

Temporal dynamics of the influence of pre- or anticipated post-sleep stress on dream content

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ARTICLE INFO

Keywords:

Dreams
Stress
Cognition
Anticipated stress

ABSTRACT

Psychosocial stress induces stress responses at physiological and cognitive levels which disrupt subsequent sleep. A recent study from our group has shown that stress-induced changes are dynamic: stress before sleep led to prolonged sleep latency and changes in the early sleep period, while anticipated post-sleep stress resulted in changes in the late sleep period. A possible explanation is that anticipated stress is spontaneously reactivated during sleep in a dynamic fashion. As reactivations might be linked to dream content, we investigated the influence of anticipated stress vs. pre-sleep stress on dream content in early and late sleep periods. One group of participants performed either a stress or a relaxation task before sleep (pre-sleep group); while another group was informed before sleep that the stress or relaxation task will occur in the morning (post-sleep group). During sleep, they were regularly woken up in the early and late sleep periods and asked about their cognitive activity, while polysomnographic data was recorded. Fifty-five subjects participated and a total of 668 dreams was collected. While there was no difference in the incorporation of threat- and stress-related elements in the dreams, we did find a temporal difference in their emotionality. The threat intensity was influenced in a dynamic manner, with higher impact on early dreams when stress occurred before sleep and higher threat intensity in late dreams when stress was anticipated after sleep. Our results speak for a reactivation of mental activity in temporal proximity to the stressor for some parameters, mainly with impacts on the dream emotionality and length.

1. Introduction

Stress has a negative impact on sleep as it induces physiological and psychological activation (e.g., [Riemann et al., 2010](#); [Van Reeth et al., 2000](#)). Specifically, psychosocial stressors are known to particularly induce stress responses at both physiological and cognitive levels ([Kogler et al., 2015](#)) which would then disrupt subsequent sleep. It has been shown that inducing psychosocial stress directly before sleep leads to a prolonged sleep onset latency (SOL), more sleep fragmentation, less deeper sleep stages, and a decrease in objective measures of sleep quality (i.e., low-/high-frequency power ratio in the electroencephalogram (EEG) during non-rapid eye movement (NREM) sleep; [Ackermann et al., 2019](#); [Beck et al., 2023](#); [Goldberg et al., 2020](#); [Wuyts et al., 2012](#)). Interestingly, most of those effects of stress induction before sleep were shown in the early period of sleep, while the late period of sleep typically remained unaffected. However, when stress induction occurred after sleep, and participants anticipated post-sleep stress when going to bed, changes in sleep parameters were mostly observed in later periods of

sleep ([Beck et al., 2023](#)). The study from [Beck et al. \(2023\)](#) showed that sleep changes occur in temporal proximity to the stressor: acute stress before sleep impacted mainly the early period of sleep, while the anticipation of stress showed changes in the late period of sleep. An important open question is how these temporal dynamics can be explained.

For pre-sleep stress, it is very likely that changes in sleep are caused by both physiological activation and cognitive arousal due to the previous stress experience. During wakefulness, physiological stress responses can typically last from 5 min up to ca. 60 min after the stressor, as indicated by increases in heart rate, cortisol levels, saliva alpha-amylase or galvanic skin response (e.g., [Ackermann et al., 2019](#); [Becker and Rohleder, 2019](#); [Bellingrath et al., 2013](#); [Janson and Rohleder, 2017](#)). For anticipation of post-sleep stress, however, it is highly unlikely that a continued physiological activation after information about the upcoming stress causes the changes in sleep parameters. In the study by [Beck et al. \(2023\)](#), no increase in heart rate and no change in the early sleep architecture was detected when anticipating stress after a

This article is part of a special issue entitled: Sleep, memory and emotion published in Neuropsychologia.

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<https://doi.org/10.1016/j.neuropsychologia.2025.109311>

Received 3 September 2025; Received in revised form 22 October 2025; Accepted 29 October 2025

Available online 30 October 2025

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90-min midday nap. However, reduced slow wave sleep (SWS) and spindle activity occurred in the later period of sleep. Thus, one possible explanation is that cognitive arousal about the upcoming event was either continuously active during sleep, or this cognitive arousal was being reactivated towards the end of the sleep period in anticipation of the upcoming stressor. This activation of cognitive arousal could then induce changes in physiological indicators during the late sleep period (e.g. changes in sleep parameters, heart rate, hormonal measures, etc.). This hypothesis is supported by findings on self-awakening, which describes the ability to awaken at the predetermined time without external assistance (Verga et al., 2023). Changes in physiological parameters were observed before a predetermined awakening time: blood pressure (Kaida et al., 2005) and heart rate (Kaida et al., 2003) would increase several minutes before awakening and adrenocorticotropin (ACTH) – which controls the production of cortisol – would increase 1 h before self-awakening (Born et al., 1999). Moreover, EEG activity in the band power reflecting sleep spindle activity – which is suggested to serve a function of sleep maintenance (Ueda et al., 2001) –, showed a decrease minutes before self-awakenings as compared to forced awakenings (Ikeda and Hayashi, 2008). These effects show that cognitive activity during sleep (e.g., the intention to awaken at a predetermined time) has an effect on physiological parameters of sleep.

Therefore, cognitive arousal (e.g., in the form of preserved/repetitive or reactivated negative thoughts about an upcoming stressor) could be the underlying mechanism that explains the changes in sleep parameters in later periods of sleep before an anticipated stress event. One prediction of this assumption is that mental content about the stressor during sleep should be increased during later periods of sleep when the stressor is anticipated. When stress occurred before sleep, mental content about the stress should be most prominent in early periods of sleep, and fade during later periods of sleep. In the current study, we used dream content as an indicator of mental content during sleep, accepting the broadest inclusive definition of dreams as “any subjective experience during sleep” (Siclari et al., 2020, p. 849).

The continuity hypothesis assumes that dream mentation reflects and embodies personal waking preoccupations and concerns (Domhoff, 2017; Erdelyi, 2017). Lauer et al. (1987) observed that a stressful film before sleep leads to more negative emotions in the subsequent dreams when awakened from the first rapid-eye movement (REM) sleep period. Weingarden (1972; as cited by Schredl, 2003) showed that stress induced by negative feedback on an intelligence test performance resulted in more dreams of failure, inadequate behaviour and injury. These studies support the general idea that inducing a strong emotion such as stress before sleep will alter the intensity of negative emotions and stress/threats included in the subsequent dreams. While the continuity hypothesis does not specify the time of the night at which the waking experiences are incorporated into dream mentation, literature investigating memory and/or emotion incorporation into dream content provides some insights into this question. For example, Baekeland et al. (1968) reported that performance of a free association task half an hour before bedtime influenced dreams from the first part of the night by including many elements of the pre-sleep material. Additionally, a recent study by Picard-Deland et al. (2023) found that early-night dreams contain more elements of recent memory sources compared to late-night dreams (see also Wamsley et al., 2024). Interestingly, Schredl (2003) reported studies which showed that dreams of the first part of the night incorporate mostly recent daytime experiences, whereas dreams at the end of the night also include elements which occurred throughout the person's past (Roussy et al., 1998; Verdone, 1965; as cited by Schredl, 2003). Overall, these studies highlight differences in the time of night in which different memory sources seem to be incorporated into dream content.

The incorporation of future stressful and/or important events into dreams has also been investigated. For example, before an important competition, reported distressing dream content was predominantly related to the upcoming competition (Erlacher et al., 2011). Indeed, in

those distressing dreams from athletes, athletic failure such as losing a game was the most predominant theme which could reflect the athletes' stress experience in the dream (Erlacher et al., 2011). This is also supported by a study with patients waiting for a major surgery: dreams before the surgery were more often characterised by references to body parts, hostility and the hospital setting, showing that subjective stress was incorporated into the dreams (Breger et al., 1971; as cited in Erlacher et al., 2011). It was also observed that amongst students who remembered a dream before an important exam, 91 % of the dreams were related to the exam (Arnulf et al., 2014); moreover, in most of those dreams, a problem with the exam appeared (e.g., problem answering the questions, being late). Interestingly, Wamsley (2022) also demonstrated that future-oriented dreams became proportionally more common in later parts of the night.

While the above-mentioned studies show evidence for the incorporation of future events into the dreaming activity, whether and how anticipation of stress alters the negative tone of the dream content mostly in the late period of sleep is still unknown. Based on the results of sleep changes in temporal proximity to the stressor, we predict that stress before sleep mainly influences dream content in the early part of the night, whereas anticipated stress will influence dream content mainly in the later part of the night. As we predict that the effects of stress and anticipation of stress on cognitive arousal in dream content will be rather broad, we focus on general stress- and threat-related elements and intensity of negative feelings in dream reports instead of concrete incorporations of the exact stress task.

To investigate the impact of completed and anticipated stress on cognitive activity during sleep, one group of 26 healthy participants performed either a stress or a relaxation task before sleep, while another group of 29 healthy participants was informed before sleep that they will conduct either a stress or a relaxation task in the morning after sleep. During sleep, we regularly woke up the participants from both groups and asked them about their cognitive activity at the moment of the awakening. Awakenings happened both in the early sleep period and in the late sleep period.

2. Methods

2.1. Participants

Sixty-three healthy French-speaking individuals completed all sessions of the experiment. One subject was excluded due to insufficient sleep in at least one of the two experimental nights (<6h) and seven were excluded for not remembering any dream in either the early or the late sleep period of one experimental session. The final sample consisted of 55 young adults (37 women, mean age = 22.55 ± 2.70 [M $\pm$ SD], age range: 18–30 years).

Participants were recruited through advertisements placed at the University of Fribourg and on social media and received 130 CHF for their participation. They were not taking any sleep-influencing medication and reported no neurological, psychiatric or sleep-related disorders. None of the participants was engaged in shift work or had intercontinental flights within 6 weeks prior to their participation in the study. They were instructed to avoid alcoholic and caffeinated beverages on experimental days as well as the day before. The local ethics committee of the University of Fribourg – Internal Review Board of the Department of Psychology – approved the study (Project ID: 2022-766), and all participants gave written informed consent prior to participating. The study was conducted in accordance with the Declaration of Helsinki. This study was preregistered and can be viewed via the following link: <https://osf.io/bexpq> (accessed on the January 23, 2025).

2.2. Design and procedure

Each participant spent one adaptation night in the sleep laboratory of the University of Fribourg, which was followed by two experimental

nights. During the experimental sessions, either a stressful or a relaxing task was performed in a virtual reality environment. The order of the conditions was counterbalanced across participants according to a within-subject design. In an additional between-subject factor, one group of participants conducted the tasks directly before sleep (maximum 20 min before bed; pre-sleep group; $n = 26$), while another group of participants received the instructions for the tasks before sleep and performed the tasks in the morning after sleep (post-sleep group; $n = 29$). Participants were randomly assigned to one of the two groups.

Both experimental sessions started between 8:30 and 9:00 p.m. and were spaced at least 10 days apart to avoid dream-lag effect (Blagrove et al., 2011; Eichenlaub et al., 2019). Each session started with the attachment of electrodes for recordings of electroencephalography (EEG), electromyography (EMG), electrooculography (EOG), and electrocardiography (ECG). Afterwards, participants of the pre-sleep group performed the respective task (stress or relax) before going to bed, while participants of the post-sleep group went to bed directly. During sleep, participants were awakened up to nine times per night and asked about their mental activity content at the time of the awakening (see “Awakenings during sleep” section). After a minimum of 8h and a maximum of 9h of sleep, participants were woken up and subjective sleep quality and mood were assessed. Upon final awakening, participants of the post-sleep group performed the respective task (stress or relax; see

Fig. 1A for a summary of the experimental procedure). Before and after the tasks, participants completed standardised questionnaires (see “Questionnaires” section).

2.3. Awakenings during sleep

Awakenings occurred in the early sleep period (first 3 h after Lights Off) and in the late sleep period (last 2 h). In-between, participants were allowed to sleep undisturbed for 3 h (see Fig. 1A for a summary of the experimental procedure).

The first awakening was performed after the participants spent 1 min in sleep stage N1. This awakening was designed to exploratorily investigate differences in hypnagogic hallucinations and is therefore not analysed in the current manuscript. After this first N1 awakening, the experimenter closely monitored sleep and waited for sleep onset. Once the participants fell back to sleep, the experimenter waited 30 min before performing the next awakening. The procedure was repeated until the first 3 h after Lights Off were over or when they reached four awakenings. After letting the participants sleep for 3 h undisturbed, the same procedure as in the early sleep period was used in the last 2 h of sleep. After the last awakening, participants were given the opportunity to sleep for an additional 20–30 min. According to this procedure, the number of awakenings per night depends on sleep onset latency after

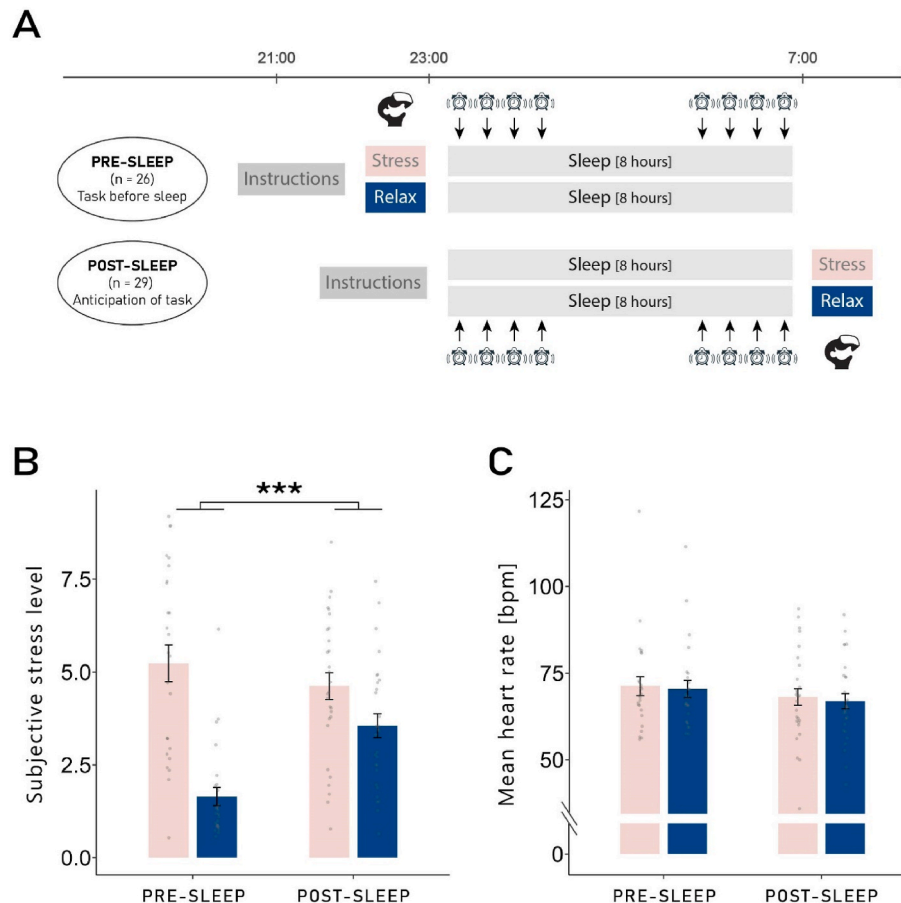


Fig. 1. A) **Experimental procedure.** One group of participants performed either a stress or a relaxation task directly before sleep (maximum 20 min before bed; pre-sleep group, $n = 26$); while another group was informed before sleep that the stress or relaxation task will occur in the morning (post-sleep group, $n = 29$). In the stress condition, the TSST was performed in a virtual reality environment, while in the relaxation task, subjects could relax in a beautiful virtual reality environment. During sleep, participants were regularly woken up in the early sleep period (first 3 h of sleep) and in the late sleep period (last 2 h of sleep) to collect dream reports. Participants were woken up maximum nine times a night. B) **Subjective stress level before sleep:** participants reported higher stress levels in the stress condition compared to the relax condition (main effect of condition: $F_{1,53} = 63.76$, $p < .001$, $\eta^2 = 0.28$). The difference was bigger in the pre-sleep group, compared to the post-sleep group (group $\times$ condition interaction: $F_{1,53} = 18.64$, $p < .001$, $\eta^2 = 0.10$). C) **Mean heart rate (HR) in beats per minute (bpm) during the sleep onset period:** no difference was observed in mean heart rate in the sleep onset period between both groups and both conditions (all p -values $> .295$). Means $\pm$ standard errors of the means are indicated. ***: $p \leq .001$.

each awakening. A maximum of four awakenings (excluding first N1 awakening) was performed in each part of the night, resulting in a maximum of eight awakenings per night.

During each awakening, the experimenter followed a standardised procedure. The first question asked was: “What was going through your mind before you woke up?”. If participants reported a dream, they were asked to provide a detailed description of all the dreams they could remember before waking up. They were then asked to rate the presence of positive and negative feelings in their dreams on a 4-point scale (1 = none present; 2 = a little present; 3 = moderately present; 4 = extremely present). This was followed by standardised questions on different aspects of the dreams such as intensity, valence, perceived control over the dream content, etc. (see Supplementary Material). If the participants did not report any dream, they were asked whether they had the impression of having a dream without being able to remember its content. Before sleep, participants were familiarised with the questions asked during the awakenings. The experimenter clarified with the participants that the term “dream” was used here to refer to any mental activity, any image, any perception, or any sensation they had prior to awakening. They were asked to give as many details as they could remember. The awakenings were recorded with Audacity® 3.3.3 and saved for later analyses.

2.4. Stress and Relaxation tasks in virtual reality

The tasks and material used in the present study are the same as the one described in our previous study (see Beck et al., 2023 for further information on the procedure and material used). Both tasks were conducted using an HTC VIVE PRO head-mounted display (<https://www.vive.com>, accessed on April 2, 2024).

To induce acute social stress, a virtual reality version of the Trier Social Stress Test (TSST; Kirschbaum et al., 1993) was used in the stress condition. It has been shown that conducting this task in a virtual reality environment can induce a stress response similar to that experienced in person (Allen et al., 2017; Zimmer et al., 2019). The TSST task consisted of two parts: a 5-min speech and a math exercise, standing in front of a panel of three jury members (here composed of three university professors). During the first part, participants were required to convince a panel of three jury members that they are the best candidate for their dream job position. They had to give a speech for 5 min; if they stopped talking before the 5 min expired, standardised questions were asked according to the TSST manual. Directly after the speech, participants were asked to count backward for 5 min from 2023 in increments of 17, in front of the jury panel. If they made a mistake, they were asked to start again at 2023. The same 15-min pre-recorded virtual reality video was used as in our previous study (Beck et al., 2023) and presented with Skybox VR Player (<https://skybox.xyz/en/>, accessed on April 2, 2024). In the instructions given onscreen before the task, participants were told that (1) a video and audio of their performance would be recorded for later behavioural and vocal analyses; (2) the task has been proven to induce psychological and physiological stress; (3) a high performance on this task indicates good resilience and stress management, while a low performance is associated with a higher risk for health issues such as cardiovascular diseases, sleep disturbances, depression and burnout; (4) their performance would be compared to their age group and if they perform very well in both parts of the task (speech and math), they would receive an additional payment of 10 CHF; (5) a high performance is crucial for the successful development of the study and the dissertations associated with the project. Directly after the task, a verbal debriefing was given to the participants informing them that no further feedback on their performance would be given, as neither video nor audio were recorded and that all subjects receive the additional payment of 10 CHF. A written debriefing sheet including the same information was signed by each subject at the end of the experiment.

In the relaxation condition, participants were asked to choose a beautiful nature-based virtual reality environment (e.g., tropical beach,

green meadow, underwater ocean) from Nature treks VR (<https://greengames.net/>, accessed on April 2, 2024), launched with Steam (Valve Corporation). They were asked to choose the environment they felt was more relaxing, based on a representative image in the game menu. After being familiarised with the environment, they were asked to search for a relaxing place within the chosen environment where they would stay for 10 min and relax. No further instructions were given. During the task, subjects were sitting on chair. In the instructions given onscreen before the task, participants were told that (1) no video or audio would be recorded; (2) the task has been proven to induce psychological and physiological relaxation; (3) relaxation is associated with health and well-being, high resilience and good stress management, and reduces the risk of cardiovascular diseases, sleep disturbances, depression and burnout; (4) no further analyses or comparison to other subjects would be performed on this task; (5) the payment would not be affected by this task.

The post-sleep group received the instructions for the task before sleep and again, after sleep before conducting the task. In both conditions, subjects were asked to indicate their subjective level of stress on a 10-point Likert scale (“To what extent do you feel stressed right now on a scale from 1 (= not at all) to 10 (=extremely)?”) at the beginning, after the 5 min (after the speech in the stress condition) and at the end of the 10 min (after the math task in the stress condition). The mean over the three time points was used to assess the subjective level of stress during the tasks.

2.5. Questionnaires

The same questionnaires were used as in our previous study (see Beck et al., 2023, for the complete list of questionnaires). Directly after waking up, participants filled out the Presleep Arousal Scale (PSAS; Nicassio et al., 1985) to assess pre-sleep cognitive and somatic arousal. The intensity of 16 symptoms during the pre-sleep period is rated on a 5-point Likert scale from 1 (= not at all) to 5 (=extremely). Out of the 16 items, eight are measuring cognitive arousal symptoms (e.g., worry about falling asleep, rumination, anxious/depressive thoughts) and eight are measuring somatic arousal (e.g. heart racing, muscle tension). This results in two subscale scores ranging from 8 to 40 with higher scores indicating a higher cognitive or somatic arousal. Regarding cognitive arousal, scores >16 suggest a high cognitive arousal (Kalmbach et al., 2020).

Subjective sleep quality was measured in the morning with the sleep quality subscale of the SF-A/R (Göertelmeyer, 2011), which consists of four indices assessing problems in the initiation and maintenance of sleep, early awakenings with inability to return to sleep and general sleep characteristics. This sleep quality subscale assesses if characteristics of good sleep quality are absent (score = 1) or strongly present (score = 5). In addition, subjective sleep onset latency (SOL) was also analysed.

Before and after sleep in all three sessions, mood and general well-being was assessed with the Multidimensional Mood State Questionnaire (MDBF short form A; Steyer, 1997) and the level of stress was assessed with a single question (“To what extent do you feel stressed right now on a scale from 1 (= not at all) to 10 (=extremely)?”). This question was again asked at the beginning, after 5 min and at the end of the virtual reality tasks.

2.6. EEG recording & sleep scoring

Electroencephalographic (EEG) data was recorded using 12 single gold cup electrodes positioned according to the international 10–20 system (C3, C4, Cz, F3, F4, Fpz, M1, M2, P3, P4, O1, O2) with a BrainAmp amplifier (Brain Products, Gilching, Germany), at a sampling rate of 500 Hz. Cz was used as a physical reference and Fpz as a ground electrode. Two electrodes were used to collect electrooculographic (EOG) data, two bipolar chin electrodes were used to collect

electromyographic (EMG) data and two electrodes for electrocardiographic (ECG) data. Impedances were kept below 10 k Ω . During the task, we attached two additional electrodes in the palm of the left-hand to collect electrodermal activity (EDA).

Following the AASM guidelines (Iber et al., 2007), EEG electrodes were re-referenced to the contralateral mastoids for offline analysis and sleep scoring. Data was pre-processed with BrainVision Analyzer 2.2 (Brain Products, Gilching, Germany), using standard filter settings suggested by the AASM (e.g., EEG 0.3–35 Hz). Sleep was scored offline by an independent scorer according to standard criteria (Iber et al., 2007). In addition, an automated online sleep scoring algorithm was used (U-Sleep; <https://sleep.ai.ku.dk/>; Perslev et al., 2021). In case of disagreement, a third expert scorer was consulted.

2.7. Analysis of dream reports

Dream reports were obtained from NREM and REM sleep epochs in the early and late sleep period as defined by post-hoc sleep scoring. Nine dreams from the late sleep period could not be attributed to a sleep stage due to technical problems (i.e., the EEG was not entirely recorded). Those dreams were however kept in the analyses as we did not differentiate between NREM and REM dreams.

The written dream reports were analysed by three independent scorers trained on how to use the dream scales. Discordant scores were adjudicated by consensus after discussion. All scorers were blind to the conditions and sleep scoring. The unit of analysis was all dream reports of one awakening; in case of several individual dreams being reported in one awakening, a total coding was made for the report. The length of the reports was measured with total word count, after removing words unrelated to the dream itself (e.g., "I don't remember", "I think that ...", etc.). To test the main hypothesis of this study, the reports were rated on the presence of stress- or threat-related elements. When stress- or threat-related elements were present, the intensity of the distress evoked by the stressor was scored on a 4-point scale (0 = no distress evoked; 1 = a little distress evoked; 2 = distress moderately evoked; 3 = extreme distress evoked). The percentage of agreement between the raters was used as a measure of interrater reliability, as suggested by Gackenbach and Kuruvilla (2008). The interrater reliability was 86.13 % for the presence of stress- and threat-related elements, and 83.19 % for the distress intensity.

We also analysed the presence of positive and negative feelings in the dreams, as reported by the participants on a 4-point scale (1 = none present; 2 = a little present; 3 = moderately present; 4 = extremely present). The emotional tone of the dreams was computed by subtracting the negative score to the positive score (positive – negative). The emotional intensity of the dreams was computed by adding the positive score to the negative score (positive + negative).

2.8. Preprocessing and artefact rejection

For power analyses, EEG data pre-processing was performed using BrainVision Analyzer 2.2 (Brain Products, Gilching, Germany). Data was filtered using a high- (0.1 Hz) and low-pass (40 Hz) filter with an additional notch filter at 50 Hz and re-referenced to averaged mastoids. Data was segmented into 30-s epochs of NREM sleep based on sleep scoring results and further segmented into equally sized segments of 2048 data points (4 s, 102 points overlap). Segments with artefacts were automatically rejected, based on the following criteria: (1) a maximum difference in EMG activity <150 μ V in both EMG channels, (2) a maximum voltage step in all EEG channels <50 μ V/ms, (3) a maximum difference in EEG activity <500 μ V in all EEG channels, and (4) a minimum activity in EEG >0.5 μ V in all EEG channels. The criteria for the automatic rejection used in the present study have already been proven efficient in our previous studies (e.g., Baselgia et al., 2023; Beck et al., 2023) and the number of removed segments was manually checked.

2.9. Electrocardiography

Electrocardiogram (ECG) was analysed using Kubios HRV Premium 3.4.3 (Kubios, Oy, Kuopio). The ECG signal was exported in EDF + format using BrainVision Analyzer 2.2.1.8266 (BrainProducts GmbH, Gilching). Kubios HRV Premium offers an automatic artefact correction based on the RR series (the interval between two R-signals) to eliminate ectopic beats and artefacts in unfiltered data (Tarvainen et al., 2014). Data was then analysed in a time and frequency domain and subsequently used for the calculation of the mean heart rate (mean HR measured in beats per minute [bpm]) which served as an index for physiological arousal (Beck et al., 2023; Kogler et al., 2015).

2.10. Statistical analyses

Statistical analyses were performed using Rstudio version 2022.12.0 (R Core Team). To compare the amount of stress/threat incorporations in dream reports, we used Chi-Square tests. The other dream data was analysed using Linear Mixed Models (LMMs) with the within-subject factors condition (relax, stress) and sleep period (early sleep, late sleep), and the between-subject factor group (pre-sleep, post-sleep). Participant ID was included as a random effect to account for inter-individual variability in repeated measures. The main assumptions of linearity, normality and homoscedasticity of residuals were assessed through visual inspection of diagnostic plots and were deemed to be adequately met. Post-hoc tests for significant interactions and main effects consisted of uncorrected pairwise contrasts of estimated marginal means (EMMs) derived from the fitted models. Other data (e.g., sleep data, manipulation check) were analysed with repeated-measures analysis of variance (ANOVA) with the same factors as the LMMs. Exploratory analyses on sleep parameters were not corrected for multiple comparisons. In case of statistically significant results, effect sizes are reported with partial eta squared (η^2) for main effects and interactions, and Cohen's d for t -tests. The level of significance was set to $p < .05$.

3. Results

3.1. Manipulation check

We first analysed whether the manipulation resulted in the desired differences in stress response before sleep. When rating their stress level on a scale from 1 (= not at all) to 10 (=extremely), subjects of both groups were significantly more stressed in the stress condition (4.91 ± 0.30) compared to the relax condition (2.65 ± 0.24 ; main effect of condition: $F_{1,53} = 63.76$, $p < .001$, $\eta^2 = 0.28$). The interaction between the factors group and condition was also significant ($F_{1,53} = 18.64$, $p < .001$, $\eta^2 = 0.10$), indicating that the difference was bigger in the pre-sleep group (stress: 5.23 ± 0.50 ; relax: 1.65 ± 0.24 ; $t_{25} = -7.49$, $p < .001$, $d = 1.47$) compared to the post-sleep group (stress: 4.62 ± 0.36 ; relax: 3.55 ± 0.32 ; $t_{28} = -3.08$, $p = .005$, $d = 0.57$; see Fig. 1B). For objective stress, we analysed the mean heart rate (HR; in beats per minute) during the sleep onset period (from Lights Off to the first sign of N1). One outlier was excluded from this analysis. No difference was observed (all p -values $> .295$; see Fig. 1C). In addition, we observed no difference neither in cognitive nor somatic subjective pre-sleep arousal (all p -values $> .325$). Overall, participants reported a cognitive arousal of 18.44 ± 0.50 , which is above the cut-off of 16 suggesting a high cognitive arousal. The overall mean for somatic arousal was lower (13.20 ± 0.36). Therefore, our manipulation was successful in increasing subjective level of stress, specifically in the group who did the task right before sleep.

During the tasks, the subjective and objective stress levels were also higher in the stress condition compared to the relax condition. On the subjective level, participants reported a significantly higher level of stress during the stress task (5.19 ± 0.27 ; mean over three time points,

see “Stress and Relaxation tasks ...” section) compared to the relax task (1.76 ± 0.14 ; main effect of condition: $F_{1,53} = 174.85$, $p < .001$, $\eta^2 = 0.56$). The interaction between group and condition was significant ($F_{1,53} = 6.69$, $p = .012$, $\eta^2 = 0.05$) indicating that the difference was higher in the pre-sleep group (stress: 5.83 ± 0.36 ; relax: 1.70 ± 0.20 ; $t_{25} = -11.47$, $p < .001$, $d = 2.25$) than in the post-sleep group (stress: 4.61 ± 0.38 ; relax: 1.83 ± 0.21 ; $t_{28} = -7.41$, $p < .001$, $d = 1.38$). On the objective level, we analysed the mean heart rate (HR; in beats per minute) during the VR task (ca. 10 min). Corroborating the subjective stress level, the mean HR was significantly higher during the stress task (93.81 ± 2.09) compared to the relax task (76.36 ± 2.34 ; main effect of condition: $F_{1,53} = 54.73$, $p < .001$, $\eta^2 = 0.22$). We observed no main effect of group, nor interaction (both p -values $> .603$).

3.2. General characteristics of the dreams

Overall, 772 awakenings (94.61 %) resulted in a dream: on 104 (13.47 %) of those awakenings, subjects did not remember the content of their dream (white dream), and on 668 (86.53 %), subjects provided a report. This resulted in a data base of 668 dream reports for the main analyses: 309 dream reports from the early sleep period (278 NREM dreams, 31 REM dreams) and 359 dream reports from the late sleep period (149 from REM, 201 from NREM, 9 uncategorised). There was no difference in the amount of dream reports between both groups or conditions (all p -values $> .082$, see [Supplementary Material Table S1](#)).

The dream reports contained on average 53.25 ± 7.73 words. A linear mixed model was conducted to examine the effects of group (pre, post), sleep period (early, late) and condition (relax, stress) on the number of words in dream reports, with random intercepts for participants. We observed a significant interaction between the factors sleep period and group ($F_{1, 612.88} = 3.89$, $p = .049$). Post-hoc comparisons revealed that, in the late sleep period, the pre-sleep group reported more words (80.84 ± 5.92) compared to the post-sleep group, with an estimated difference of 28.4 ± 8.22 words ($t_{78.9} = 3.45$, $p < .001$). No significant difference was found between groups in the early sleep period (pre-sleep group: 43.34 ± 6.20 words; post-sleep group: 30.11 ± 5.83 words; $p = .124$; see [Table 3](#)). Independent of the sleep period, the dream reports of the pre-sleep group contained significantly more words (62.09 ± 5.39) compared to the post-sleep group (41.28 ± 5.12 ; $F_{1,53.82} = 7.84$, $p = .007$). In addition, dream reports were generally longer in the late sleep period (66.6 ± 4.11) compared to the early sleep period (36.7 ± 4.26 ; $F_{1,612.88} = 60.66$, $p < .001$). No other interactions were observed (all p -values $> .640$). The model explained 27 % of the variance (conditional $R^2 = 0.273$; marginal $R^2 = 0.108$).

Overall, 101 dreams (15.12 %) contained stress- or threat-related elements (see [Table 1](#) for details and [Table 2](#) for examples).

3.3. Stress- and threat-related elements in dreams

The main aim of this study was to investigate the dynamic changes (early vs. late sleep period) of the presence of stress- and threat-related elements in dreams, depending on whether the stress task (vs. relaxation) occurred before sleep (pre-sleep group) or was anticipated (post-sleep group). Thus, the most relevant conditions for this hypothesis are the early sleep period after the task in the pre-sleep group, and the late sleep period for the post-sleep group, as the task was anticipated to occur after sleep. In contrast to our hypothesis, we did not find a significant

increase in the number of stress-related dreams depending on the experimental condition (i.e., stress-task vs relaxation): the pre-sleep group experienced 12 stress-related dreams (16.2 %) in the early sleep period after performing the stress task and 12 stress-related dreams (16.9 %) after performing the relaxation task. The difference was not significant ($\chi^2_{(1)} = 0.00$, $p = 1.0$). Similarly, the post-sleep group reported 13 stress-related dreams (14.1 %) in the anticipated stress condition in the late sleep period and 12 stress-related dreams (13.2 %) when anticipating the relaxation task ($\chi^2_{(1)} < 0.01$, $p = 1.0$; see [Fig. 2A](#)). Similarly, no difference was found in the two other periods (late sleep of the pre-sleep group, early sleep of the post-sleep group; both p -values $> .784$; see [Table 1](#) and [Fig. 2A](#)).

We conducted further analyses on the intensity of the distress evoked by the stressor/threat in those dreams. In these analyses, we used a linear mixed model including only the dreams that contained stress- or threat-related elements. We used the fixed effects of group (pre, post), condition (relax, stress) and sleep period (early, late), and random intercepts for participants. Independently of the groups, the difference between the conditions (stress, relax) differed depending on the sleep period (condition $\times$ sleep period interaction: $F_{1,79.249} = 9.49$, $p = .003$). In the late sleep period, the distress intensity was higher in the stress condition (1.93 ± 0.19 ; scale from 0 = no distress evoked to 3 = extreme distress evoked) compared to the relax condition (1.27 ± 0.20 ; estimated difference: 0.66 ± 0.25 ; $t_{78.4} = 2.64$, $p = .010$). The opposite pattern was found in the early sleep period (stress: 0.92 ± 0.25 ; relax: 1.52 ± 0.25) however, the difference only showed a statistical trend (estimated difference: 0.61 ± 0.34 ; $t_{85.5} = -1.82$, $p = .073$). Moreover, the difference between conditions also varied depending on the groups, irrespective of the sleep period (condition $\times$ group interaction: $F_{1, 81.397} = 6.73$, $p = .011$). In the pre-sleep group, there was a tendency for a higher distress intensity in the relax condition (1.65 ± 0.22) compared to the stress condition (1.14 ± 0.20 ; estimated difference: 0.51 ± 0.26 ; $t_{83.6} = -1.97$, $p = .052$). However, the opposite pattern (stress: 1.70 ± 0.27 ; relax: 1.14 ± 0.26) was not significant in the post-sleep group (estimated difference: 0.56 ± 0.33 ; $t_{84.2} = 1.70$, $p = .092$). The three-way interaction was not significant ($p = .407$; see [Fig. 2B](#)). The model explained 39 % of the variance (conditional $R^2 = 0.385$; marginal $R^2 = 0.177$). To control for potential differences between NREM and REM dreams, we compared our model to a more complex model including the factor sleep stage (NREM, REM). The model comparison was not significant ($\chi^2_{(8)} = 7.73$, $p = .460$), indicating that adding the sleep stage did not significantly improve model fit.

To directly test our hypothesis of temporal differences, we compared the early sleep period to the late sleep period for each group and condition. In both groups, the relax condition did not lead to significant differences between early (pre-sleep group: 1.57 ± 0.31 ; post-sleep group: 1.47 ± 0.39) and late dreams (pre-sleep group: 1.72 ± 0.26 ; $t_{75.9} = -0.41$, $p = .687$; post-sleep group: 0.82 ± 0.31 ; $t_{87.3} = 1.39$, $p = .168$). In the stress condition however, the distress intensity was higher in the late dreams compared to early dreams both in the pre-sleep group (estimated difference: 1.07 ± 0.35 ; $t_{80.7} = -3.03$, $p = .003$) and in the post-sleep group (estimated difference: 0.95 ± 0.47 ; $t_{87.3} = -2.02$, $p = .047$; see [Fig. 2B](#)). Moreover, in the post-sleep group during late sleep (when the upcoming task was in close temporal proximity), the distress intensity was higher in the stress condition (2.14 ± 0.28) compared to the relax condition (0.77 ± 0.28 ; estimated difference: 1.37 ± 0.33 ; $t_{29.2} = 4.19$, $p < .001$; see [Fig. 2B](#) and [Table 3](#)). Unexpectedly, in the pre-

Table 1

Number of dreams containing stress- or threat-related elements in both groups and both conditions, in the early and late sleep period. In parenthesis is the total number of dreams.

	Pre-sleep group				Post-sleep group			
	Stress	Relax	χ^2	p	Stress	Relax	χ^2	p
Early sleep	12 (74)	12 (71)	0.000	1.0	7 (85)	7 (79)	<0.001	1.0
Late sleep	21 (92)	17 (85)	0.075	0.784	13 (92)	12 (91)	<0.001	1.0

Table 2
Examples of dreams scored as containing stress- or threat-related elements, translated from French.

	Pre-sleep group		Post-sleep group	
	Stress	Relax	Stress	Relax
Early sleep	I was in a forest [...], I had a mission and there were monsters in the trees, watching me [...].	I was doing a math exam, and it was not going very well. [...]. I was really struggling.	I was feeling anxious. I had the impression that I couldn't breathe, as if I was under water.	[...] The aim was to scare me, so they sprayed a gas where we couldn't breathe. So, I ran to lock me in a room so I could breathe. [...]
Late sleep	I had the impression to be paralysed, I couldn't move. [...] I was scared. There wasn't a real danger, but I wasn't feeling well.	It was a nightmare [...], I was being chased. [...] We were trying to escape; we were in the forest. We were getting shot by some kind of robots.	I was in an oral exam where I had to speak [...]. I was in the middle of a field. It was weird and I was stressed.	I had to go upstairs [...] but I had phobia of stairs, and I couldn't get up the stairs [...] every time I was looking behind me [...] it stressed me even more.

sleep group in the early sleep period (when the performed task was in close temporal proximity), the opposite pattern occurred: distress in the dreams containing a stress- or threat-related elements was significantly more intense in the relax condition (1.64 ± 0.29) than in the stress condition (0.53 ± 0.28 ; estimated difference: 1.11 ± 0.36 ; $t_{38.3} = -3.12$, $p = .003$). Thus, while a completed stress task before sleep resulted in a reduction in stress intensity of stressful dreams during early sleep, an anticipated stress after sleep induced an increase in stress intensity of stressful dreams. No significant main effect of group or condition were found (both p -values $> .257$).

3.4. Self-reported emotionality of dreams

Similarly to the previous analysis, we focused this analysis on the dreams containing threat- or stress-related elements. No significant effect was observed (all p -values $> .097$; see Fig. 2C).

When including all dreams in the analysis – rather than solely those containing threat- or stress-related elements –, we observed a very similar descriptive pattern as in the threat intensity of stressful dreams: more negative emotional ratings in the stress condition (vs relax) in the late dreams of the post sleep group, and more positive ratings in the stress condition (vs relax) in the early dreams of the pre-sleep group. The three-way interaction was highly significant ($F_{1,561.49} = 12.35$, $p < .001$). In three of the conditions, the results followed the expected pattern of a more negative emotional tone of the dreams in the stress condition compared to the relaxation condition (late dreams, pre-sleep group: estimated difference: 0.48 ± 0.019 , $t_{559} = -2.51$, $p = .012$; early dreams, post-sleep group: estimated difference: 0.61 ± 0.20 , $t_{566} = -3.00$, $p = .003$; late dreams, post-sleep group: estimated difference: 0.14 ± 0.19 , $t_{561} = -0.76$, $p = .450$). Only in the early dreams of the pre-sleep group did the dreams show an unexpected pattern (estimated difference: 0.46 ± 0.21), with dreams being more negative following the relaxation condition (-0.01 ± 0.17) compared to the stress condition (0.44 ± 0.17 ; $t_{559} = 2.14$, $p = .033$; see Fig. 3 and Table 3). The main effect of sleep period as well as its interaction with the factor group were significant (both p -values $< .006$). The model explained 13 % of the variance (conditional $R^2 = 0.130$; marginal $R^2 = 0.054$). To control for potential differences between NREM and REM dreams, we compared our model to a more complex model including the factor sleep stage (NREM, REM). The model comparison was not significant ($\chi^2_{(8)} = 5.12$, $p = .745$), indicating that adding the sleep stage did not significantly improve model fit.

Similarly to the analysis of the threat intensity, we directly compared the early sleep period to the late sleep period for each group and condition. Only in the relax condition of the pre-sleep group was a significant difference observed: the early dreams were significantly more negative (-0.01 ± 0.17) compared to late dreams (1.05 ± 0.16 ; $t_{558} = -5.22$, $p < .001$; see Fig. 3). The other differences were not significant (all p -values $> .148$).

The emotional intensity was analysed in a similar way, and only a main effect of the sleep period was observed ($F_{1,555.09} = 10.43$, $p = .001$), indicating that the emotional intensity was higher in the late sleep period (1.98 ± 0.12) compared to the early sleep period (1.69 ± 0.12 ; see Supplementary Material Fig. S2). No other main effect or interaction were observed (all p -values $> .170$).

3.5. Subjective and objective sleep quality

Subjective sleep quality was not affected by the conditions (stress, relax), independently of whether the task was performed before sleep or anticipated (see Table 4). No significant results were observed for both main effects (condition, group), nor for the interaction (all p -values $> .771$). No difference was found in subjective SOL either (all p -values $> .440$). For objective sleep, seven subjects (three in the pre-sleep group, four in the post-sleep group) were removed from the analyses of sleep architecture and power analyses due to technical problems during EEG

Table 3

Intensity of the distress evoked by the stress- or threat-related elements in stressful dreams and emotional tone in all dreams.

	Pre-sleep group		Post-sleep group		Main effect of condition		Main effect of group		Main effect of sleep period		3-way interaction	
	Stress	Relax	Stress	Relax	F	p	F	p	F	p	F	p
Distress intensity in stressful dreams												
Early sleep	0.60 ± 0.30	1.57 ± 0.31	1.23 ± 0.41	1.47 ± 0.39	0.01	0.905	0.02	0.903	3.31	.072 ^a	0.70	0.407
Late sleep	1.67 ± 0.23	1.72 ± 0.26	2.18 ± 0.30	0.82 ± 0.31								
Self-reported emotional tone in stressful dreams												
Early sleep	-0.15 ± 0.40	-1.13 ± 0.42	-0.59 ± 0.53	0.14 ± 0.61	0.02	0.900	0.28	0.602	0.02	0.888	1.36	0.248
Late sleep	-0.46 ± 0.30	-0.41 ± 0.36	-0.69 ± 0.42	-0.33 ± 0.42								
Self-reported emotional tone in all dreams												
Early sleep	0.44 ± 0.17	-0.01 ± 0.17	0.27 ± 0.16	0.87 ± 0.16	3.75	.053 ^a	0.04	0.850	7.48	.006	12.35	<.001
Late sleep	0.58 ± 0.15	1.05 ± 0.16	0.44 ± 0.15	0.59 ± 0.15								
Number of words in all dreams												
Early sleep	44.26 ± 7.39	42.41 ± 7.48	29.48 ± 6.93	30.74 ± 7.08	0.22	0.640	7.84	.007	60.66	<.001	0.00	0.980
Late sleep	83.36 ± 6.90	78.32 ± 7.07	53.23 ± 6.75	51.68 ± 6.80								

Notes: The distress intensity was scored on a scale from 0 (= no distress evoked) to 3 (= extreme distress evoked) only in the dreams which contained stress- or threat-related elements. The presence of positive and negative feelings in all the dreams was reported by the participants on a scale from 1 (= non present) to 4 (= extremely present). The emotional tone was computed by subtracting the negative score to the positive score (positive – negative). Values are estimated marginal means (EMM) and their standard error. Main effects and interactions refer to the main analyses between the early sleep of the pre-sleep group and the late sleep of the post-sleep group. The length of the dream reports was measured with total word count, after removing words unrelated to the dream itself (e.g., "I don't remember", "I think that ...", etc.). Values are means ± standard errors of the mean. Significant results are highlighted in bold. ^a: $p < .075$.

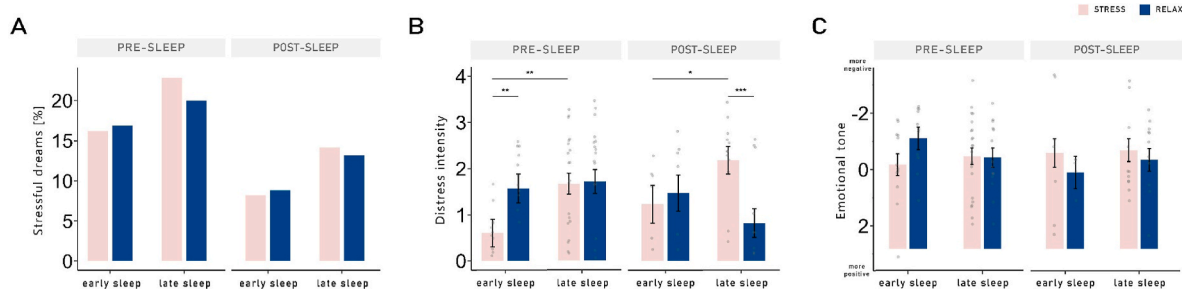


Fig. 2. A) Overall percentages of stressful dreams in the pre-sleep group and the post-sleep group for both sleep periods. No difference was found between both conditions (stress, relax) in either group and sleep period (all $\chi^2 < .075$, all p -values $> .784$). B) Intensity of evoked distress in dreams containing stress- or threat-related elements, in the pre-sleep group and the post-sleep group for both sleep periods. When directly comparing the early to the late dreams for each group and condition, in both groups, the relax condition did not lead to significant differences between early and late dreams (both p -values $> .168$). However, in the stress condition, significant differences were observed in both groups: in the pre-sleep group, the early dreams were significantly less intense compared to the late dreams ($t_{80.7} = -3.03$, $p = .003$); in the post-sleep group, the late dreams were significantly more intense compared to the early dreams ($t_{87.3} = -2.02$, $p = .047$). Moreover, in the late sleep of the post-sleep group, the distress intensity was significantly higher in the stress condition ($t_{29.2} = 4.19$, $p < .001$), while the opposite was found in the early sleep period of the pre-sleep group ($t_{38.3} = -3.12$, $p = .003$). C) Self-reported emotional tone (positive – negative) of the stressful dreams in the pre-sleep group and the post-sleep group for both sleep periods. A similar pattern was observed: in the pre-sleep group, dreams were more negative in the relax condition; while in the post-sleep group, dreams were more negative in the stress condition. However, the differences were not significant (all p -values $> .132$). Estimated Marginal Means (EMM) ± their standard errors are shown. ***: $p \leq .001$; **: $p \leq .01$.

recording. These subjects were kept in the analysis of SOL, slow-wave sleep (SWS) latency and REM latency. A significant interaction between the factors group and condition was found for the latency to reach SWS ($F_{1,53} = 6.19$, $p = .016$, $\eta^2 = 0.04$). Indeed, in the pre-sleep group, subjects took longer to reach SWS in the relax condition (25.50 ± 2.83 min) compared to the stress condition (16.52 ± 0.80 min; $t_{25} = 2.42$, $p = .023$, $d = 0.47$), while no difference was observed in the post-sleep group (stress: 17.38 ± 1.29 ; relax: 16.59 ± 0.92 ; $p = .638$). We also observed a significant main effect of condition ($F_{1,53} = 4.34$, $p = .042$, $\eta^2 = 0.03$), indicating that the latency to reach SWS was generally higher in the relax condition (20.80 ± 2.12) compared to the stress condition (16.97 ± 1.08). Moreover, there was a statistical trend for an interaction between the factors group and condition for the time spent in REM (minutes: $F_{1,46} = 3.72$, $p = .060$, $\eta^2 = 0.03$; percentage: $F_{1,46} = 3.19$, $p = .081$, $\eta^2 = 0.02$) which showed that in the pre-sleep group, subjects spent less time in REM in the relax condition (minutes: 66.96 ± 2.07 ; percentage: 14.59 ± 0.42) compared to the stress condition (minutes: 77.35 ± 2.71 ; $t_{22} = -2.17$, $p = .041$, $d = 0.45$; percentage: 16.77 ± 0.58 ; $t_{22} = -2.11$, $p = .047$, $d = 0.44$), while no difference was seen in the post-sleep group (both p -values $> .516$). No other effect was found in the other parameters of sleep architecture (minutes and percentage spent in

Wake, N1, N2, SWS, Total Sleep Time (TST), SOL, REM latency; all p -values $> .134$; see Table 4). We also measured objective sleep quality with the SWA/beta power ratio in the frontal area and no difference was observed (all p -values $> .372$).

4. Discussion

In this study, we investigated the impact of both completed and anticipated stress on subsequent dream content in the early and late sleep period respectively. Generally, stress before or after sleep did not influence the number of stressful dreams, compared with the relax condition. However, when focusing only on the stressful dreams, we observed dynamic changes in the intensity of the distress evoked by the stress- or threat-related elements (as rated by independent raters). When stress was anticipated to occur after sleep (post-sleep group), dreams in the late sleep period in particular were more stressful and intense compared to the dreams of the early sleep period and compared to when relaxation was anticipated. In contrast, completion of the stress task (TSST) before sleep reduced the intensity of stressful dreams in the early sleep period compared with the late dreams and with the VR relaxation condition. A similar result pattern was descriptively observed in the

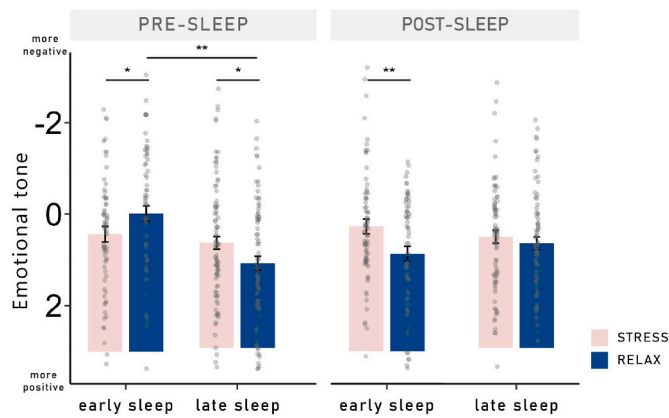


Fig. 3. Self-reported emotional tone (positive – negative) of all the dreams in both groups and both sleep periods. The three-way interaction was highly significant ($F_{1,561.49} = 12.35$, $p < .001$). In three of the conditions, the results followed the expected pattern of a more negative emotional tone of the dreams in the stress condition compared to the relax condition. Only in the early dreams of the pre-sleep group did the dreams show an unexpected pattern, with dreams being more negative following the relax condition compared to the stress condition ($t_{559} = 2.14$, $p = .033$). When directly comparing the early to the late dreams for each group and condition, only the relax condition of the pre-sleep group showed a statistical difference: the early dreams were more negative compared to the late dreams ($t_{558} = -5.22$, $p < .001$). The other differences were not significant (all p -values $> .148$). Estimated marginal means (EMM) $\pm$ their standard errors are represented. **: $p \leq .01$; *: $p \leq .05$.

emotional tone of dreams as rated by the participants themselves.

In accordance with our hypothesis, the anticipation of stress did result in more stressful dreams in the late part of sleep. This suggests that the anticipation of a stressful event after sleep affects mostly the mental content of later periods of the night, which are in closer temporal proximity to the anticipated stress. This finding aligns with our previously reported dynamic changes of slow-waves and sleep spindles, which mainly occurred in later parts of a nap when a stress task was anticipated after sleep (Beck et al., 2023). During wakefulness, the anticipation of future events becomes more active or is reactivated

closer to the expected event, a phenomenon which is conceptualised as prospective memory (McDaniel and Einstein, 2007). Similarly, before sleep, we are capable to plan future actions. These pre-sleep intentions remain active during sleep and influence our sleeping behaviour, e.g., responding to certain sound with a certain action (e.g., on-call situations, responding to baby cries) and even timing the end of our nocturnal sleep (self-awakenings; for a review see Verga et al., 2023). Interestingly, we have recently shown that also event-related brain responses to tones presented during sleep are altered depending on our pre-sleep intentions to react to these tones (Combertaldi et al., 2022). Thus, our pre-sleep intentions and anticipation seem to remain active or be reactivated during sleep, exerting an influence on our sleep and our mental activity during sleep. The data reported in the current study supports this notion, as the anticipation of a stressful event influences distress intensity of dream reports. Our finding that this influence occurs mainly in the second part of the night suggests a time-dependent activation or reactivation of the anticipation of stress during sleep. Nevertheless, given that no three-way interaction was observed when comparing with the other sleep periods, further studies are required to confirm our conclusions. In addition, it can only be speculated whether the changes of stress intensity in dream reports are causally related to changes in sleep architecture associated with stress anticipation (e.g. as reported by Beck et al., 2023), or whether both changes in sleep and dream reports are caused by a third, rather unconscious process of reactivation of intentions and anticipation of events during sleep. It is also interesting to note that shorter dreams were reported in the late sleep period of the post-sleep group. Those dreams also showed a more neutral emotional tone compared to the other conditions. Also over the whole night, the post-sleep group reported shorter dreams than the pre-sleep group. As the sample characteristics of the two groups were highly similar, these differences in dream report length might be causally related to the anticipation vs the completion of a (stress) task. It can be speculated that the anticipation induced a preoccupation with the upcoming task, thereby reducing the length of dream reports. This explanation would explain why the strongest difference in dream report length was observed in the late sleep period of the post-sleep group, as the preoccupation with the upcoming task should increase as the task comes closer in time. Alternatively, the completion of a task before sleep could have induced more and longer dreaming activity leading to longer

Table 4
Subjective and Objective sleep parameters.

	Pre-sleep group		Post-sleep group		Main effect of condition			Main effect of group			Interaction effect		
	Stress	Relax	Stress	Relax	F	p	η^2	F	p	η^2	F	p	η^2
Subjective Sleep Parameters													
Cognitive PSA	18.21 $\pm$ 0.98	17.77 $\pm$ 1.13	18.90 $\pm$ 1.00	18.79 $\pm$ 0.93	0.16	0.691	<0.01	0.46	0.499	<0.01	0.06	0.806	<0.01
Somatic PSA	13.62 $\pm$ 0.84	12.65 $\pm$ 0.69	13.21 $\pm$ 0.65	13.31 $\pm$ 0.72	0.64	0.426	<0.01	0.02	0.891	<0.01	0.99	0.325	<0.01
Sleep Quality	3.37 $\pm$ 0.15	3.40 $\pm$ 0.14	3.37 $\pm$ 0.15	3.35 $\pm$ 0.14	0.00	0.969	<0.01	0.02	0.890	<0.01	0.09	0.771	<0.01
SOL	26.96 $\pm$ 2.59	26.15 $\pm$ 2.50	24.31 $\pm$ 2.76	26.21 $\pm$ 2.63	0.10	0.754	<0.01	0.15	0.696	<0.01	0.61	0.440	<0.01
Objective Sleep Parameters													
SOL [min]	31.56 $\pm$ 4.75	34.31 $\pm$ 5.49	34.10 $\pm$ 4.49	35.19 $\pm$ 4.78	0.33	0.567	<0.01	0.08	0.778	<0.01	0.06	0.804	<0.01
WASO [%]	14.94 $\pm$ 1.34	15.96 $\pm$ 1.36	13.57 $\pm$ 1.07	14.12 $\pm$ 1.16	0.61	0.438	<0.01	1.28	0.264	0.02	0.05	0.816	<0.01
N1 [%]	5.93 $\pm$ 0.41	5.80 $\pm$ 0.46	6.09 $\pm$ 0.47	5.80 $\pm$ 0.44	0.65	0.423	<0.01	0.02	0.890	<0.01	0.10	0.748	<0.01
N2 [%]	47.74 $\pm$ 0.97	48.77 $\pm$ 1.00	47.88 $\pm$ 0.95	46.90 $\pm$ 1.34	0.00	0.982	<0.01	0.44	0.509	<0.01	1.51	0.225	<0.01
SWS [%]	14.62 $\pm$ 0.77	14.88 $\pm$ 0.90	15.69 $\pm$ 0.89	15.90 $\pm$ 1.07	0.14	0.712	<0.01	0.83	0.368	0.01	0.00	0.966	<0.01
REM [%]	16.77 $\pm$ 0.84	14.59 $\pm$ 0.61	16.79 $\pm$ 0.97	17.26 $\pm$ 0.99	1.31	0.258	0.01	1.83	0.182	0.02	3.19	0.081 ^a	0.02
TST [min]	461.57 $\pm$ 3.55	459.30 $\pm$ 7.63	459.20 $\pm$ 5.61	468.04 $\pm$ 4.98	0.61	0.439	<0.01	0.22	0.639	<0.01	1.74	0.194	0.01
SWS Latency [min]	16.52 $\pm$ 1.17	25.50 $\pm$ 4.12	17.38 $\pm$ 1.77	16.59 $\pm$ 1.26	4.34	.042*	0.03	2.32	0.134	0.03	6.19	.016*	0.04
REM Latency [min]	118.98 $\pm$ 9.86	136.96 $\pm$ 9.51	118.48 $\pm$ 9.96	121.62 $\pm$ 9.94	1.79	0.187	0.01	0.47	0.494	<0.01	0.88	0.352	<0.01

Notes: Cognitive and somatic pre-sleep arousal (PSA) are based on subjective ratings in the Presleep Arousal Scale (PSAS; Nicassio et al., 1985) with higher scores indicating a higher cognitive or somatic arousal. Regarding cognitive arousal, scores >16 suggest a high cognitive arousal (Kalmbach et al., 2020). Subjective sleep quality and SOL are based on subjective ratings in the SF-A/R (Görlmeyer, 2011). Objective values are based on polysomnographic recordings. Non-rapid eye movement sleep (NREM), stage 1, 2, 3 sleep (N1, N2, SWS), rapid eye movement sleep (REM), wake after sleep onset (WASO), total sleep time (TST), sleep onset latency (SOL), slow wave sleep (SWS) latency, REM sleep latency are indicated as percentages of TST [%]. Values are Means (M) $\pm$ Standard Error of Mean (SEM). * indicates $p < .05$, ^a indicates $p < .09$. Significant results are highlighted in bold. η^2 represents the effect sizes where a value below or equal to 0.02 reflects a small effect, a value between 0.02 and 0.14 reflects a medium effect, and a value above 0.14 represents a large effect.

dream reports. An additional experimental control condition without any task before or after sleep would be necessary to decide between these alternative interpretations. Future studies should consider investigating whether quantitative and qualitative differences can be observed in dreams in the context of anticipation or preoccupations as shown during wakefulness with lower verbal performance in cognitively loaded situations (e.g., King and Finn, 2017; Vytal et al., 2013).

While the result of the anticipation of stress and higher distress in late-night dreams aligned with our hypothesis, the result pattern in the pre-sleep group did not. Here, stress intensity in dreams of the early sleep was significantly lower after pre-sleep stress compared with the relaxation condition. In fact, stress intensity in early dreams after the relaxation condition was notably elevated, and the participants themselves rated their dreams after the relaxation task as very negative, even more negative than in all other conditions. One possible explanation is that the completion of a stressful task does not result in ongoing negative mental activity during sleep. In fact, it was shown that the successful completion of a (stressful) task can induce feelings of relief (Hoerl, 2015; Sweeny and Vohs, 2012), which might be reflected in dream emotions according to the dream continuity hypothesis (Schredl and Reinhard, 2010). Interestingly, the effects of pre-sleep stress on sleep are rather mixed and might be influenced by the temporal dynamics of the physiological response to stress: increases in cortisol and heart rate are typically observed to last ca. 60 min after the stressor (e.g., Ackermann et al., 2019; Becker and Rohleder, 2019; Bellingrath et al., 2013; Janson and Rohleder, 2017). Thus, performing a stressful task directly before sleep will typically increase sleep latency and reduce sleep quality (Kim and Dimsdale, 2007). However, when the physiological stress response is back to normal, no effect or even improvements of sleep might be observed after the completion of stress. In a previous study from our group, we found that watching a suspenseful TV series before sleep led to small decreases in objective sleep quality in the early sleep period (i. e., less slow-wave sleep, lower slow-wave/beta ratio), but a shorter sleep onset latency (Baselgia et al., 2023). Also in our nap study, slow-wave and spindle parameters were even increased in the later parts of the nap when stress occurred before sleep (Beck et al., 2023). And recently, Hein et al. (2024) reported even improvements in sleep when the stress task (VR TSST) was performed ca. 2 h before nocturnal sleep onset. Thus, completion of stress before sleep might actually improve sleep when the direct physiological consequences of stress are attenuated. This notion would fit to the reduction in distress in dreams after completion of the stress task in the pre-sleep group, although more studies are needed to explore these effects further.

Still, a striking result of our study is also that participants rated the emotional tone of their dreams very negatively after completion of the relaxation task in the early sleep period. Typically, relaxation tasks like progressive muscle relaxation, meditation or breathing exercises are well-known to reduce sleep onset latency and improve sleep quality (e. g., Rusch et al., 2019; Simon et al., 2022). However, here we used an atypical relaxation task in a virtual setting (to control for the VR setting of the stress task). Thus, it can be hypothesised that using a VR-based relaxation setting before sleep might generally have negative consequences on sleep and mental activity during sleep. Notably, this effect was only found when VR was used before sleep and was not observed in the post-sleep group who did not perform any VR task before sleep. Thus, using VR relaxation directly before sleep might generally affect our dreams (see also Picard-Deland et al., 2021). Indeed, subjective ratings of emotional tones and also the distress ratings by the independent raters revealed that dreams were more negative in the relaxation condition of the pre-sleep group. Future studies should directly compare relaxation effects on sleep by VR settings vs. traditional settings. Furthermore, it is noteworthy that the emotional intensity of the dreams remained unaltered by our manipulations. It is known that (REM) dreams from the late part of the night typically are more emotional than early (REM) dreams (Fosse et al., 2001; Sikka et al., 2018; Wamsley et al., 2007). This observation was replicated in the current study. Whilst

this would be expected to bias our results, it appears that this was not the case in our study, speaking for an independence between both variables.

Our results need to be confirmed with further studies which might consider increasing the personal significance of the stressor, as artificial stress might not affect sleep, nor dreams (Akerstedt, 2006). Our sample consisting mainly of university students, it might be possible that their daily life contains more stressful events – such as exams – that might interfere with our manipulation. Moreover, we performed up to nine awakenings per night, which might have added a source of worry for our subjects. Indeed, they reported a generally higher pre-sleep cognitive arousal as compared to our previous study (Beck et al., 2023). This is also illustrated by a relatively high number of dreams containing elements of the sleep laboratory (24.96 %). A recent study suggested that lab incorporations in dreams might be caused by higher levels of arousal (Picard-Deland et al., 2021) which would support the idea that our design, containing many awakenings, might have induced stress in some of our participants. Moreover, this high number of “laboratory dreams” might also explain the lack of increase of stress-related dreams in our study. Indeed, the laboratory situation might have competed with our stress induction manipulation resulting in dream incorporations due to salience, as observed in previous studies (Trenholme et al., 1984). Furthermore, it has been demonstrated that external raters tend to underestimate dream emotions compared to self-ratings (Schredl and Doll, 1998; Sikka et al., 2014). While we followed the recommendations to use self-rating scales to measure dream emotions (Schredl, 2010), it is important to be aware that our external ratings of distress intensity might not completely reflect the dreamer’s experience.

In our study, we focussed on threat-related elements and emotional intensity as we expected a broad effect of (anticipated) stress on dream content. However, it would be worthwhile to include a measure of concrete task incorporation which could be compared to laboratory incorporations and would provide more detailed insights into the incorporation competition. Future studies might also want to include a control condition without any task to be able to also interpretate the effects of the relaxation task on dreams. Relaxation techniques have been shown to improve both sleep quality and negative emotions (e.g., anxiety, depression; Blanaru et al., 2012; Xiao et al., 2020). It is therefore possible that our relaxation task impacted some aspects of the dreams – such as the emotional tone – biasing the interpretation of the effects of the stress task. Previous studies already showed promising results for relaxation techniques in clinical population, such as patients with insomnia, or with nightmare disorders (Davis and Wright, 2005; Means et al., 2000). Therefore, exploring the effects of relaxation on dreams might help in understanding and creating appropriate therapy.

In conclusion, in the present study, we observed some evidence of a dynamic reactivation of cognitions in dream characteristics. Interestingly, while we expected parameters such as threat-incorporation to be highly impacted, the effects were observed in more subtle parameters, for example the emotionality and the length of the dreams. Indeed, the anticipation of a stressful event negatively influenced distress intensity of stressful dreams in the late sleep period which suggests a time-dependent reactivation of the anticipation of stress during sleep. Moreover, the distress intensity was reduced in the early dreams after the completion of the stressful task, possibly due to the induction of feelings of relief. In contrast, the VR relaxation before sleep negatively impacted the early dreams which speaks against the use of VR protocol right before sleep. While our hypotheses were not fully confirmed, the relatively large sample size ($n = 55$) and the substantial number of dream reports ($n = 668$) gathered from different parts of the night provide a rich dataset that advances the understanding of the relationship between stress and dreams. Future studies might want to consider externally reactivating the stressful event during sleep as an attempt to manipulate dream content. It was recently shown that playing relaxing words during sleep increases sleep depth, suggesting that activating mental concepts during sleep can influence sleep parameters (Beck et al., 2021). Therefore, it would be interesting to investigate this idea further

by observing if the reactivation of completed or anticipated stress during sleep can influence dream content and possibly inform on the functional relevance of these dreams.

CRedit authorship contribution statement

Sandrine Baselgia: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Björn Rasch:** Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Aleksandra Mladenovic, Anouk Déléze, Arnaud Genin, Cécile Grand, Chloé Demagistri, Dansi Sterckx, Emilie Zaza, Erika Dupas, Joana Carrel, Julie Cheseaux, Laetitia Merian, Louisa Schouwey, Mathilde Heyer, Morgane Epiney, Romain Vuillemin, Sophie Dafflon, Théa Rochat, William Scandella, Yaël Frachebourg, Yannick Maring for their great work in the data collection, Arnaud Genin and Romain Vuillemin for their careful help in the dream scoring, and all subjects for their participation. This study was conducted at the Department of Psychology of the University of Fribourg and was funded by a grant of the European Research Council under the European Union's Horizon 2020 research and innovation program (grant agreement number 677875) and the Swiss National Science Foundation (SNSF; grant number 10.002.483).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.neuropsychologia.2025.109311>.

Data availability

Data will be made available on request.

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