or negative; 0–100 scales) and emotion duration (positive or negative; 0–100 scales). Next, we tested whether sleep (duration, quality) was associated with emotion regulation (use of strategies coded as binary variables: 0 = not used, 1 = used either/both).

Unlike models with continuous outcomes, which represent expected effects at both the participant and sample level, the results of multilevel models with binary outcome variables are participant-specific only (Hox et al., 2010). Therefore, sample-level trends were calculated in the form of predicted probabilities as per recommendations for logistic models (Persoskie & Ferrer, 2017). All analyses were conducted using maximum likelihood estimates (McCulloch, 2003). All predictors were centred, with time-varying predictors centred using the individual's mean and time-invariant predictors using the grand mean (Snijders & Bosker, 2012). Sleep duration was assessed as a linear predictor in all models, consistent with previous EMA designs (e.g., Littlewood et al., 2019).

Outliers were calculated by generating weighted averages (using the number of surveys returned by each participant) for each variable. Outliers were defined as where the participant's average exceeded IQR +1.5 or fell below IQR −1.5. We repeated analyses with and without outliers and found similar patterns of significant effects (see Tables S3 and S4). We also conducted sensitivity analyses removing participants with ISI scores in the moderate to severe range (>14), to test whether the effects were driven by these higher-symptom individuals (n = 19). As for analyses removing outliers, we found largely comparable patterns of results when excluding these 19 individuals (see Tables S5 and S6).

3 | RESULTS

3.1 | Participant characteristics

One hundred and one individuals (85 female, 16 male) took part in this study, with a mean age of 21.69 years (SD = 1.91; range 18–24 years). Approximately half had completed secondary school level education (45.54%), and half had obtained higher education qualifications (bachelor's degree: 37.62%, master's degree: 14.85%). Descriptive statistics for baseline assessments of sleep and trait-level emotion regulation tendencies are shown in Table 1.

The mean experience sampling survey completion rate was 72.84% (SD = 17.54). The mean sleep quality score was 3.46 (SD = 0.95; median = 4, range = 1–5, IQR = 3–4) and the mean sleep duration was 8.01 h (SD = 0.99; median = 8.06 h, range = 4.00–10.50 h, IQR = 7.61–8.57 h). The mean ISI scores reported (Table 1) were comparable to those reported in a recent large student sample (mean ISI score = 8.99; Walsh et al., 2020). Most participants' ISI scores fell below the clinical cut-off for moderately severe, or severe insomnia symptoms (absence of insomnia, <8, n = 44; sub-threshold insomnia, 8–14, n = 38; moderate insomnia, 15–21, n = 16; severe insomnia, 22–28, n = 3). Mean emotion and regulation ratings are displayed in Figure 3.

For positive regulation strategies, the most frequently used was emotion-focused strategies (57.69% of all reports). Self-focused emotion regulation (19.94%) and dampening (11.66%) were less frequently used. For negative emotion regulation, the frequency of reported use was similar for all three regulation strategies (reappraisal: 29.32%, suppression: 23.66%, distraction: 39.08%). Further descriptive statistics for the experience sampling emotion regulation ratings are presented in Table 2. Within and between-person standard deviations indicate that strategy use varied at least as much within individuals as between individuals. Intra-class correlations show that 12%–47% of the variance within each individual strategy was accounted for by between-person variation.

3.2 | How are baseline trait measures and EMA measures related?

Bivariate correlations between baseline and EMA measures are presented in Figure 4. Overall, trait and EMA measures of the same constructs showed significant positive correlations. Baseline insomnia severity was significantly associated with EMA-measured sleep quality (r = −0.34), but not sleep duration (r = −0.13). Baseline trait emotion regulation strategy use was significantly associated with EMA measured use of the same strategy for both positive emotions (emotion-focused: r = 0.32; self-focused: r = 0.33; dampening: r = 0.28) and negative emotions (reappraisal: r = 0.24; suppression: r = 0.27; see Supplementary Materials for full description of these findings).

3.3 | Effects of sleep on positive and negative emotion intensity and duration

Four multilevel models examined the effect of daily variation in self-reported sleep quality and duration on daily levels of: (i) positive emotion intensity, (ii) positive emotion duration, (iii) negative emotion intensity, and (iv) negative emotion duration.

3.3.1 | Positive emotion: experience and duration

For positive emotion intensity, there was a small, but statistically significant effect of prior night's sleep quality. Higher quality sleep was associated with higher daily ratings of positive emotion intensity (Table 3; Table S2 for results of models including outliers). In this model, the ISI and two subscales of the RPA (emotion-focused and self-focused positive emotion regulation) were also statistically significant with small effect sizes: lower levels of insomnia symptoms and greater trait use of both emotion-focused and self-focused regulation were associated with higher positive emotion. There was no statistically significant effect of sleep duration or the RPA dampening subscale.

For positive emotion duration, higher ratings of prior night's sleep quality were associated with small increases in the duration of

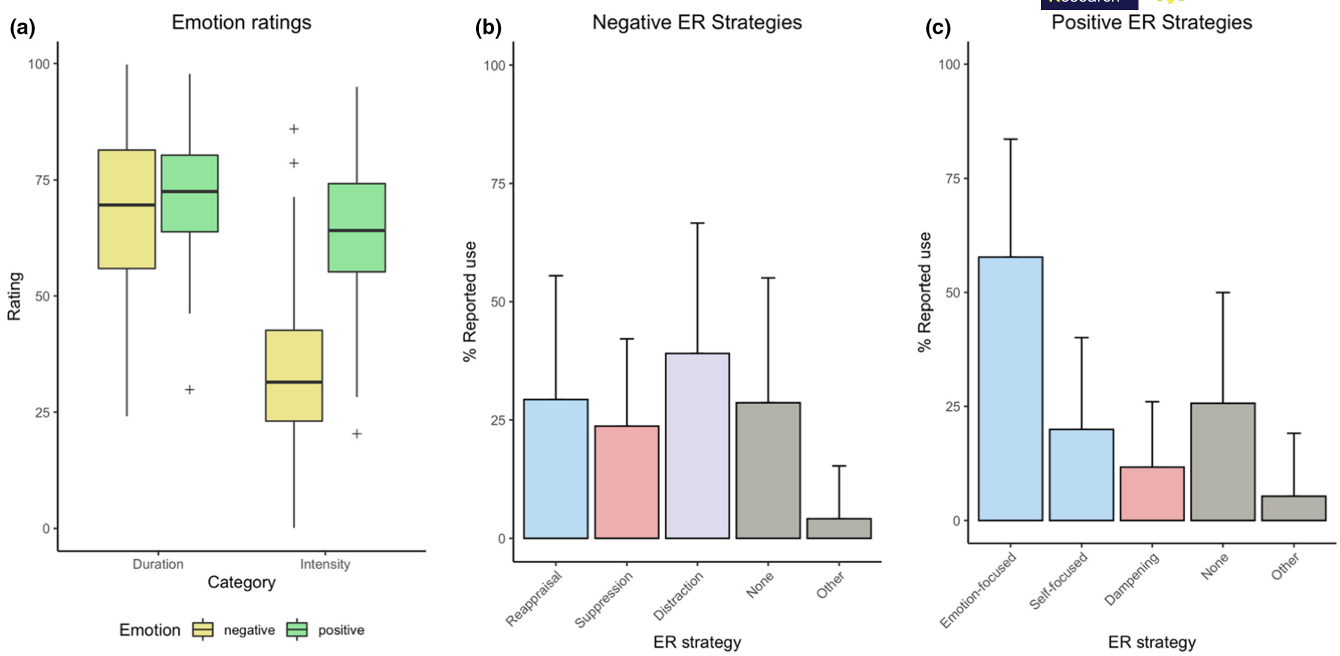

FIGURE 3 Mean ratings of reported emotion intensity and duration (a) and regulation strategy use (b and c). Error bars indicate mean ± standard deviation, "+" in panel (a) denotes outlier values. Note that individuals were able to select more than one regulation strategy at each EMA prompt (therefore total across strategy usage >100%)

TABLE 2 Descriptive statistics for the experience sampling Emotion Regulation (ER) strategies

ER strategy	Item	M[a]	95% CI lower	95% CI upper	SD between-person	SD within-person residual	ICC
Emotion-focus	1	0.43	0.38	0.48	0.25	0.29	0.42
	2	0.33	0.28	0.38	0.22	0.28	0.38
Self-focus	1	0.14	0.10	0.17	0.15	0.21	0.34
	2	0.11	0.08	0.14	0.13	0.18	0.32
Dampening	1	0.08	0.06	0.10	0.06	0.17	0.12
	2	0.05	0.03	0.07	0.08	0.13	0.29
Reappraisal	1	0.16	0.12	0.20	0.18	0.22	0.40
	2	0.21	0.16	0.26	0.22	0.23	0.47
Suppression	1	0.18	0.15	0.21	0.14	0.24	0.25
	2	0.12	0.10	0.15	0.10	0.21	0.20
Distraction	1	0.20	0.16	0.24	0.19	0.23	0.41
	2	0.32	0.27	0.37	0.25	0.27	0.47

Abbreviation: ICC: intra-class correlations at the subject level, denoting the amount of variance attributable to between-person effects.
[a]Mean proportion of strategy use per day, averaged across participants.

positive emotions, but ratings of prior night's sleep duration were not statistically significant. In this model, greater use of emotion-focused regulation was also associated with small increases in positive emotion duration. The ISI and other two RPA subscales were not.

3.3.2 | Negative emotion: experience and duration

For negative emotion intensity, there was a small, but significant, effect of prior night's sleep quality. Lower quality sleep was associated with higher ratings of negative emotion intensity (Table 4; Table S3 for results of models including outliers). In this model, the ISI and the ERQ cognitive reappraisal subscale were also significant with small effect sizes: higher levels of insomnia symptoms and less trait-level use of cognitive reappraisal were associated with higher negative emotion intensity. Neither prior night's sleep duration nor the ERQ expressive suppression subscale were statistically significant.

For negative emotion duration, there were no statistically significant effects of prior night's sleep quality, or duration. In this model, the ISI and ERQ subscales were also not statistically significantly associated with negative emotion duration.

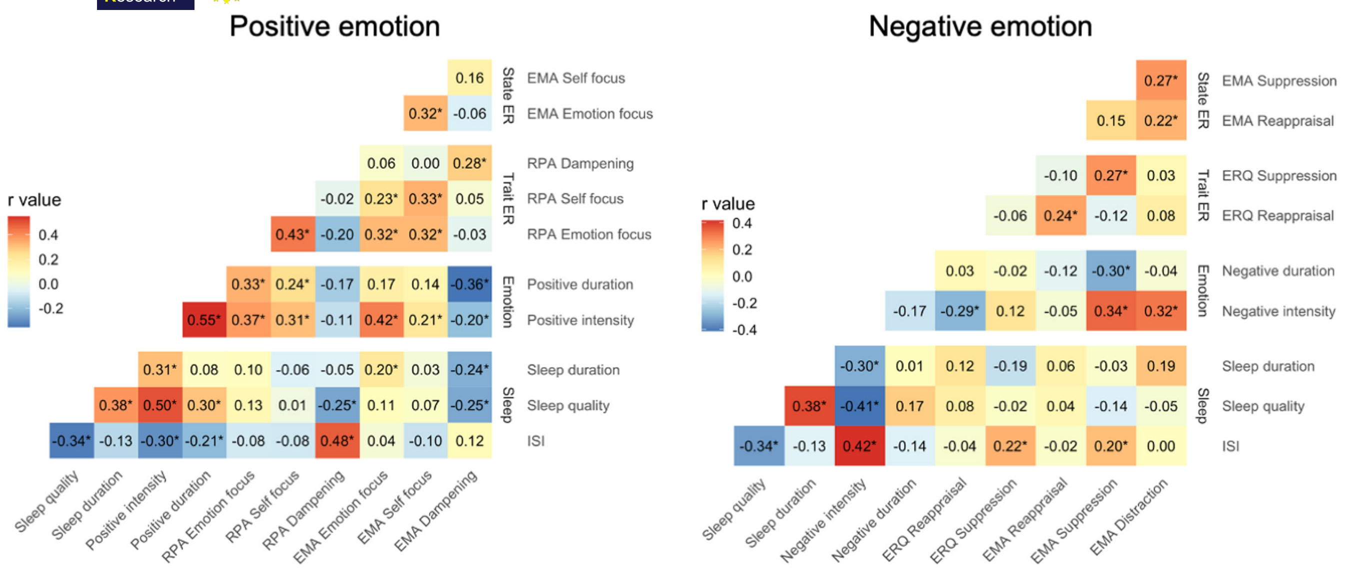

FIGURE 4 Heatmaps of bivariate correlations between sleep (ISI and EMA-reported Sleep quality, Sleep duration), emotion (EMA-reported intensity, duration) and state (EMA) and trait emotion regulation measures (RPA, ERQ) presented separately for positive and negative emotion and regulation strategies ($N = 101$). [* denotes significance at $p < 0.05$; EMA: ecological momentary assessment, ER: emotion regulation, ERQ: emotion regulation questionnaire, ISI: insomnia severity index, RPA: responses to positive affect scale]

3.4 | Effects of sleep on emotion regulation strategy use

Six multilevel models examined the effect of daily variation in sleep quality and duration on daily levels of emotion regulation strategy use (3 positive regulation strategies, 3 negative regulation strategies).

3.4.1 | Positive emotion regulation strategies

For emotion-focused regulation, higher prior night's sleep quality was associated with greater daily use of emotion-focused regulation (Figure 5, Table 3; Table S2 for results of models including outliers). For each point increase on sleep quality rating, there was an increase in emotion-focused strategy use by a factor of 1.38. There were no statistically significant effects of sleep duration. In this model, higher trait-level emotion-focused regulation was significantly associated with more frequent daily emotion-focused regulation (for each point on the trait-level measure, there was an increase in the daily measure by a factor of 1.21). There were no statistically significant effects of insomnia symptoms, or the other subscales of the RPA.

For self-focused regulation, there were no statistically significant effects of prior night's sleep quality or duration. In this model, higher trait-level self-focused regulation was significantly associated with more frequent daily self-focused regulation (for each point on the trait-level measure, there was an increase in the daily measure by a factor of 1.21). There were no statistically significant effects of insomnia symptoms or the other subscales of the RPA.

For dampening regulation, higher prior night's sleep quality was significantly associated with less frequent daily use of dampening regulation. For each point increase on sleep quality rating, the use of dampening strategies decreased by a factor of 1.79. There was no statistically significant effect of sleep duration. In this model, higher trait-level dampening was significantly associated with more frequent daily use of dampening (for each point on the trait-level measure, there was an increase in the daily measure by a factor of 1.09). There were no statistically significant effects of insomnia symptoms or the other subscales of the RPA. In sum, for positive emotion regulation, we found that sleep quality was associated with more use of an adaptive emotion regulation strategy (emotion-focused), and less use of a maladaptive strategy (dampening).

3.4.2 | Negative emotion regulation strategies

For cognitive reappraisal, there were no statistically significant effects of prior night's sleep quality or duration (Figure 5, Table 4; Table S3 for results of models including outliers). However, baseline use and daily use of cognitive reappraisal were significantly positively associated, where greater trait-level use of cognitive reappraisal was associated with greater daily use of cognitive reappraisal (for each point on the trait-level measure, there was an increase in the daily measure by a factor of 1.08). There were no statistically significant effects of insomnia symptoms or the other subscale of the ERQ.

For expressive suppression, there were no statistically significant effects of prior night's sleep quality or duration. There were also no statistically significant effects of insomnia symptoms or either subscale of the ERQ on daily levels of expressive suppression. In the model including outliers, there was a significant positive relationship between trait-level use of expressive suppression and daily use of expressive suppression (see Table S3), but otherwise

TABLE 3 Results from multilevel models examining positive emotions and positive emotion regulation (outliers removed)

Model variables	β	SE	Lower CI	Upper CI	p	ES
Positive emotion intensity						
Sleep quality	6.16	1.18	3.85	8.47	<0.001	0.03
Sleep duration	1.19	0.81	−0.39	2.78	0.14	0.00
ISI	−0.64	0.25	−1.13	−0.15	0.01	0.02
RPA-EF	1.04	0.47	0.12	1.95	0.03	0.02
RPA-SF	1.10	0.49	0.14	2.07	0.03	0.02
RPA-DP	0.23	0.28	−0.32	0.78	0.41	0.00
Positive emotion duration						
Sleep quality	2.52	1.04	0.48	4.56	0.02	0.01
Sleep duration	0.14	0.71	−1.25	1.53	0.84	0.00
ISI	−0.47	0.28	−1.03	0.08	0.10	0.01
RPA-EF	1.19	0.53	0.14	2.24	0.03	0.02
RPA-SF	0.52	0.56	−0.59	1.62	0.36	0.00
RPA-DP	−0.13	0.32	−0.76	0.50	0.68	0.00
Emotion-focus						
Sleep quality	0.32	0.14	0.04	0.60	0.02	1.38
Sleep duration	0.11	0.10	−0.09	0.30	0.28	1.11
ISI	0.00	0.03	−0.06	0.07	0.88	1.00
RPA-EF	0.19	0.06	0.07	0.31	0.002	1.21
RPA-SF	0.05	0.07	−0.08	0.18	0.41	1.06
RPA-DP	0.06	0.04	−0.01	0.13	0.11	1.06
Self-focus						
Sleep quality	0.35	0.18	0.00	0.69	0.05	1.41
Sleep duration	0.14	0.13	−0.11	0.38	0.28	1.14
ISI	−0.03	0.04	−0.11	0.04	0.41	0.97
RPA-EF	0.11	0.07	−0.03	0.25	0.12	1.12
RPA-SF	0.19	0.08	0.04	0.34	0.01	1.21
RPA-DP	0.02	0.04	−0.06	0.11	0.59	1.02
Dampening						
Sleep quality	−0.59	0.20	−0.98	−0.19	0.003	0.56
Sleep duration	−0.16	0.15	−0.45	0.13	0.28	0.85
ISI	0.01	0.03	−0.06	0.08	0.80	1.01
RPA-EF	0.03	0.07	−0.10	0.16	0.65	1.03
RPA-SF	0.07	0.07	−0.06	0.21	0.30	1.07
RPA-DP	0.09	0.04	0.00	0.17	0.04	1.09

Note: Effect sizes (ES) are marginal Cohen's f^2 for intensity and duration variables and odds ratios for binary emotion regulation variables.
Abbreviation: ISI, insomnia severity index; RPA-DP, responses to positive affect dampening subscale; RPA-EF, responses to positive affect emotion-focused subscale; RPA-SF, responses to positive affect self-focused subscale.

there were no differences between the models including or excluding outliers.

For distraction, there were no statistically significant effects of prior night's sleep quality or duration. There were also no statistically significant effects of insomnia symptoms or either subscale of the ERQ on daily levels of distraction use. In sum, in contrast to that seen for positive emotion, there were no statistically significant associations between sleep quality and emotion regulation strategy use for negative emotion.

4 | DISCUSSION

Using experience sampling in young adults, we found that naturally occurring variations in at home sleep patterns, reported each morning for 7 days, were associated with the daily experience of positive emotion. Prior night's sleep quality was associated with the experience of positive emotion, its intensity and duration, and also with reported engagement in strategies to regulate it. Young

TABLE 4 Results from multilevel models examining negative emotions and negative emotion regulation (outliers removed)

Model variables	β	SE	Lower CI	Upper CI	*p*	ES
Negative emotion intensity						
Sleep quality	−5.92	1.31	−8.49	−3.34	<0.001	0.02
Sleep duration	−1.55	0.90	−3.31	0.21	0.09	0.00
ISI	0.94	0.26	0.42	1.45	0.001	0.05
ERQ-CR	−0.45	0.22	−0.87	−0.02	0.04	0.02
ERQ-ES	0.09	0.25	−0.40	0.59	0.71	0.00
Negative emotion duration						
Sleep quality	−0.01	1.24	−2.45	2.43	0.99	0.00
Sleep duration	0.38	0.85	−1.28	2.04	0.65	0.00
ISI	−0.54	0.33	−1.18	0.10	0.10	0.01
ERQ-CR	0.11	0.28	−0.43	0.65	0.70	0.00
ERQ-ES	0.15	0.32	−0.47	0.77	0.63	0.00
Cognitive reappraisal						
Sleep quality	−0.02	0.16	−0.34	0.31	0.92	0.98
Sleep duration	0.03	0.12	−0.20	0.25	0.82	1.03
ISI	0.02	0.04	−0.05	0.09	0.56	1.02
ERQ-CR	0.07	0.03	0.01	0.13	0.02	1.08
ERQ-ES	−0.06	0.04	−0.13	0.01	0.09	0.94
Expressive suppression						
Sleep quality	−0.13	0.14	−0.42	0.15	0.35	0.87
Sleep duration	−0.05	0.10	−0.24	0.15	0.64	0.95
ISI	0.04	0.02	0.00	0.09	0.07	1.04
ERQ-CR	−0.03	0.02	−0.07	0.01	0.13	0.97
ERQ-ES	0.04	0.02	0.00	0.08	0.07	1.04
Distraction						
Sleep quality	0.15	0.14	−0.12	0.42	0.26	1.17
Sleep duration	−0.02	0.10	−0.21	0.17	0.83	0.98
ISI	0.04	0.04	−0.03	0.11	0.23	1.04
ERQ-CR	0.02	0.03	−0.04	0.08	0.45	1.02
ERQ-ES	0.00	0.03	−0.07	0.06	0.90	1.00

Note: Effect sizes (ES) are marginal Cohen's f^2 for intensity and duration variables and odds ratios for binary emotion regulation variables.
Abbreviations: ERQ-CR, emotion regulation questionnaire, cognitive reappraisal subscale; ERQ-ES, emotion regulation questionnaire, expressive suppression subscale; ISI, insomnia severity index.

adults with higher ratings of sleep quality tended to report greater engagement in an adaptive regulation strategy, taking an emotion-focused approach (e.g., appreciating the moment), and less engagement in a maladaptive regulation strategy, dampening (e.g., thinking the positive feelings will go away). Longer sleep duration was not associated with intensity or duration of daily emotion experience, nor with engagement in any of the tested regulation strategies. Our significant effects were small in magnitude, consistent with recent meta-analytic estimates of the impact of experimental sleep reduction on components of emotion processing and experience (Tomaso et al., 2021).

For negative emotion, and negative emotion regulation, sleep pattern associations were apparent only for the measure of emotion intensity. Higher sleep quality, but not longer sleep duration, was associated with reporting of less intense daily negative emotion. The association between better perceived sleep quality and less negative emotion intensity is in line with what might be predicted from neural studies of emotion processing after sleep, whereby sleep deprivation (approx. 35 h) has been associated with an amplified, hyper-limbic response in the amygdala to negative emotional stimuli (Yoo et al., 2007). However, against our initial predictions, participants' reports of three negative emotion regulation strategies, cognitive reappraisal, suppression, and distraction, were not statistically significantly associated with sleep quality or duration.

While a large body of studies have illustrated links between sleep and general mood, or sleep and PANAS-measured affect (Ben Simon et al., 2020), we show that sleep is also associated with reported use of positive emotion regulation strategies. We measured young

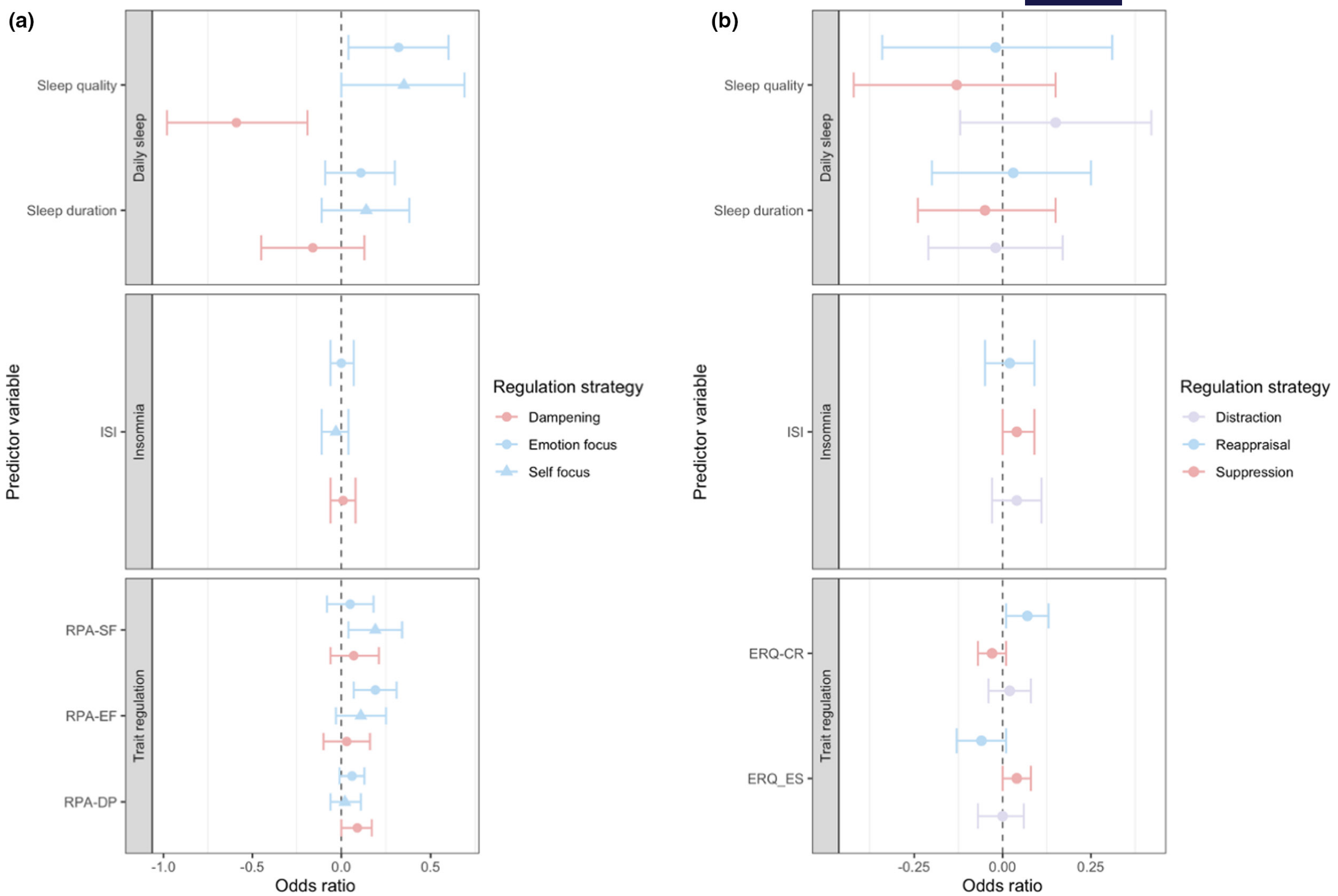

FIGURE 5 Results of multilevel regression models with sleep (daily ESM-reported sleep, baseline ISI) and trait-level emotion regulation (RPA; ERQ) as predictors of daily emotion regulation strategy use. Predictors were mean centred by participant, deviations from zero therefore represent the effects of variations in sleep or trait-level emotion regulation averaged across all participants. (a) For positive emotion regulation strategies, higher daily sleep quality was associated with significantly more "emotion-focused", and significantly less "dampening" strategy use. (b) For negative emotion regulation strategies, there were no statistically significant associations with daily sleep quality or duration

adults' reported daily tendencies to engage in regulation strategies that can influence the experience of positive emotion, multiple times per day over the course of a week, controlling for trait regulation abilities measured at baseline (ERQ, RPA) and sleep difficulties (ISI). Our focus on emotion regulation is of importance, because poor regulation is a transdiagnostic risk factor for psychopathology (Aldao et al., 2010), and effective regulation of positive emotion is associated with life satisfaction (Quoidbach et al., 2010).

As has been recommended (Palmer & Alfano, 2017), we measured both positive and negative emotion experiences, as well as a range of well-defined emotion regulation strategies. Moving beyond cross-sectional measurements of a single regulation strategy, our use of EMA allowed us to capture day-to-day variations in strategy use in a sample of young adults. For positive emotion, we tested two adaptive positive regulation strategies: emotion-focused and self-focused (e.g., taking pride), and one maladaptive strategy (dampening). Self-focus was not significantly associated with sleep quality, whereas the effects for the other two strategies were small to moderate. We found no statistically significant effects for negative emotion regulation strategies, in contrast to work restricting sleep in young adults, which reported reduced cognitive reappraisal success after less sleep (Tamm et al., 2019). We speculate that, because our participants broadly fell within the healthy 7–9-h sleep range (M = 8.01 h; SD = 0.99), their sleep may have been insufficiently variable to detect effects measurable in a more severe experimental condition of just 3 h sleep.

4.1 | Blunting or a negative bias? And what might these findings mean?

Our findings suggest that poorer self-reported sleep quality is associated with a move towards the negative: reducing positive emotion intensity and duration of experience but increasing negative emotion intensity. This is distinct from an overall "blunting" of emotion, whereby negative emotion would also be dampened, along with positive emotion (colloquially a "meh" reaction, see Beattie et al., 2015). It is an open question as to why only positive emotion regulation was related to our participants' previous night's sleep quality, and not negative regulation also. We can speculate that the capacity to observe, savour, and reflect on positive feelings and emotions, as was measured with our adaptive regulation questions, is impacted by day-to-day fluctuations in sleep quality. But negative emotion regulation, where our items centred on "keep a lid on it" approaches, might only show a decline with more drastic sleep disruption than the naturalistic variations measured here.

Night-to-night sleep variability is common in the general population (e.g., Dillon et al., 2015; Knutson et al., 2007) and is especially marked in some clinical populations (e.g., attention deficit hyperactivity disorder; Van Veen et al., 2010). Our findings suggest that deliberate strategies to upregulate positive emotion may be a useful tool in those experiencing poor sleep quality. For example, Positive Affect Training, a novel intervention to increase reward sensitivity, focuses initial sessions on anticipating and savouring reward through recounting prior exercises (Craske et al., 2019). Similar training strategies might be useful for individuals experiencing poor sleep quality, especially given the association between impaired sleep quality and the development and maintenance of mood disorders.

4.2 | Comparing trait and daily measures of emotion regulation

We obtained baseline indices of emotion regulation, using two well-established questionnaire instruments the ERQ and the RPA, with reasonable psychometric properties (test-retest reliability for RPA subscales from 0.51-0.65; for both ERQ subscales: 0.69, internal consistency for RPA subscales from 0.62-0.80, and for the ERQ from 0.73 to 0.79 (Gross & John, 2003; Raes et al., 2012)). We found that the participants' responses on the ERQ and RPA subscales were significantly correlated with the related EMA measures: for example, trait "suppression" (ERQ) correlated with EMA-measured suppression. Effect sizes were in the small to medium range (Figure 4), as might be anticipated for trait to daily measure correlations. We interpret these correlations as indicating that our EMA measures are reasonably related to the constructs measured in the two standardised questionnaire instruments.

4.3 | Limitations and future directions

Our study was observational and complementary to the controlled experimental studies that have directly manipulated sleep (e.g., Baum et al., 2014; Tamm et al., 2019). We assessed prior nights' sleep, preceding next day experiences of emotion and emotion regulation, and we did not address effects in the opposite direction (daily emotion predicting next night of sleep). Future studies might consider approaches such as autoregressive models to examine within-person temporal dynamics (Bulteel et al., 2016). Within our experience sampling measures, we used the same questions and question anchors every day, whereas variation in scale formats, item order, and the avoidance of repeated use of the same anchor points would be useful to address common method variance a priori (Hirschmann & Swoboda, 2017). We treated sleep duration as a linear variable, consistent with previous EMA studies (Littlewood et al., 2019; Short et al., 2017). However, both undersleeping (<5 h) and oversleeping (e.g., over 9 h) have been associated with health outcome impairments (Itani et al., 2017; Jike et al., 2018). Future work might sample participants falling outside the 7–9 h range, which is typically characterised as healthy, along with focused analyses of chronotype differences and sleep pattern regularity (Bauducco et al., 2020). Given the well-established differences between the measures of objective and subjective sleep (Smith et al., 2018), further work would benefit from including additional measurements of sleep quality and sleep time from, for example, actigraphy.

Our participants were asked at each EMA prompt to record their emotions, and how they were regulating these emotions, but were not required to describe the context of emotional experiences themselves. The appropriateness of a regulation strategy is likely to differ depending on the context, so consideration of environmental conditions will be important in future work. To give an example, although dampening is generally defined as maladaptive to positive emotions, if an individual was in a serious situation at the time of the survey prompt, reducing the expression of their positive emotions may have been socially appropriate or culturally expected (John & Gross, 2004). Our measure of regulation strategy use can be characterised as an assessment of participants' tendencies, or reported use of strategies, as distinct from an assessment of their emotion regulation ability (e.g., using measures of efficacy of a strategy to upregulate or downregulate an emotion, see for example Reddy et al. (2017)). While our assessments of trait-level emotion regulation at baseline comprised questionnaires, it would also be possible to combine laboratory measures of regulation with EMA methodology in future work.

5 | CONCLUSION

Positive and negative emotion intensity were associated with self-reported sleep quality but not duration, as predicted from previous studies (Palmer & Alfano, 2017). Sleep quality was also associated with daily adaptive use of positive emotion regulation strategies, as measured in young adults using EMA. Sleep quality was therefore linked with both emotion intensity *and* regulation of emotion. These findings add to the body of studies, which emphasise the importance of sleep quality over sleep duration in overall emotion experience (e.g., Shen et al., 2018). Our findings emphasise the link between sleep and positive emotion, and are broadly consistent with studies suggesting that poor sleep quality is more robustly associated with impaired positive relative to negative mood (e.g., Bower et al., 2010; de Wild-Hartmann et al., 2013a). We suggest that emotion regulation strategy use may be a candidate mechanism linking poor sleep quality and disrupted positive mood, which could be investigated further in experimental designs.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

CEP and KSY devised the study concept, all authors contributed to measurement design. BS and SB collected the data, BS, SB, and KSY conducted data analyses. CEP wrote the manuscript and all authors provided comments and feedback.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions. Analysis code is freely available to other researchers at: https://osf.io/urjsf/

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