

Sandrine Baselgia

The Influence of Pre-Sleep Cognitions on Sleep and Dreams

**Empirical Evidence for Dynamic
Cognitive-Emotional Reactivation**



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THE INFLUENCE OF PRE-SLEEP COGNITIONS ON SLEEP AND DREAMS: EMPIRICAL EVIDENCE FOR DYNAMIC COGNITIVE-EMOTIONAL REACTIVATION

Thèse de doctorat cumulative présentée à la Faculté des lettres et
des sciences humaines de l'Université de Fribourg (Suisse)

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« Dans le sommeil, ce voyage aventureux de tous les soirs, il y a quelque chose de positivement miraculeux; c'est un miracle dont la ponctualité a émoussé le mystère. »

C. Baudelaire, *Les Paradis artificiels*, 1860

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ABSTRACT

Pre-sleep cognitive activity is a well-known factor that affects subsequent sleep; however, the mechanisms underlying these effects remain unclear. The “Memories-of-Sleep” (MemoSleep) hypothesis proposes that pre-sleep wake- and sleep-related memories are reactivated during sleep, which triggers associated neural and physiological responses and shapes sleep physiology and architecture. Dreams may be particularly informative in this context, as they have the potential to reflect ongoing reactivation processes during sleep. The present dissertation aims to provide empirical support for this reactivation mechanism, thereby advancing the understanding of the relationship between sleep and cognition. To this end, four controlled laboratory studies were conducted to investigate distinct aspects of cognitive influence on sleep. Each study was designed to test predictions derived from the MemoSleep hypothesis, allowing its core assumptions to be examined across multiple cognitive mechanisms and experimental contexts.

The first study investigated the effects of binge-watching suspenseful TV series, with and without cliffhangers, on subsequent sleep. Although subjective pre-sleep arousal was increased following suspenseful content, only minor alterations in sleep parameters were observed, restricted to the first two sleep cycles. Surprisingly, sleep onset latency was even shorter following suspenseful TV series. The second study examined whether the reactivation of cognitions during sleep occurs in a time-specific manner, using dream content as indicator of these reactivation processes. To this end, the effects of pre-sleep and anticipated stress on early and late dreams were compared to pre-sleep or anticipated relaxation. Differences in dream emotionality were observed as a function of stress timing, with pre-sleep stress affecting early dreams and anticipated stress impacting late dreams, suggesting a dynamic reactivation of cognitive content during sleep. The third study shifted focus to positive pre-sleep cognitive activity by investigating whether activating the concept of relaxation before sleep improves subsequent sleep quality and physiology. By replicating a previous study from our laboratory with the introduction of a neutral control condition, this study showed differences that suggest a facilitative effect of relaxation-related cognitions on sleep, while simultaneously highlighting the role of anticipatory processes, even in neutral control conditions. Finally, the fourth study investigated whether pre-sleep hypnotic suggestions and circadian manipulation could modulate REM sleep parameters. While circadian manipulation effectively increased REM sleep duration, REM-targeted hypnotic suggestions did not affect REM sleep, highlighting the

limits of cognitive influences on sleep physiology. Furthermore, no evidence was found for a functional role of REM sleep in emotional regulation, as assessed in a karaoke paradigm.

Taken together, the findings provide converging evidence for the reactivation mechanism proposed in the MemoSleep hypothesis, while also highlighting important temporal dynamics and motivating several extensions of the framework. Across studies, pre-sleep cognitive-emotional states appeared to be differentially reactivated during sleep, as reflected in dream characteristics and selective modulations of sleep physiology. Building on these results, an extended MemoSleep framework is outlined to advance the understanding of how cognitive-emotional material shapes reactivation processes during sleep and their consequences for dreams and sleep physiology. The present dissertation thus provides novel insights into the influence of cognitive processes on sleep and dreaming by conceptualising cognitive activity during sleep as a multidimensional continuum, enabling the consideration of individual differences and informing the development of targeted cognitive interventions to improve sleep quality. Overall, this work provides a conceptual framework that enables future research on sleep-promoting cognitions and their interaction with physiological and subjective dimensions of sleep, while also situating dreams as a window into cognitive-emotional processes during sleep.

LIST OF INCLUDED STUDIES

This cumulative dissertation includes the following studies:

Study I:

Baselgia, S., Combertaldi, S. L., Fahr, A., Wirz, D. S., Ort, A., & Rasch, B. (2023). Pre-sleep arousal induced by suspenseful series and cliffhangers have only minor effects on sleep: A sleep laboratory study. *Sleep Medicine*, 102, 186-198.

Study II:

Baselgia, S., & Rasch, B. (2025). Temporal dynamics of the influence of pre- or anticipated post-sleep stress on dream content. *Neuropsychologia*, 109311.

Study III:

Baselgia, S., Beck, J., & Rasch, B. (2025). Anticipation of stress and relaxation dynamically impacts sleep. *Clocks & Sleep*, 7(4), 68.

Study IV:

Baselgia, S., Cordi, M., & Rasch, B. (2026). Can hypnotic suggestions and circadian manipulation increase REM sleep and REM-related emotional processing? A proof-of-concept study. [Unpublished manuscript]. Department of Psychology, University of Fribourg.

LIST OF ABBREVIATIONS

EEG	electroencephalography
EMG	electromyography
EOG	electrooculography
FNE	first night effect
MemoSleep	Memories-of-Sleep hypothesis
N1	non-rapid eye movement stage 1
N2	non-rapid eye movement stage 2
N3	non-rapid eye movement stage 3
NREM	non-rapid eye movement
REM	rapid eye movement
SFSR	sleep to forget, sleep to remember hypothesis
SOL	sleep onset latency
SWA	slow wave activity
SWS	slow wave sleep
TMR	targeted memory reactivation
WASO	wake after sleep onset

1. Introduction

Sleep is vital for human physical and mental health, playing a crucial role in key aspects of human health, notably physical restoration, emotional regulation and cognitive functioning. Indeed, it is well-known that a good sleep quality is essential for a wide range of health outcomes, including endocrine, immune and cardiovascular functions, as well as for psychological well-being (Vorster et al., 2024). Not only is sleep essential to prevent diseases, but it is also necessary, with sleep-related problems being associated with a wide range of adverse outcomes, including increased all-cause mortality (Wallace et al., 2021). Despite the crucial importance of sleep, sleep disturbances are highly prevalent in industrialised Euro-American societies, and their prevalence is rising, affecting a significant proportion of the population (e.g., Madrid-Valero et al., 2017; OFS/BFS, 2024). Consequently, understanding the factors that promote or interfere with sleep represents a priority from both scientific and public health perspectives. Among these factors, cognitive mechanisms appear as highly influential.

Cognitive factors have received increasing attention for their role in shaping sleep experiences. Specifically, rumination, stress, or intrusive thoughts before sleep are well-known barriers to healthy sleep, preventing sleep onset and disturbing ongoing sleep (e.g., Valck et al., 2004; Wicklow & Espie, 2000; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Models of insomnia have paid specific attention to these cognitive influences, conceptualising pre-sleep cognitive arousal as a major driver for sleep disturbances (e.g., Espie, 2002; Harvey, 2002; Perlis et al., 1997). However, despite extensive evidence linking pre-sleep cognitive arousal to difficulties initiating sleep, it remains unclear how cognitive activity continues to affect sleep after sleep onset, and through which mechanisms such influences operate during ongoing sleep. Evidence from memory research has shown that memory traces are reactivated during sleep (Diekelmann & Born, 2010; Rasch & Born, 2013). Building on this observation, the “Memories-of-Sleep” (MemoSleep) hypothesis (Rasch, 2016), extends the idea of reactivation to wake- and sleep-related memories. Specifically, it posits that sleep- and wake-related memories activated before sleep have a high likelihood of being reactivated during subsequent sleep, and that such reactivation triggers the physiological and neural responses associated with sleep or wakefulness respectively, thereby influencing sleep parameters. By proposing a mechanism through which cognitive activity can shape sleep physiology and architecture, the MemoSleep hypothesis enables the generation of testable predictions that can substantially advance the understanding of the relationship between sleep and cognition and

ultimately inform the development of effective interventions to improve sleep quality and treat sleep disorders.

Based on the MemoSleep hypothesis, the present work is composed of four controlled laboratory studies that each investigate different aspects of cognitive influence on sleep. Specifically, media-induced arousal, pre-sleep stress and anticipated stress were explored as negative influences on sleep. On the other hand, relaxation and hypnotic suggestions were used to explore the potential for sleep-promoting cognitive activity. Importantly, dreams, as a form of cognitive activity during sleep, were given specific attention in their potential to reflect the reactivation process postulated in the MemoSleep hypothesis. Indeed, dreams are tightly connected with waking cognitions, often reflecting waking concerns and experiences (Graveline & Wamsley, 2015; Scarpelli et al., 2022). However, their precise relationship with waking cognitions and the extent to which they reflect sleep-related cognitive processes remains poorly understood. Together, these studies aimed to provide a multilevel investigation of the relationship between cognition and sleep, by integrating subjective dream reports with objective sleep measures.

The next section presents the theoretical and empirical background guiding this work. Following an overview on sleep and dreams, current models of insomnia are described. This is followed by an in-depth presentation of the MemoSleep hypothesis (Rasch, 2016), which provides the conceptual framework for the present work. Finally, the negative and positive effects of cognitive activity on sleep and dreams are reviewed. The specific aims of the studies are detailed at the end of the section.

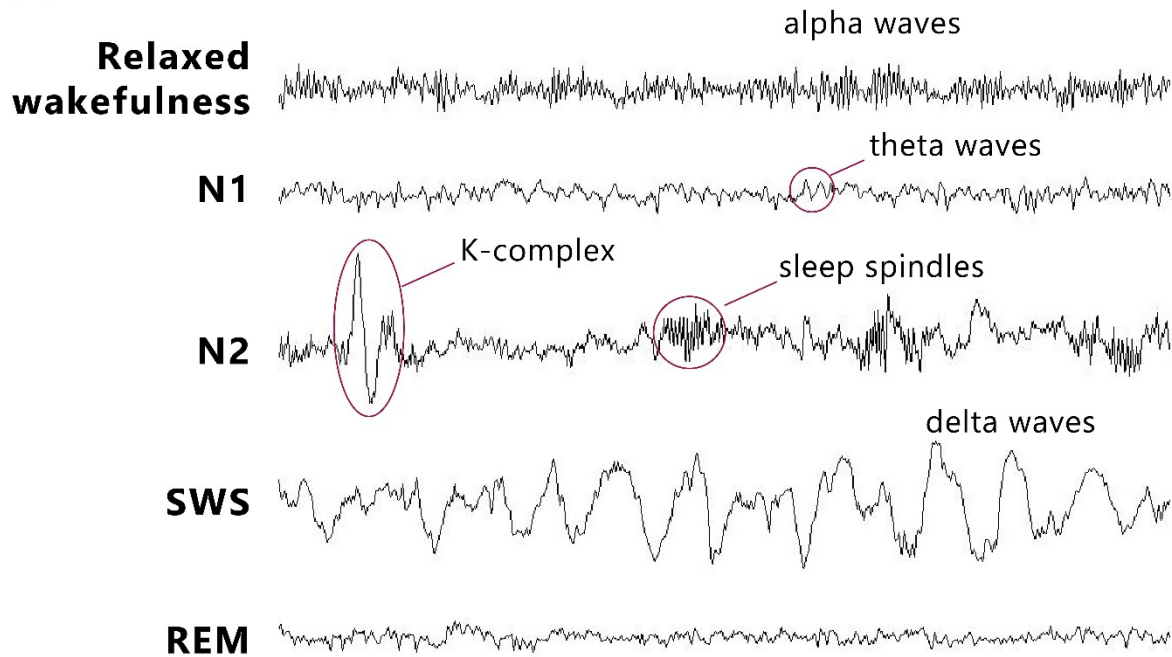
2. Theoretical background

2.1. Sleep

Sleep is defined as a natural and reversible behavioural state marked by a disengagement from and reduced responsiveness to the external environment (Carskadon & Dement, 2005). Physiological measures have substantially advanced the understanding of sleep, facilitated by technologies such as electroencephalography (EEG), electrooculography (EOG) and electromyography (EMG), which measure brain electrical activity, eye movements and muscle activity, respectively. These measures enable the distinction between two principal states of human sleep: rapid eye movement (REM) sleep, characterised by wake-like cortical activity and rapid eye movements, and non-rapid eye movement (NREM) sleep, characterised by synchronised, slower brain activity. NREM sleep is further subdivided into three stages – N1, N2 and N3 – which represent progressively deeper stages of sleep. The first stage, N1, serves as a transitional phase from wakefulness to sleep and can intermittently recur throughout the night, typically accounting for around 2–5 % of total sleep time in healthy adults (Lee-Chiong, 2008). N1 is characterised by a decrease in occipital alpha activity – EEG oscillations in the 8–11 Hz range, typically observed during relaxed wakefulness with eyes closed – and the appearance of slow, rolling eye movements. N2 represents the most prevalent sleep stage, constituting approximately 45–55% of nighttime sleep. It is characterised by two hallmark EEG patterns: (1) biphasic waveforms, known as K-complexes, lasting over 0.5 sec and consisting of a large surface-negative deflection followed by a surface-positive peak, and (2) spontaneous bursts of waxing-and-waning oscillatory activity at 10–16 Hz, lasting 0.5–1 sec, called sleep spindles (Caporro et al., 2012). N3, also referred to as slow-wave sleep (SWS) or deep sleep, is the deepest stage of sleep and typically accounts for about 20% of total sleep time in healthy adults. N3 is characterised by the presence of slow, high-amplitude EEG oscillations within the 0.5–4.5 Hz range, known as slow-wave activity (SWA). Finally, REM sleep, which represents 25% of nighttime sleep, is defined by distinctive features including large, irregular, rapid eye movements, muscle atonia, and fast, low-amplitude, wake-like oscillatory brain activity (see Figure 1A). Across the night, NREM and REM sleep alternate in cycles of approximately 90 minutes with SWS being most dominant in the first third of the night, and REM sleep becoming increasingly prominent in the final third of the night (Carskadon & Dement, 2005; see Figure 1B). In healthy adults, the initial REM episode typically emerges approximately 70 to 90 minutes after sleep onset (Ohayon et al., 2004), suggesting that during a 90-minute nap, REM sleep can be attained and may persist for up to 20 minutes (Feinberg et al., 1992). In summary, sleep is organised into NREM and REM states, each characterised by distinct EEG, EOG and

EMG signatures, providing the physiological framework for investigating the interaction between cognition and sleep, which is central to this dissertation.

A



B

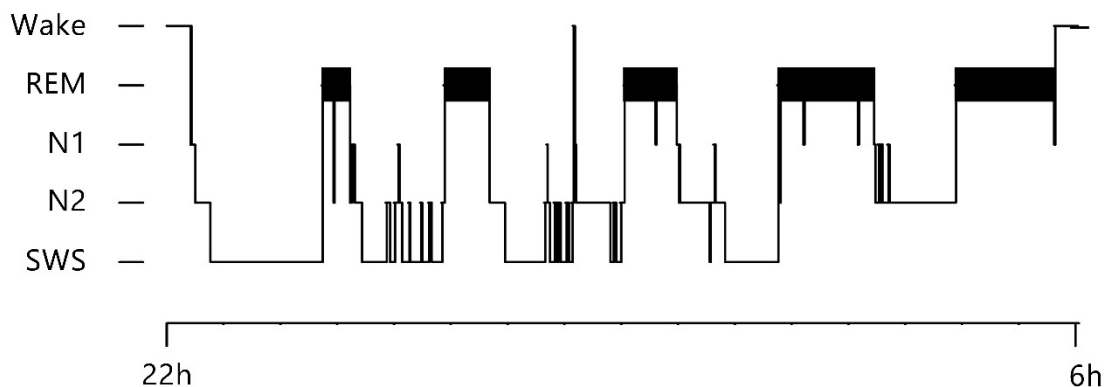


Figure 1: A) EEG brain wave patterns during sleep. Distinct brain activity patterns are observed during the different sleep stages. **B) Sleep architecture of a healthy adult.** NREM sleep (stages N1, N2, SWS) and REM sleep alternate throughout the night in cycles of approximately 90 minutes with a predominance of SWS in the first third of the night, and a predominance of REM sleep in the last third of the night. Retrieved from Baselgia & Rasch (2025).

Having described sleep in terms of its physiological architecture, it is important to consider how sleep is regulated across the 24-hour day, a process captured by the two-process

model proposed by Borbély (Borbély, 1982; Borbély et al., 2016). As conceptualised in this model, the regulation of the sleep-wake cycle is governed by the interaction of two primary biological mechanisms: the circadian process, termed Process C, and the sleep homeostatic process, termed Process S. Process C represents the endogenous biological clock that organises the timing of sleep and wake cycles over a period of approximately 24 hours. This process is regulated by a brain structure located in the hypothalamus called the suprachiasmatic nucleus which responds to light and dark cues. Consequently, Process C promotes wakefulness during the day and sleepiness at night, synchronising the sleep-wake cycle with external cues. Complementing this circadian process, the homeostatic process, Process S, reflects the pressure to sleep that accumulates during wakefulness and dissipates during sleep, ensuring that the body maintains a balance between sleep and wakefulness (see Figure 2). The depth of sleep, as indicated by SWA, is the principal marker of the increase of sleep pressure after a prolonged period of wakefulness: in the first hours of nighttime sleep, SWA increases as a function of the amount of time awake before sleep, and then decreases throughout the night, showing the restorative function of sleep (Borbély et al., 2016; Maric et al., 2017).

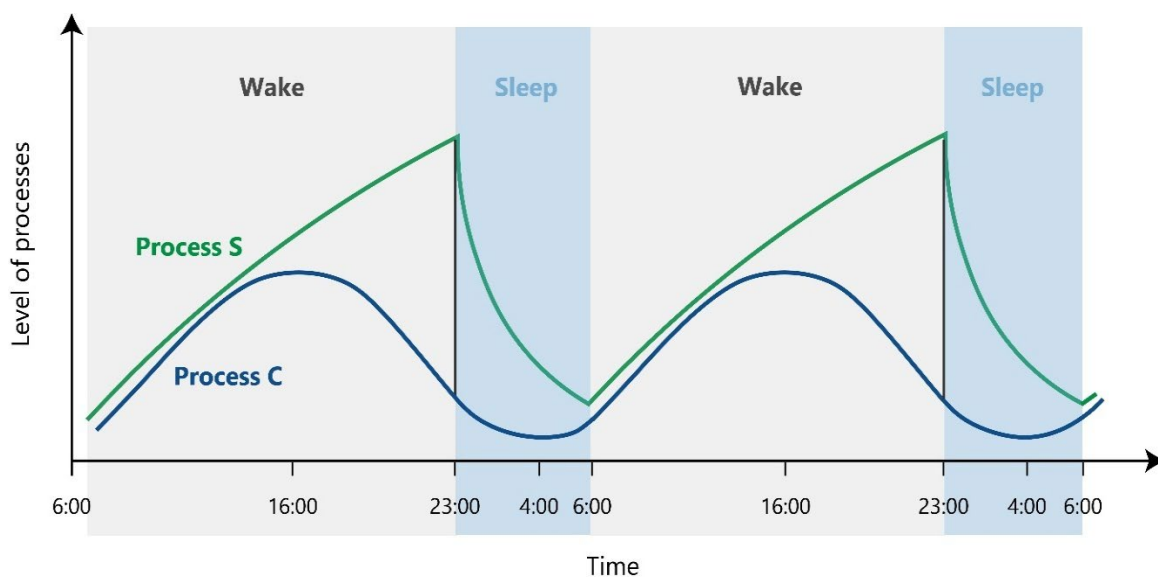


Figure 2: The two-process model of sleep regulation (adapted from Borbély, 1982). The sleep-wake rhythm is regulated by two processes. Process C is the circadian component that represents the endogenous biological clock which organises the timing of sleep and wake cycles over a period of approximately 24 hours. It promotes wakefulness during the day and sleepiness at night, thereby synchronising the sleep-wake cycle with the external environment. Complementing the circadian process, Process S represents the homeostatic process, reflecting the pressure to sleep that accumulates during wakefulness and dissipates during sleep, ensuring that the body maintains a balance between sleep and wakefulness.

Sleep is essential for physical and mental health, as well as for general well-being, and support several essential processes. For example, it contributes to immune system functions (e.g., Besedovsky et al., 2012, 2019; Lange et al., 2010), memory consolidation (e.g., Rasch & Born, 2013; Vorster & Born, 2015), physical and brain restoration (e.g., Desai et al., 2024; Vyazovskiy & Delogu, 2014), and emotional stability (e.g., Allen et al., 2016; Lau et al., 2021). While the precise mechanisms underlying these processes continue to be investigated, there is a scientific consensus regarding the critical role of sleep in supporting overall health (e.g., Irwin, 2015; Vorster et al., 2024) and that sleep disturbances have severe detrimental consequences on physical and cognitive functioning (e.g., Deak & Stickgold, 2010). Evidence suggests that the different stages serve distinct purposes. For example, SWS is known for highly benefitting the immune system, cognitive functioning and brain plasticity (Lange et al., 2010; Rasch & Born, 2013). The functional role of REM sleep, however, remains a debated topic (Peever & Fuller, 2017), with evidence showing its involvement in the consolidation of emotional memories (Diekelmann & Born, 2010; Poe et al., 2010; Wagner et al., 2001), creativity (Cai et al., 2009) and emotion regulation (Goldstein & Walker, 2014; Vandekerckhove & Cluydts, 2010; Vandekerckhove & Wang, 2017). Among these functions, emotion regulation has been a major focus of research, with growing evidence pointing to a central role of REM sleep in emotional processing. Given its relevance to this dissertation, the following paragraphs focus on the mechanisms and evidence linking REM sleep to emotions.

During wake, the generation, processing and regulation of emotional experiences rely in large part on a group of interconnected brain structures known as the limbic system (Underwood et al., 2021). The limbic system includes the amygdala, which plays a crucial role in the processing of emotions, particularly fear (Öhman, 2005). Importantly, these emotion-related structures are also strongly engaged during REM sleep, as evidenced by increased activity in anterior limbic structures, the insula and the medial prefrontal cortex (e.g., Braun et al., 1997; Dang-Vu et al., 2010; Hobson & Pace-Schott, 2002; Maquet et al., 1996; Miyauchi et al., 2009). Beyond the activation of limbic structures, REM sleep is characterised by a broader neurophysiological milieu that appears particularly favourable for the processing of emotionally charged experiences. For example, a nucleus in the brainstem called the locus coeruleus is inhibited (Aston-Jones & Bloom, 1981a, 1981b). As the locus coeruleus is the primary source of noradrenaline in the brain, its inhibition during REM sleep results in noradrenergic levels lower than during NREM sleep or wakefulness (Ouyang et al., 2004; Shouse et al., 2000). This reduction during REM sleep is of particular interest as noradrenaline

is thought to modulate emotional processing during wakefulness by heightening vigilance, arousal and responsiveness to emotionally salient stimuli, especially stress-related ones (Bang et al., 2023; Van Stegeren, 2008; Van Stegeren et al., 2005). Thus, these observations suggest that REM sleep may play a key role in emotional processes, through its distinctive pattern of neural activation and neurochemical profile.

This distinctive REM neurochemical environment, characterised by low noradrenergic tone and high acetylcholine, forms the basis of the “sleep to forget, sleep to remember” (SFSR) hypothesis (Van der Helm & Walker, 2009), which proposes that REM sleep consolidates the factual and contextual elements of emotional memories while simultaneously attenuating the intensity of their associated emotional charge. At the network level, the predominance of theta oscillations during REM sleep may further facilitate this process by coordinating large-scale neural networks that would integrate the reactivated experiences into existing memory structures (Buzsáki, 2002). In sum, the reactivation of emotional experiences within a neurochemical environment largely devoid of aminergic modulation, combined with network-level integration supported by REM-specific oscillatory activity, is thought to maintain and strengthen the memory content while reducing the emotional responses they typically elicit. Numerous studies support the first component of the SFSR hypothesis, namely that emotional memories are consolidated during REM sleep (e.g., Cunningham et al., 2014; Groch et al., 2013, 2015; Lara-Carrasco et al., 2009; Nishida et al., 2009; Wiesner et al., 2015). For example, several studies demonstrated that memory for emotional (vs. neutral) pictures or texts is typically enhanced after late REM sleep-rich sleep in comparison with early SWS-rich sleep (Carr & Nielsen, 2015; Nishida et al., 2009; Wagner et al., 2001; Wiesner et al., 2015). Moreover, better retention of emotional material has been associated with greater amounts of REM sleep in naps (Nishida et al., 2009) and nighttime sleep (Wiesner et al., 2015). Evidence for the second component of the SFSR hypothesis, namely the attenuation of the emotional charge, is also supported by empirical evidence. For example, a pre-to-post-sleep reduction of the amygdala activity was observed during the viewing of emotional pictures (Van der Helm et al., 2011), and sleep deprivation leads to an increased amygdala activation in response to negative stimuli (Yoo et al., 2007). As the amygdala is critically involved in emotional processing, this reduction in activity suggests that REM sleep helps attenuate the emotional charge of memories, while preserving their factual content, as stated in the SFSR hypothesis. Moreover, Gujar et al. (2011) used a face recognition task and observed a decreased reactivity to negative emotions, specifically fear and anger, after a 90-min nap opportunity. In contrast,

emotional reactivity was increased for positive emotions such as happiness. Interestingly, these effects were observed only in the subjects who reached REM sleep during the nap opportunity, speaking for a specific role of REM sleep in emotional processing (Gujar et al., 2011; see also Nishida et al., 2009).

However, evidence for a REM-specific role in emotional processing remains inconsistent. Recent meta-analyses report that sleep does not selectively enhance emotional memory, nor does REM sleep specifically confer a consistent additional retention benefit when emotional and neutral material are compared (Lipinska et al., 2019, 2022; Morgenthaler et al., 2014; Rawson & Jackson, 2024; Schäfer et al., 2020). Evidence for a systematic attenuation of emotional reactivity is also mixed (e.g., Baran et al., 2012; Cellini et al., 2016; Tempesta et al., 2015; Werner et al., 2015; Wiesner et al., 2015), with reviews highlighting no straightforward relationship between REM sleep duration and reduced emotional responses (Cunningham et al., 2014; Rawson & Jackson, 2024; Schäfer et al., 2020). To reconcile these findings, recent theoretical accounts propose that emotional processing may unfold dynamically across multiple nights, with REM sleep initially increasing next-day emotional reactivity before contributing to long-term reduction in emotional responses across the following nights (Werner et al., 2015, 2021; see also Deliens & Peigneux, 2014). Given this mixed and sometimes contradictory evidence, new approaches are needed to clarify the mechanisms linking REM physiology and emotional processing. In particular, it remains unclear whether emotional processing during REM sleep is intrinsically linked to the specificity of REM dreaming (see 2.2. *Dreams*). Taken together, these findings suggest that REM sleep provides a unique neurophysiological environment for the reactivation and integration of affective experiences. However, despite strong correlational evidence, experimental manipulations of REM sleep remain scarce, making it difficult to establish a causal role of REM sleep in emotional processing.

Beyond the role of REM sleep in emotional processing, sleep serves numerous functions that are essential for health and well-being. However, sleep problems are increasingly present and are one of the most common complaints associated with industrialised lifestyle in Euro-American countries (Ohayon et al., 2004). Sleep disturbances are associated with the development of major diseases, including cardiovascular diseases, hypertension, diabetes, obesity and Alzheimer's disease (e.g., Cappuccio et al., 2010, 2011; Reddy & Van der Werf, 2020; St-Onge, 2017). Moreover, sleep problems negatively affect psychological health (e.g., increased depressive symptoms; e.g., Bei et al., 2016; Castiglione-Fontanellaz et al., 2023) and are linked to an increased all-cause mortality (e.g., Cappuccio et al., 2010; Wallace et al., 2021).

Therefore, there is a pressing need to understand the underlying mechanisms and factors that can affect sleep quality, and to develop effective methods to promote healthy sleep.

While biological and environmental factors (e.g., disruption of the circadian rhythm, light exposure, pharmacological factors, etc.) are well-documented (e.g., Philippens et al., 2022; Roth, 2004), cognitive processes, which are the primary focus of this dissertation, have received increasing attention for their role in shaping sleep experiences. For example, sleep disturbances frequently co-occur with psychiatric conditions such as depression or anxiety disorders (e.g., Alvaro et al., 2013; Cox & Olatunji, 2020; Murphy & Peterson, 2015), and are often triggered or exacerbated by psychological stress, critical life events and intrusive or distressing thoughts (e.g., Clancy et al., 2020; Y. Li et al., 2019). These observations underscore that the content and patterns of cognitive activity play a central role in the modulation of sleep. However, despite a growing recognition of their importance, the mechanisms through which cognitive factors affect sleep remain less clearly defined. Both pre-sleep cognition, including worry, rumination, stress-related thoughts, expectations and mental imagery, and cognitive activity occurring during sleep, including dreaming and memory reactivation, represent important avenues for investigation. Within this cognitive framework, dreaming represents a particularly salient form of sleep-related cognition, providing a crucial window into how cognitive processes unfold across the sleep state. The next section will therefore focus on dreams, emphasising their significance for the understanding of how cognitive processes affect sleep.

2.2. Dreams

Dreaming is considered a universal human experience and refers to the wide variety of conscious subjective experiences occurring during sleep (Schredl, 2018). This includes images, sensations, thoughts, emotions, speech and/or motor activity. One definition is given by Salvesen et al. (2024) who define dreams as “*spontaneous, internally generated conscious experiences that emerge while we sleep, [...] ranging from simple abstract thoughts to complex movie-like narratives*” (p. 1). Although not universally accepted (for a discussion on the definition of dreams see Pagel et al., 2001), the present work adopts a broad and inclusive view of dreams, hereafter also referred to as dream mentation when emphasising the cognitive processes implied. While it was initially thought that dreaming predominantly occurred during REM sleep (Aserinsky & Kleitman, 1953; Dement & Kleitman, 1957), it is now well-established that dreams can occur in all sleep stages throughout the night. However, the question of whether REM and NREM sleep stages result in dreams of a qualitatively different nature

remains unresolved. Dream reports obtained after awakenings from REM sleep are typically longer, more vivid, more bizarre, more intense, more emotional, and more story-like (e.g., Oudiette et al., 2012; Wamsley et al., 2007). On the other hand, dream reports obtained after awakenings from NREM sleep tend to be more thought-like, less elaborate, less affectively and visually involving, more fragmented and more prone to forgetting (e.g., Fosse et al., 2004; Nielsen, 2000; Nielsen et al., 2001). However, these differences tend to disappear as the night progresses, resulting in highly vivid, intense, emotional and story-like dream reports obtained from awakenings from NREM sleep in the second half of the night (e.g., Casagrande et al., 1996; Fosse et al., 2004; Malinowski & Horton, 2021; Martin et al., 2020; Wamsley et al., 2007). This observation suggests that the time of the night at which the dream occurs is more relevant for the quality of the dreams than the actual sleep stage. Dreams have long been a subject of interest to researchers with numerous theories proposed to explain their functions, origins and mechanisms. These theories range from neurobiological to psychological and cognitive models. For the purpose of this work, the most prominent theoretical perspectives will be outlined, highlighting their implications for understanding cognitive activity and its influence on sleep.

The most prominent hypothesis in recent dream research is the continuity hypothesis of dreaming. This hypothesis, not yet assigned a name, was originally introduced by Bell & Hall (1971) and subsequently elaborated by Domhoff (1996, 2003). It states that dreams reflect and embody personal waking experiences, preoccupations and concerns, suggesting a continuity between waking and dreaming cognition (Bell & Hall, 1971; Domhoff, 2017; Erdelyi, 2017). Typically, this continuity relates to both waking thoughts and behaviours. However, Domhoff (1996) also explains how it can pertain exclusively to thoughts: for example, an individual who experiences highly aggressive dreams may not necessarily be aggressive but may acknowledge having aggressive thoughts during waking life. The idea of continuity appears as a challenge to earlier views that suggest a discontinuity between dreaming and waking cognition (Freud, 1913), as well as more recent interpretations that regard dreams as meaningless (e.g., Hobson & McCarley, 1977). Instead, it posits that themes, characters and emotional tone of dreams are meaningfully related to waking life, particularly to salient individual concerns and preoccupations (Domhoff, 1996). Empirical support for the continuity hypothesis has come from dream diary studies and content analyses of dream reports. For example, Fosse et al. (2003) conducted a study in which they asked 29 subjects to record both their dreams and their daily activities over the course of two consecutive weeks. They observed that more than 65%

of elements contained within the dreams were directly related to their waking activities, sometimes modified or distorted. Other studies show that significant life events such as divorce (Cartwright et al., 1984), major surgery (Breger et al., 1971) or important exams (Arnulf et al., 2014) influence the content of dreams. However, although the continuity has been demonstrated, it is still necessary to specify it further by including factors which could modulate the incorporation rate of waking-life events into dreams. For example, the type of waking-life experience or the emotional involvement seem to play a role. Schredl and Hofmann (2003) have shown that highly focused cognitive activities such as reading or writing are significantly less present in dreams compared to other activities such as driving a car or walking. Furthermore, studies have shown that waking event are more susceptible to be incorporated into dreams when they are emotionally salient for the individual (e.g., Eichenlaub et al., 2017; Eichenlaub, Van Rijn, Gaskell, et al., 2018; Eichenlaub, Van Rijn, Phelan, et al., 2018; Malinowski & Horton, 2014a; Schredl, 2006; Stickgold et al., 2001). This phenomenon is exemplified by the high prevalence of nightmares in individuals diagnosed with post-traumatic stress disorder (Geldenhuys et al., 2022). Furthermore, after stressful events such as the 9/11 attacks or the COVID-19 lockdown, an increase in threat elements in dream content was observed (Propper et al., 2007; Solomonova et al., 2021), suggesting an impact of highly distressing daily life events on dream content. Dream content is therefore intricately associated with the dreamer's mental and physical health as well as their ongoing preoccupations (for reviews see Graveline & Wamsley, 2015; Scarpelli et al., 2022). Overall, by framing dreams as reflections of waking concerns and mental processes, the continuity hypothesis underscores the intimate connection between waking cognitive activity and sleep-related processes.

While it is well established that memories are processed and integrated during sleep (e.g., Brodt et al., 2023; Diekelmann & Born, 2010; see 2.4. *The “Memories-of-Sleep” hypothesis*), the role of dreams in these processes remains unclear (Plailly et al., 2019; Wamsley, Tucker, et al., 2010; Wamsley & Stickgold, 2019), particularly regarding whether dreams contribute to memory processing and consolidation during sleep, or whether they occur independently of memory-related activity. Dream elements often arise from memories of waking events (Picard-Deland et al., 2022). However, dreams rarely replay exact episodic memories but rather distort or change them, reflecting only one or two aspects of the waking experiences (Hartmann, 2010a; Malinowski & Horton, 2014b; Picard-Deland et al., 2022; Stickgold, Hobson, et al., 2001; Wamsley, 2022). A multilevel system of sleep-associated memory processing can be hypothesised, in which dreams reflect the activation of complex

brain systems involved in the reprocessing of memories during sleep. For example, studies demonstrated that subjects who reported dream mentation related to the navigation task they had trained before a 90-min nap showed the biggest improvement on the task re-test after sleep (Wamsley, Tucker, et al., 2010). Interestingly, the reports that contained task-related elements were not exact replay of the task, but remote associations, such as hearing the music of the task in their dream or dreaming of maze-like environments resembling the one from the task. Those results were replicated in a night study in which the subjects who incorporated elements of the task into their dreams showed a greater overnight improvement in the performance compared to the ones who did not report task-related elements in their dreams (Wamsley & Stickgold, 2019). These findings support the idea that the reactivation of memories during sleep is not entirely independent from dream content. However, while those results provide valuable insights, limitations include the small number of subjects who reported task-related elements in their dreams and the fact that most of these dreams were collected during sleep onset. Such dreams, known as hypnagogic hallucinations, are specific in nature (Ghibellini & Meier, 2023; Speth et al., 2013), meaning that conclusions drawn from them may not necessarily generalise to dreams occurring at other parts of the night. These limitations underscore the need for further research to clarify the extent to which dreams may reflect memory reactivation and to determine the functional significance of this process.

Other perspectives emphasise the role of dreams in emotion regulation (for a review see Scarpelli et al., 2019). As discussed above, REM sleep is commonly associated with emotional processing (Fairholme & Manber, 2015; Goldstein & Walker, 2014; Palmer & Alfano, 2017; Vandekerckhove & Wang, 2018). Although the idea that dreams are exclusively related to REM sleep has been overcome, several studies demonstrated that emotionally and perceptually vivid dreams are more frequent following awakenings from REM sleep (Hobson et al., 2000; Kahn et al., 2002; Merrit et al., 1994; Nielsen et al., 1991). Therefore, it has been suggested that (REM) dreams are involved in emotional mechanisms. Studies investigating dream content in relationship with emotional processing are scarce, and the theories advocating for the role of dreams in emotion regulation mostly rely on the specific physiology of REM sleep (see 2.1. *Sleep*) and the prevalence of intense emotions in REM dreams (Hobson et al., 2000; Scarpelli et al., 2019). For example, some theories claim that the coupling of the negative imagery of dreams seen in nightmares to the muscle atonia during REM sleep allows the “desomatisation” of the emotion (Perlis & Nielsen, 1993), meaning that the emotion would progressively become independent of its physiological responses. The AMPHAC/AND (amygdala, medial prefrontal

cortex, hippocampus, anterior cingulate cortex/affect network dysfunction; Levin & Nielsen, 2009) model proposes that one function of REM sleep is the extinction of fear memories, with dreaming reflecting this process. In this model, dreams deconstruct episodic memories into isolated elements, recombine them into a coherent imagery, which provides a new context within which emotionally arousing memories can be expressed. This recombination creates environments incompatible with fear memories, facilitating fear extinction and emotional regulation. According to this model, dreams would allow the integration of emotional concerns and traumatic experiences into the pre-existing memory system within the context of sleep, thereby offering a protective environment for processing these memories. By integrating recent and old memories, dreams would allow emotional concerns and traumatic experiences to be processed safely during sleep, whereas nightmares may reflect dysfunctions of this regulatory mechanism (Levin et al., 2010; Levin & Nielsen, 2007, 2009). Overall, evidence suggests that dreams may contribute to emotional processing, potentially enabling the brain to integrate emotionally significant experiences while regulating their associated emotional intensity; however, the precise mechanisms and functional significance of these effects remain poorly understood.

In sum, while the continuity between waking cognition and dreams seems to be well-established, the specific functions and mechanisms of dreaming remain unclear. Specifically, while some theories highlight the role of dreams in memory consolidation during sleep, others recognise their role in emotional processing. However, these accounts often remain broad and rarely specify when or how different types of waking experiences are incorporated into dreams. In particular, little is known about how waking cognitions that differ in temporal focus, emotional intensity, or personal relevance are selectively incorporated into dreams, and how such incorporation varies across the night. Addressing these gaps is crucial, as the timing and nature of dream incorporation may offer insight into how cognitive and emotional processes unfold during sleep. Since dreams represent a form of in-sleep cognitive activity, studying them provides a unique window into the interaction between cognition and sleep. This interaction is especially evident in insomnia, where dysfunctional cognitive processes play a central role, as reflected in cognitive and cognitive-behavioural models of the condition. In the following section, the most influential of these models are presented, as they provide an essential framework for understanding how cognitive processes shape both sleep and dream experiences.

2.3. Models of insomnia

Insomnia is the most common sleep disorder affecting approximately 10% of adult population in Europe (Riemann et al., 2023). It is characterised by difficulties initiating and maintaining sleep, early awakenings and/or a lack of restorative sleep (Riemann et al., 2010). These sleep difficulties are accompanied by significant daytime problems such as fatigue, attention problems, irritability and depressed mood, which greatly affects daily functioning (Riemann et al., 2010, 2023). The most effective method to treat insomnia is cognitive-behavioural therapy for insomnia (CBT-I) which may have contributed to the conceptualisation of insomnia primarily as a psychological disorder (e.g., cognitive model of insomnia; Harvey, 2002). More recent models include physiological and neurobiological factors offering a more integrative view of the disorder (e.g., hyperarousal model of insomnia; Riemann et al., 2010). These developments have led to several influential models of insomnia, which are reviewed in the following section.

The first widely accepted model of insomnia is the 3P behavioural model by Spielman et al. (1987), which explains the transition from acute insomnia to chronic and self-maintaining insomnia through the interplay of predisposing traits, precipitating stressors and perpetuating behaviours. The model focuses on the latter, emphasising on the behaviours that the individual will adopt to cope or compensate for their sleep disturbances, but that ultimately lead to the exacerbation and the chronicity of the problems. Typical maladaptive behaviours include the tendency to engage in sleep-unrelated activities in bed or in the bedroom and to spend excessive amounts of time in bed while awake, a behaviour called sleep extension. However, the model does not take into account physiological influences (e.g., circadian system, sleep-wake homeostasis) and fails to explain how the precipitating factors create the transition from healthy sleep to acute insomnia (Perlis et al., 2011). Moreover, the focus on behavioural mechanisms overlooks the cognitive processes involved in the development and maintenance of insomnia. Addressing these limitations, Harvey (2002) proposed a cognitive model of insomnia which assumes a causal role of cognitive processes such as rumination, worry and beliefs, occurring during nighttime as well as during daytime, in the maintenance of insomnia. These cognitive processes are seen as perpetuating factors that maintain insomnia even after the initial triggers are gone. This cognitive perspective shifted treatment targets from behaviour to cognition.

Other models build on that cognitive focus while integrating physiological dimensions, converging on the broader concept of hyperarousal as central to the development and maintenance of insomnia. The neurocognitive model of insomnia (Perlis et al., 1997) extends

on this notion of hyperarousal by specifying three different dimensions: cognitive, somatic, and cortical arousal. A conditioning mechanism explains that sleep-related stimuli, when repeatedly associated with insomnia-related arousal, ultimately elicit or maintain higher levels of cortical arousal at sleep onset and during sleep. For example, an individual who frequently experiences difficulties falling asleep may begin to associate their bed or bedroom environment with frustration and wakefulness, so that simply lying in bed triggers heightened alertness and physiological arousal. Insomnia is thus seen as a state of hyperarousal at both the behavioural and neurophysiological levels. Similarly, Espie (2002) proposed the attention-intention-effort (AIE) model of insomnia, which describes maladaptive cognitive and behavioural processes associated with insomnia (see also Espie et al., 2006). This model underscores the automaticity and involuntariness of sleep, with insomnia being the consequence of a disruption of this automaticity. This automatic process is compromised when the individual selectively directs their attention towards sleep, has an explicit intention to sleep and makes increased cognitive and behavioural efforts to fall asleep, which results in the development of maladaptive sleep-preventing behaviours.

The aforementioned models all postulate that sleep impairments observed in insomnia are attributable to an elevated arousal, which does not correspond with the de-arousal state that is characteristic of sleep. These developments culminated in the hyperarousal model of insomnia (Riemann et al., 2010), which conceptualises insomnia as a 24 h psychobiological disorder involving persistent elevation in cognitive, emotional, and physiological arousal. By integrating neurobiological aspects, this model enables a shift in perspective regarding the conceptualisation of insomnia, moving from a classification as a purely psychological disorder to acknowledging it as a psychobiological condition. The model posits that chronic insomnia is not merely a nocturnal sleep disorder, but rather a constant state of heightened arousal that persists throughout the day. Indeed, individuals suffering from insomnia experience increased levels of cognitive, emotional and physiological arousal during the day and the night (e.g., Bonnet & Arand, 2010), which compromise their ability to initiate and maintain sleep.

Altogether, the models enabled a shift in the conceptualisation of insomnia, moving from the perspective of insomnia as predominantly a behavioural disorder – 3P model (Spielman et al., 1987) – to recognising the role of cognitions – cognitive model of insomnia (Harvey, 2002), neurocognitive model (Perlis et al., 1997), AIE model (Espie, 2002; Espie et al., 2006) – and neurobiological factors – hyperarousal model (Riemann et al., 2010). These models, summarised in Table 1, generally assume that hyperarousal, whether cognitive,

somatic, cortical and/or a combination thereof, is incompatible with sleep, and thus leads to sleep disturbances. However, despite their invaluable insights, they remain centred on clinical populations, emphasise negative consequences of cognitive activity, and rarely consider how cognition may continue during sleep itself. Recently, Rasch (2016) proposed the “Memories-of-Sleep” (MemoSleep) hypothesis, which provides a theoretical framework that accounts for these limitations. This hypothesis, which will be explored in detail in the next section, provides the theoretical framework for the present dissertation. It explains how different cognitions can either enhance or disrupt sleep and how they remain active during sleep, further influencing sleep physiology throughout the night in people with and without sleep disorders.

Table 1: Summary of the models of insomnia presented in this dissertation.

3P behavioural model (Spielman et al., 1987)	Chronic insomnia develops through a combination of predisposing traits, precipitating stressors and perpetuating behaviours. The model highlights how maladaptive behaviours maintain insomnia over time.
Cognitive model of insomnia (Harvey, 2002)	Insomnia is maintained by excessive worry and beliefs about sleep, which heighten arousal and bias attention towards sleep-related threats. Cognitive processes create a cycle of anxiety and sleep disturbances.
Neurocognitive model of insomnia (Perlis et al., 1997)	Chronic insomnia arises from conditioned cortical arousal and heightened central nervous system activation, maintaining the brain “awake” during sleep. Insomnia is seen as a state of hyperarousal at both behavioural and neurophysiological levels.
Attention-Intention-Effort (AIE) model (Espie, 2002)	Insomnia arises when the automaticity of sleep is compromised by the individuals focusing their attention on sleep, intentionally trying to sleep, and making efforts to control it, paradoxically making sleep harder to achieve.
Hyperarousal model of insomnia (Riemann et al., 2010)	Insomnia reflects a chronic hyperarousal state involving cognitive, emotional, autonomic, and neuroendocrine activation. This overactivation interferes with the ability to initiate and maintain sleep.

2.4. The « Memories-of-Sleep » hypothesis

The “Memories-of-Sleep” (MemoSleep) hypothesis, proposed by Rasch (2016), is founded upon two different research areas. The first relates to embodied cognitions, a concept that contrasts with traditional models conceptualising cognition as entirely separated from body representations and motor control (e.g., connectionism; for a review see Elman, 2005). The second is the domain of memory and sleep, specifically the active system consolidation hypothesis, described in greater detail later in this section. The MemoSleep hypothesis is constituted of three main assumptions: (1) memories related to sleep and wake states are embodied; (2) if sleep- or wake-related embodied memories are activated before sleep, they are more likely to be reactivated during sleep; and (3) during sleep, the reactivation of sleep- or wake-related embodied memories can trigger associated physiological responses, thereby influencing sleep architecture and physiology. By addressing both sleep-disrupting and sleep-promoting cognitions and acknowledging that cognitive activity persists during sleep, the MemoSleep hypothesis provides a novel framework that advances beyond classical models of insomnia and traditional memory research. Furthermore, this hypothesis allows for the generation of directly testable predictions to explain the general effects of cognitive and emotional processes on ongoing sleep. In this section, the three assumptions are described in detail. Since the original formulation of the hypothesis focused specifically on the reactivation of sleep- and wake-related memories, the three main assumptions are defined using the original terminology of “memories” to maintain conceptual continuity. However, for the remainder of this dissertation, the focus is broadened to include cognitions more generally, reflecting the wider scope of cognitive processes that influence sleep.

1. Memories related to sleep and wake states are embodied.

The first assumption proposes that memories related to sleep and wake are constituted of both a semantic meaning, and a sensorimotor body representation. This assertion is based on literature on embodied cognitions, a field of study that emphasises the central role of sensory and motor functions in cognition. In this perspective, cognitions are the result of the interaction between the body and the physical and social environment, where bodily experiences play an important role in shaping thoughts, perceptions and emotions (Foglia & Wilson, 2013). Moreover, cognitions are represented in the brain not only in semantic form but also across multiple modal systems. These systems include perceptual systems, such as vision or audition;

action-related systems, such as movement and proprioception; and introspective systems, such as mental states and affect (Barsalou, 2008). According to embodied theories, memories that constitute our knowledge are generated through all sensorimotor experiences related to that particular memory (Barsalou, 2008). The reactivation of a specific memory therefore simulates its body-related perceptions, actions and introspections. Supporting this idea, studies showed that reading words related to arm or leg actions, such as pick or kick, activates brain areas that overlap with those activated by the actual movement of the corresponding limb (Boulenger et al., 2012; Kiefer & Pulvermüller, 2012). In the MemoSleep hypothesis, it is postulated that semantic concepts related to sleep and wake are closely linked to and can evoke associated sensorimotor representations and physiological responses (Rasch, 2016).

Initial evidence for this assumption has recently been provided by Hülsemann and Rasch (2021). In this study, the authors demonstrated that the processing of sleep- and wake-related words is facilitated when the body is in a congruent position to the word in question: the words associated with sleep are more easily processed when the subject is in a relaxed, lying position, whereas those associated with wakefulness are more easily processed when the subject is standing. To observe this effect, the neural responses to the presented words were extracted from the EEG in order to obtain the potential related to each type of word, a measure known as an event-related potential (ERP). Specifically, differences were observed in a negative component of the ERP commonly associated with high-order semantic processing (e.g., Kutas & Federmeier, 2011) known as N400: N400 showed a reduced amplitude in the congruent condition compared with the incongruent condition, suggesting a facilitation of word processing due to the congruence between the semantic meaning of the words and the body position (i.e., lying or standing). Therefore, pre-activating a sleeping position facilitated the semantic processing of sleep-related words. These results thus support the first assumption of the MemoSleep hypothesis that posits that mental representations of sleep-related concepts are linked to their sensorimotor body representations, offering initial evidence of the embodiment of sleep- and wake-related words observable at the neural level.

2. If sleep- or wake-related embodied memories are activated before sleep, they are more likely to be reactivated during sleep.

The second assumption is based on the active system consolidation hypothesis (Diekelmann & Born, 2010) which explains the role of sleep in memory consolidation. This

hypothesis posits an active contribution from sleep to brain plasticity involved in memory consolidation through memory reactivation during sleep, specifically during slow-wave sleep (SWS). During sleep, newly acquired and initially fragile memory traces are spontaneously and repeatedly reactivated which leads to the redistribution of the memory trace from the hippocampus to the neocortex, where it is strengthened and integrated into pre-existing memory networks (Rasch & Born, 2013). The memory consolidation process via reactivation relies on specific sleep oscillations: the depolarising up-states of cortical slow oscillations (<1 Hz) synchronise hippocampal sharp-wave ripple events to thalamo-cortical spindles (10–16 Hz). The hippocampal sharp-wave ripples, which are high frequency oscillation bursts (30–100 Hz) during which spontaneous reactivation occurs (Buzsáki, 2015), are thus nested into the troughs of spindles. This synchronisation is thought to favour the hippocampal-neocortical dialogue needed for the formation and stabilisation of declarative long-term memories (Brodt et al., 2023; Rasch & Born, 2008, 2013). Most importantly, it was shown that presenting memory cues during sleep, a method called targeted memory reactivation (TMR), increased reactivation and led to an improved memory performance the next morning (e.g., Rasch et al., 2007; Rudoy et al., 2009; Schreiner & Rasch, 2017). While two recent studies from our laboratory were not able to replicate this effect (Baselgia et al., 2024; Wick & Rasch, 2023), a recent meta-analysis including results from over 70 studies concluded that TMR applied during N2 sleep and SWS selectively improves memory for the associated information (Hu et al., 2020). Beyond these observations, the functional role of sleep for memory consolidation is widely approved and established. The second assumption of the MemoSleep hypothesis therefore extends the concept of reactivation beyond declarative memories to sleep- and wake-related embodied memories. Pre-sleep activation of these cognitive representations is hypothesised to increase their probability to be spontaneously and repeatedly reactivated during sleep, similar to the mechanisms observed in memory consolidation. The reactivation of these sleep- and wake-related embodied memories during sleep is proposed to differentially modulate ongoing sleep processes, as outlined in the third assumption of the hypothesis.

3. During sleep, reactivation of sleep- or wake-related embodied memories triggers associated physiological responses, thereby influencing sleep architecture and physiology.

The final assumption is put forward as an explanation for sleep alterations that can be observed, not only during the sleep onset period, but also during sleep itself. In this

conceptualisation, cognitions remain active or are reactivated during sleep and can continuously affect sleep physiology. This could in turn affect post-sleep cognitive and affective functioning. Specifically, the reactivation of sleep-related memories during sleep should activate the associated sensorimotor representations, including the systems regulating sleep. This activation should, in turn, result in an increase in sleep depth manifesting as an increase in slow-wave activity (SWA). A recent study by Beck et al., (2021) provides strong evidence for this idea. In this experiment, healthy participants were exposed to words related to the concept of relaxation (e.g., “sleep”, “quiet”, “pleasant”) during NREM sleep in one night, and with neutral control words (e.g., “gold”, “phase”) in another night, according to a balanced crossover design (Beck, Loretz, et al., 2021). This manipulation relies on the ability of the sleeping brain to process the meaning of words and activate their representations in multimodal neuronal networks, including auditory, motor and visual areas (Blume et al., 2018; Kouider et al., 2014; Schreiner & Rasch, 2017). Supporting the third assumption of the MemoSleep hypothesis, activating the semantic concept of “relaxation” resulted in an increase in time spent in SWS, enhanced SWA following the cues, and higher subjective sleep quality compared with nights where neutral control words were presented. Additional analyses revealed that presenting relaxation-related words was also associated with reduced heart rate activity (Koroma et al., 2024), further supporting the notion of embodied sleep-related memories. Although the idea has not yet been empirically tested, activating wake-related memories during sleep would, on the contrary, trigger the corresponding wake-related sensorimotor representations. For example, reactivating the semantic concept of “running” during sleep would elicit bodily responses such as elevated heart rate, increased muscle tension and heightened physiological arousal, thereby resulting in a decrease in sleep depth.

This third assumption aligns with the perseverative cognition hypothesis (Brosschot et al., 2006) which states that the sustained impact of stress on physiological activity (e.g., elevated heart rate) is driven by ongoing conscious and unconscious perseverative cognitions about the stressor. Perseverative cognitions, defined as the repeated or chronic activation of stress-related cognitive representations (Brosschot et al., 2006), include conscious perseverative thinking such as anticipatory worry or depressive rumination; however, the majority of perseverative cognition is thought to occur automatically or unconsciously, as manifested by attentional hypervigilance for example (Verkuil et al., 2011). By prolonging physiological and emotional reactions to stressors, these processes are thought to contribute to adverse mental and somatic health outcomes, such as cardiovascular diseases or anxiety

disorders (Brosschot et al., 2006). Importantly, perseverative cognitions may persist during sleep (Brosschot, 2010), as evidenced by associations between daytime worry and elevated heart rate during subsequent sleep (Brosschot et al., 2007). This persistence suggests that stressful experiences may be mentally reactivated during sleep, potentially interfering with physiological recovery (Brosschot et al., 2007; Verkuil et al., 2011). Similarly, the MemoSleep hypothesis proposes that sleep- and wake-related memories can persist and be reactivated during sleep and that this reactivation triggers the associated physiological responses. These reactivated responses during sleep would explain changes in sleep physiology and architecture.

In sum, the MemoSleep hypothesis, for which a graphical representation is proposed in Figure 3, offers a novel theoretical framework for understanding how pre-sleep and in-sleep cognitions, both sleep-disrupting and sleep-promoting, can influence sleep physiology and architecture in healthy and disordered sleep. Unlike traditional models which primarily emphasise negative consequences of cognitive activity or focus on cognitive processes occurring prior to sleep onset, the MemoSleep hypothesis explicitly considers the role of mental concepts in both improving and disrupting ongoing sleep processes. Within this perspective, dreams constitute a particularly salient example of in-sleep cognitions: as subjective experiences that emerge during sleep, they may reflect ongoing cognitive and emotional processes and thus provide a valuable window into the mechanisms proposed in the hypothesis. By linking sleep outcomes to the reactivation of waking memories and concepts, the MemoSleep hypothesis allows for the explanation of cognitive effects on sleep by generating testable predictions about how specific pre-sleep or in-sleep mental states can modulate sleep quality and physiology. In the following sections, this perspective is elaborated by first reviewing the literature on the negative consequences of cognitions on sleep and dreams, which provides a robust empirical basis for the MemoSleep hypothesis.

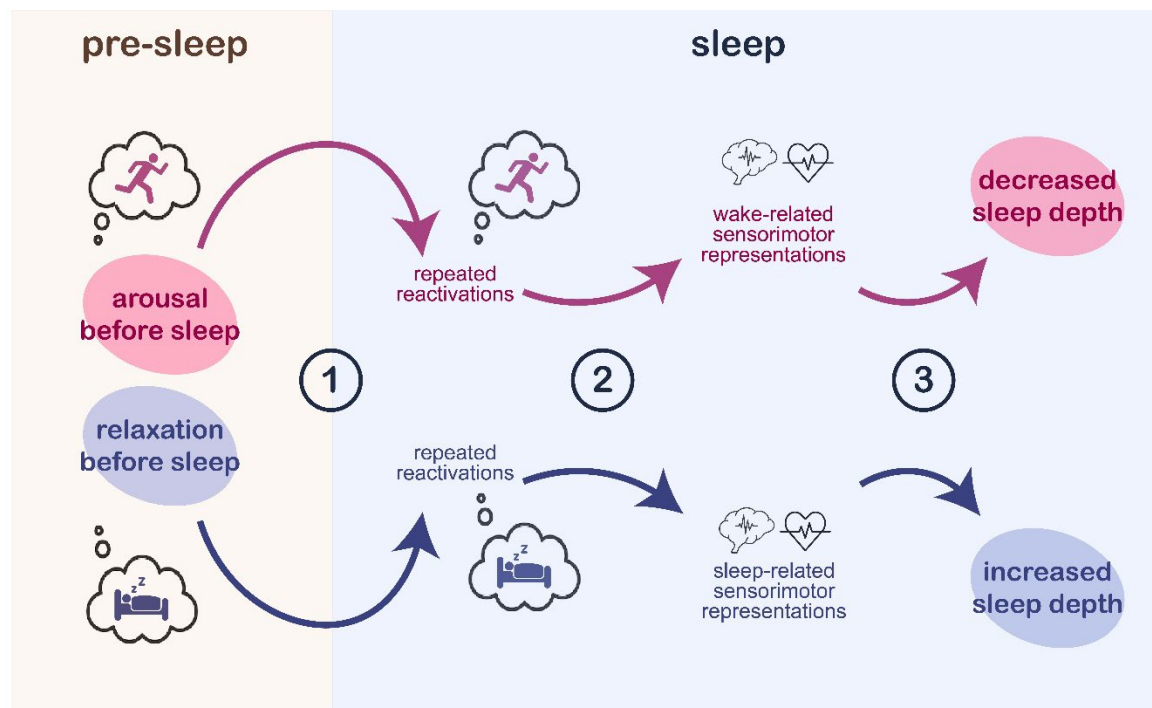


Figure 3: Graphical representation of the “Memories-of-Sleep” (MemoSleep) hypothesis. The hypothesis is based on the assumption that memories related to sleep and wake states are embodied, which means that they are constituted of both a semantic meaning and a sensorimotor body representation. Based on that assumption, it can be hypothesised that the activation of sleep- or wake-related embodied memories before sleep increases their probability to be spontaneously and repeatedly reactivated during sleep (1); these reactivations of sleep- or wake-related embodied memories during sleep trigger the associated physiological responses (2). Wake-related cognitions (e.g., running) will activate wake-related sensorimotor representations (e.g., increased heart rate, muscle tension), which will lead to a decreased sleep depth. In contrast, sleep-related cognition (e.g., relaxation) will activate sleep-related sensorimotor representations (e.g., decreased heart rate, muscle relaxation), which will lead to an increased sleep depth (3).

2.5. Negative effects of cognitions on sleep and dreams

As proposed in insomnia models discussed previously, negative pre-sleep cognitions, including worry, rumination, and intrusive thoughts, contribute to a state of pre-sleep arousal, which is a critical factor in explaining sleep disturbances such as extended sleep onset latency (SOL), increased wake after sleep onset (WASO), reduced slow-wave sleep (SWS) and poorer subjective sleep quality, as demonstrated in several studies (e.g., Valck et al., 2004; Wicklow & Espie, 2000; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Thus, because elevated arousal before bedtime counteracts the physiological and cognitive changes required for sleep initiation, pre-sleep arousal has emerged as a central construct in sleep research, particularly for understanding mechanisms underlying insomnia and sleep disturbances. Traditionally, pre-sleep arousal is conceptualised as including both physiological

and cognitive aspects: physiological arousal refers to elevated levels of physiological tension such as elevated heart rate, stomach tension, and shortness of breath; cognitive arousal refers to increased levels of cognitive activity, for example worries, rumination, racing mind, and negative and intrusive thoughts. Both are separate constructs, albeit related: they can interact, occur in parallel or independently of each other (Čapková et al., 2018; Oldehinkel et al., 2011).

Pre-sleep arousal thus represents a state that counteracts the natural process of falling asleep, which implies a progressive decrease in physiological arousal accompanied by a gradual loss of control over mental activity (Espie, 2002; Ogilvie, 2001; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Physiological de-arousal can be observed in a decrease in cortical activity (Gorgoni et al., 2019), heart rate or core body temperature (Okamoto-Mizuno et al., 2008; Shinar et al., 2006). At the cognitive level, the process of de-arousal should be reflected by a decline in attentional engagement, in executive functions and in goal-directed thoughts, and the emergence of spontaneous, internally generated mentation such as mind-wandering or hypnagogic imagery (Ogilvie, 2001). Heightened cognitive arousal before sleep thus strongly interferes with the mental de-arousal needed to fall asleep, leading to a prolonged SOL (e.g., Haynes et al., 1981; Tang & Harvey, 2004; Wicklow & Espie, 2000), likely due to intrusive thoughts and rumination while trying to fall asleep (Åkerstedt, 2006; Åkerstedt et al., 2007). As outlined in the hyperarousal model of insomnia (Riemann et al., 2010; see 2.3. *Models of insomnia*), difficulties in initiating sleep arise when de-arousal does not occur, and in contrast, the individual is in a state of hyperarousal, whether cognitive, somatic or cortical. In healthy sleepers as well, experimentally inducing elevated levels of cognitive arousal before sleep has detrimental effects on subsequent sleep, specifically inducing longer SOL, more WASO and lower sleep efficiency (Åkerstedt et al., 2007; Gross & Borkovec, 1982; Haynes et al., 1981; Wicklow & Espie, 2000; Yeh et al., 2015).

However, the sensitivity of sleep to cognitive pre-sleep arousal also depends on pre-sleep activities, their characteristics (i.e., physical and/or cognitive activities), the time between the activity and bedtime, and whether they elicit emotional involvement. For example, Wuyts and colleagues (2012) investigated the impact of inducing a cognitive load before sleep on sleep architecture and physiology (Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Importantly, the cognitive load was devoid of any emotional component by ensuring that the performance was independent of reward or punishment. This cognitive load induction resulted in a mean increase of 8 minutes in subsequent SOL, compared with a control night. To explore how this manipulation affected sleep at a finer level, the authors examined sleep

microstructure by calculating an EEG power ratio, which reflects the prevalence of fast activity (alpha, beta) relative to slow activity (delta, theta). In addition to a higher beta activity, they observed that this EEG power ratio was lower, which means that the prevalence of fast activity was greater compared to low activity during the early phases of deep sleep. This pattern reflects an acceleration in the EEG, which is indicative of a reduced sleep depth. Indeed, during wakefulness, fast activity has been associated with cognitive functioning (e.g., Joliot et al., 1994; Pulvermüller et al., 1996; Tiitinen et al., 1997) and beta activity is thought to indicate an increased cortical arousal in insomnia patients (Perlis, Merica, et al., 2001; Perlis, Smith, et al., 2001). The authors thus conclude that performing a cognitive task before sleep can impede the process of de-arousal in the brain, thereby hindering the automaticity of the sleep onset process (Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Moreover, they observed concomitant fluctuations in physiological parameters (e.g., skin temperature, heart rate), which suggest that pre-sleep cognitive arousal might also impact the physiological level, which may contribute to the observed effects on subsequent sleep. In a previous study that also used a cognitive task devoid of emotional load before bedtime, a decrease in the delta (0.5–4 Hz) power band was observed in the first NREM sleep period of subsequent sleep, which also speaks for a decrease in sleep depth (Takahashi & Arito, 1994). No difference was found in SOL; however, it should be noted that the manipulation involved a mild sleep deprivation, which may have influenced this result. Moreover, anxious cognitive arousal before sleep has been linked to lower self-reported sleep quality compared to non-anxious cognitive arousal, while no difference was observed in subjective SOL (Čapková et al., 2018). Taken together, these findings highlight the impact of pre-sleep cognitive and emotional states on subsequent sleep (see also Hantsoo et al., 2013; Ree et al., 2005; Schmidt et al., 2010).

In industrialised Euro-American societies, common pre-sleep activities include digital media consumption, such as watching TV, playing video games or scrolling on social media. Consequently, a large body of research is investigating the impact of such activities on sleep quality. The use of technologies in general has been linked to delayed bedtimes, shorter sleep durations and sleep problems in children and adolescents (e.g., Cain & Gradisar, 2010; S. Li et al., 2007) and in adults (e.g., Brautsch et al., 2023; Han et al., 2024). Furthermore, the use of digital media has been demonstrated to be particularly problematic when it occurs near bedtime, leading to inadequate sleep quantity, poor sleep quality and excessive daytime sleepiness (Carter et al., 2016; Eggermont & Van den Bulck, 2006; King et al., 2014; Suganuma et al., 2007). For example, playing exciting computer games before bedtime has been shown to

significantly increase SOL and decrease sleep efficiency (Dworak et al., 2007; Higuchi et al., 2005; King et al., 2013; Pieters et al., 2014). With the proliferation of streaming platforms, the impact of TV consumption before bed has become increasingly relevant, as content is now continuously available and can be consumed on demand and without temporal constraints. This has led to the phenomenon of binge-watching, which is defined as the act of watching multiple episodes of TV series in a row in one sitting (Merikivi et al., 2020). A survey study by Exelmans and Van den Bulck (2017b) showed that 32% of binge-watchers reported bad sleep quality. Moreover, higher frequency of binge-watching was associated with more insomnia symptoms and daytime fatigue. These results were further confirmed in subsequent studies (Bandla et al., 2024; Forte et al., 2023; Vinothkumar & George, 2022; for a review see Alimoradi et al., 2022).

The association between digital media consumption and poor sleep outcomes can be explained by a media-induced increase in cognitive arousal before bed. For example, computer games before bed have been shown to increase cognitive arousal, without increasing physiological arousal (King et al., 2013; Weaver et al., 2010), an explanation frequently invoked in studies investigating social media use (e.g., Combertaldi et al., 2021; Harbard et al., 2016; Kinsella & Chin, 2024; Wang & Scherr, 2022). Similar mechanisms have been proposed for binge-watching, which involves sustained cognitive and emotional engagement with narrative content. In line with this, Exelmans and Van den Bulck (2017b) found that cognitive arousal explained the link between binge-watching and sleep disturbances, while physiological arousal only marginally predicted this relationship. Importantly, the frequent use of cliffhangers, which abruptly end the episode in the middle of a critical scene, creates heightened suspense (Michlin, 2011), and have been shown to increase both cognitive and physiological arousal (Wirz et al., 2022). By leaving narratives unresolved, cliffhangers may prolong cognitive engagement beyond viewing. Research has shown that unresolved intentions maintain heightened cognitive activation until the intention can be enacted, often experienced as intrusive thoughts keeping the intention mentally active and making disengagement more difficult (Beckmann, 1998; Ghibellini & Meier, 2025; Goschke & Kuhl, 1997). Similarly, unresolved narratives following cliffhangers may elicit intrusive thoughts and sustained cognitive activation, which at bedtime can interfere with disengagement from media-related content and delay sleep onset. Consistent with this account, unresolved tasks and ongoing concerns have been linked to increased bedtime rumination and poorer subjective sleep quality (Syrek & Antoni, 2014; Weiher et al., 2022).

According to cognitive models of insomnia, difficulty disengaging from unresolved cognitions such as those prompted by unresolved media narratives, is expected to impair sleep by promoting repetitive thoughts and increasing arousal. Supporting this mechanism, pre-sleep arousal has been shown to mediate the relationship between repetitive thoughts and sleep quality (Yeh et al., 2015). This aligns with the perseverative cognition hypothesis discussed previously, which posits that the sustained activation of cognitive representations of stressors prolongs physiological arousal and thereby negatively impacts health and sleep (Brosschot et al., 2006). Building on this framework and within the MemoSleep hypothesis, it can be expected that binge-watching suspenseful TV series before bed may activate wake-related memories such as tension and suspense, which are likely to be reactivated during sleep and thereby trigger associated physiological responses that further disrupt sleep physiology. However, the specific effects of cliffhangers on sleep remain unexplored. Previous studies on digital media use before sleep have largely focused on factors such as screen time, light exposure, or general arousal, while the content of media and its cognitive-emotional consequences have received little systematic investigation under controlled laboratory conditions, constituting a critical gap in the literature. The example of cliffhangers may illustrate how unresolved pre-sleep cognitions can heighten arousal and interfere with sleep. This mechanism is not limited to media-related content but is also central to understanding the impact of stress and anticipated stress on sleep, which will be discussed in the following paragraphs.

Indeed, pre-sleep cognitive arousal is closely intertwined with stress, as stressful experiences and worries often serve as triggers for intrusive thoughts and rumination (J.M. Smith & Alloy, 2009). Stress can be defined as a physiological and psychological response to perceived threats or challenges. On the physiological level, the stress response involves the activation of the hypothalamic-pituitary-adrenal (HPA) axis and the autonomic nervous system, encompassing the sympathetic nervous system, which drives the stress response, and parasympathetic nervous system, which modulates it. When a stressor is detected, the hypothalamus releases corticotropin-releasing hormone (CRH), which stimulates the pituitary gland to secrete adrenocorticotrophic hormone (ACTH). This in turn activates the adrenal cortex to produce cortisol, which mobilises energy resources and heightens alertness (Kudielka & Kirschbaum, 2005). While this system is adaptative in acute situations, chronic activation of the HPA axis can lead to dysregulation, resulting in persistent elevated cortisol levels (Guilliams & Edwards, 2010; Knezevic et al., 2023). Importantly, it is widely accepted that

stress is a major factor contributing to sleep disturbances (Kalmbach et al., 2018; Morin et al., 2003; Petersen et al., 2023; Reffi et al., 2023; Riemann et al., 2010).

Pre-sleep stress represents a completed stress experience whose physiological and cognitive effects gradually decline after the stressor has ended. Physiological stress responses, measured by increase in heart rate, cortisol levels, salivary alpha-amylase or galvanic skin response, typically persist for several minutes up to approximately one hour following stress exposure (e.g., Ackermann et al., 2019; Becker & Rohleder, 2019; Bellingrath et al., 2013; Janson & Rohleder, 2017). As a result, stress experienced shortly before bedtime may carry residual physiological and cognitive arousal into the sleep period, directly interfering with sleep initiation and early sleep processes (e.g., Ackermann et al., 2019; Beck et al., 2023; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). These effects are typically confined to the beginning of the night, consistent with the gradual decline of the physiological stress response across time. This explanation aligns with classical models of insomnia presented above, which emphasise heightened pre-sleep arousal as a key factor in sleep disruption (Espie, 2002; Espie et al., 2006; Harvey, 2002; Riemann et al., 2010). However, the persistence of sleep alterations once sleep has already been initiated suggests that residual physiological activation alone may not fully account for these effects, highlighting a potential role for reactivation of stress-related cognitive processes during sleep. Most stressors, particularly psychosocial ones, elicit cognitive activation (Åkerstedt, 2006; Kogler et al., 2015; Riemann et al., 2010; Van Reeth et al., 2000) that may remain accessible even after sleep onset. Experimentally inducing acute psychosocial stress shortly before sleep has been linked to impaired sleep continuity and altered sleep architecture, including increased WASO, reduced duration of deeper sleep stages, and declines in objective indices of sleep quality, such as the ratio of low- to high-frequency EEG activity during NREM sleep (Ackermann et al., 2019; Beck et al., 2023; Goldberg et al., 2020; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). These findings suggest that stress-related cognitive activation may persist or be reactivated during sleep, thereby compromising sleep quality even when physiological arousal is sufficiently reduced to successfully initiate sleep.

In the context of anticipatory stress, such reactivation mechanisms may be particularly relevant. In contrast to completed stress experiences, anticipatory stress involves sustained cognitive preoccupation with a future event, which intensifies as the anticipated stressor approaches (Kramer et al., 2022; Ouwehand et al., 2008). Rather than reflecting a transient physiological response, anticipatory stress is thus marked by a persistent mental engagement

with possible future scenarios, accompanied by heightened physiological arousal (Engert et al., 2013; Kramer et al., 2022). According to the perseverative cognition hypothesis (Brosschot et al., 2006), such future-oriented thoughts can prolong physiological and cognitive components of the stress response even in the absence of an immediate threat. As a result, anticipatory stress may sustain elevated cognitive arousal through (unconscious) repetitive negative thinking, which may disrupt sleep in a qualitatively different manner than acute pre-sleep stress. Indeed, anticipatory stress does not appear to substantially elevate physiological arousal before sleep while still impacting sleep quality in the late sleep period (Beck et al., 2023), suggesting that its effects on sleep may be driven by mechanisms other than residual physiological activation. Within the MemoSleep framework, it can be hypothesised that stress-related cognitive activity is reactivated during sleep which, due to the embodied nature of such cognitions, may influence physiological sleep parameters. From this perspective, anticipatory stress may be particularly disruptive due to repetitive reactivations of stress-related cognitions during and across sleep. Supporting this view, Beck et al. (2023) compared the effects of completed pre-sleep stress and anticipated post-sleep stress on a 90-min nap (see also Gross & Borkovec, 1982; Tang & Harvey, 2004). They found that alterations in sleep occurred in temporal proximity to the stressor: acute pre-sleep stress primarily impacted the early part of the nap, whereas the anticipation of a future stressor disturbed the later part of the nap. Along these lines, an “on-call” situation during sleep, which requires responsiveness to work-related demands, also induces anticipatory alertness and typically impairs sleep quality by increasing objective WASO and SOL (Combertaldi et al., 2022; Wuyts, De Valck, Vandekerckhove, Pattyn, Exadaktylos, et al., 2012), altering brain activity (Torsvall & Åkerstedt, 1988; Wuyts, De Valck, Vandekerckhove, Pattyn, Exadaktylos, et al., 2012) and lowering subjective sleep quality (Ziebertz et al., 2017). These effects may be explained by the generation of perseverative cognitions related to the on-call situation, which would remain active or be reactivated during sleep, thereby altering sleep quality. Thus, whereas sleep disruptions following pre-sleep stress may partly reflect residual physiological activation, the effects of anticipatory stress can be understood as resulting from the reactivation of stress-related cognitions during sleep.

Supporting evidence for the idea of reactivation comes from research on self-awakening, which is the ability to awaken at a predetermined time without external assistance (for a review see Verga et al., 2023): changes in physiological parameters, including blood pressure, heart rate or EEG activity, were observed before the predetermined awakening time (Born et al., 1999; Ikeda & Hayashi, 2008; Kaida et al., 2003, 2005). These findings

demonstrate that cognitive processes during sleep, such as the intention to wake up at a certain time, can significantly impact physiological parameters during sleep. Another example is found in evidence that shows that individuals sleep less efficiently and less deeply in a new environment, a phenomenon called first night effect (FNE; Agnew Jr. et al., 1966). A recent meta-analysis confirmed that sleep quality is consistently poorer on the first night in a novel setting, with increased SOL and WASO, and decrease in sleep duration and efficiency (Ding et al., 2022). The FNE illustrates how cognitive evaluations of novelty or unsafety can disrupt sleep depth and continuity, even in later parts of the night. Together, these findings highlight that beliefs, expectations and intentions can alter both subjective sleep experiences and objective sleep physiology. As proposed by the MemoSleep hypothesis, one explanation is that these changes are caused by the reactivations of repetitive thoughts during sleep.

Although such cognitive reactivations during sleep can influence both subjective and objective sleep parameters, it remains debated whether these mental activations are mirrored in the content of dreams (see 2.2. *Dreams*). If anticipatory stress can trigger reactivation of stress-related cognitions during sleep, as proposed by the MemoSleep hypothesis, it is plausible that these cognitions are also incorporated into dreams. Previous studies have shown that pre-sleep cognitions can shape subsequent dream content and characteristics. For example, pre-sleep learning material is often incorporated into dreams from the first half of the night (Kusse et al., 2012; Wamsley, Perry, et al., 2010; Wamsley, Tucker, et al., 2010; Wamsley & Stickgold, 2019). Moreover, pre-sleep emotional states can also impact subsequent dreams, as demonstrated by a study in which watching a stressful film before sleep increased negative emotions in subsequent dreams from the first REM sleep period (Lauer et al., 1987; see also Davidson & Lynch, 2012). Similarly, the anticipation of stressful and/or important events has been shown to influence dream content: athletes reported distressing dream content before a major competition, representing athletic failure such as losing a game (Erlacher et al., 2011); patients awaiting major surgery experienced dreams featuring hospital settings and bodily concerns (Breger et al., 1971; Hartmann, 2001), and students preparing for an important exam had dreams largely centred on exam-related problems such as problems answering the questions or being late (Arnulf et al., 2014). Together, these findings suggest that subjective stress can be incorporated into, or shape dream content and characteristics.

While previous research shows that pre-sleep experiences and anticipatory stress can be incorporated into dreams, the temporal dynamics of such incorporation across the night remain largely unexplored (Picard-Deland et al., 2022; Wamsley et al., 2024). Studies suggest that

dreams from the early part of sleep primarily reflect recent experiences and immediate memory traces (e.g., Baekeland et al., 1968; Picard-Deland et al., 2020, 2022; Schredl, 2003; Wamsley et al., 2024; Wamsley & Stickgold, 2019), whereas dreams in the later part of the night are more likely to integrate remote memories and future-oriented concerns (Wamsley, 2022; see also Roussy et al., 1998; Verdone, 1965; as reported in Schredl, 2003). This temporal distinction aligns with findings of Beck et al. (2023) presented above, who demonstrated that acute stress before a nap predominantly affected early sleep, whereas anticipatory stress exerted effects later in the sleep period. However, no study to date has directly examined whether this temporal pattern extends to the incorporation of stress and anticipated stress into dream content. Addressing this gap is essential for clarifying how cognitive and emotional processes unfold across the night and are reflected in dreaming. Understanding these temporal dynamics is particularly relevant within the MemoSleep framework, as dream content may provide insight into the reactivation of cognitions during sleep and their influence on sleep physiology.

While most of the literature reviewed above has focused on negative cognitions and their disruptive effects, it is equally important to address the complementary question of how cognitive activity may positively influence sleep. Given that most theoretical models addressing the role of cognitions on sleep have focused on negative cognitions, one of the innovative aspects and key contributions of the MemoSleep hypothesis lies in its consideration of sleep-promoting cognitions. Indeed, sleep-related cognitions, such as those elicited through relaxation techniques, could counteract pre-sleep arousal and facilitate sleep processes, a perspective explored in the following section.

2.6. Positive effects of cognitions on sleep

Although cognitive activity before and during sleep is often assumed to negatively impact sleep, it is not inherently disruptive. Certain forms of cognitions, such as those associated with safety or relaxation, may instead facilitate sleep continuity and restoration. This section thus reviews evidence indicating that cognitions can exert beneficial effects on sleep, highlighting conditions under which cognitive activity may support sleep. As discussed previously, insomnia patients report heightened mental hyperactivity, such as rumination, worry and negative thoughts, which contributes to difficulties in initiating and maintaining sleep (Harvey, 2000; Lemyre et al., 2020). These observations underscore the importance of identifying strategies that promote calming or sleep-promoting cognitions at bedtime to

counteract hyperarousal and facilitate sleep. One such strategy is relaxation, which refers to a state of peace and comfort characterised by the absence of tension in the body and the mind (J.C. Smith, 2007). Therefore, relaxation techniques may improve sleep by acting on both the physiological and cognitive levels. Indeed, interventions such as progressive muscle relaxation, guided imagery, breathing, yoga and meditation have been shown to be effective in reducing both physiological and cognitive arousal by normalising elevated heart rate and blood pressure and by counteracting rumination and intrusive thoughts with more positive emotions (Kim & Kim, 2018; Klainin-Yobas et al., 2015). Consistent with these mechanisms, these interventions have been demonstrated to improve sleep efficiency, shorten SOL, reduce WASO and enhance subjective sleep quality, even in patient populations (e.g., Blanaru et al., 2012; De Niet et al., 2009; Liu et al., 2020; Rusch et al., 2019; Simon et al., 2022).

Importantly, evidence suggests that reductions in cognitive arousal is a stronger predictor of sleep improvements than reductions in physiological arousal. For example, following an 8-week mindfulness-based stress management programme, patients with insomnia reported a significant decrease in pre-sleep cognitive arousal, which mediated improvements in insomnia severity (Cincotta et al., 2011). Similarly, pre-sleep cognitive arousal partially mediated the relationship between mindfulness and sleep quality in young athletes with late-evening training, a routine that typically heightens arousal before sleep (C. Li et al., 2018). In line with these findings, a systematic review by Winbush et al. (2007) concluded that sleep improvements (e.g., decreased SOL and sleep efficiency) associated with mindfulness-based interventions are likely driven by reductions in sleep-interfering cognitive processes such as worry. Collectively, these findings suggest that calming cognitions before sleep can enhance subjective and objective sleep parameters. Within the MemoSleep framework, it is proposed that activating sleep-related embodied memories prior to sleep promotes better sleep quality by increasing their likelihood of being reactivated during sleep. From this perspective, pre-sleep relaxation and related cognitive interventions may actively facilitate restorative sleep rather than merely reflecting the absence of stress-related interference. However, the specific contribution of pre-sleep relaxation to sleep quality has often been overlooked. Determining whether relaxation actively promotes better sleep or simply reduces competing stress-related interferences is therefore essential for clarifying the mechanisms through which pre-sleep cognition influences sleep.

Assuming that calming pre-sleep cognitions promote better sleep quality, it is important to note that volitional control over sleep and mental activity, both before and during sleep,

remains limited. Indeed, the desire to fall asleep can, on occasion, hinder the process, and individuals suffering from insomnia often benefit from paradoxical instructions to stay awake with eyes closed (Jansson-Fröjmark et al., 2022). Along these lines, a study in our laboratory showed that instructing healthy young adults to “sleep as well as possible” did not lead to improved sleep (Combertaldi & Rasch, 2020). On the contrary, these subjects were able to impair their sleep when instructed to do so, both in terms of subjective experience and objective markers such as decreased sleep quality, increased SOL, and more awakenings. These findings indicate that while sleep can be influenced voluntarily, this tends to be easier in the negative direction. Therefore, approaches such as hypnosis or indirect suggestions, which rely on subconscious regulatory processes, may offer more effective ways to enhance sleep quality. Hypnosis can be defined as an induced state of modified consciousness that is characterised by focused attention, reduced awareness and enhanced responsivity to suggestions (Elkins et al., 2015; Oakley & Halligan, 2009). These specific changes allow targeted verbal suggestions to effectively modify perceptions and behaviours (Thompson et al., 2019). Psychological theories of hypnosis propose that hypnosis creates a shift in attentional processes that decreases the influence of higher executive functions and the monitoring of sensory cues (Jensen & Patterson, 2014), which appears ideal to manipulate sleep processes. Specifically, directives can be given in the state of hypnosis to influence thoughts or behaviours after the emergence from the hypnotic state (Barnier et al., 2004). These directives, termed posthypnotic suggestions, appear particularly suited for the manipulation of sleep: posthypnotic suggestions given before sleep might have the potential to influence subsequent sleep.

Hypnosis has been demonstrated to be a valid method of reducing cognitive and physiological arousal (Hammond, 2010) and positive effects of hypnosis have already been reported for insomnia and sleep disturbances, leading to higher subjective ratings of sleep quality (Borkovec & Fowles, 1973; Hauri et al., 2007). These findings already demonstrate promising potential for the use of hypnosis in enhancing sleep quality. A recent meta-analysis including 44 studies has concluded that hypnotherapy may be a therapeutic intervention to improve subjective and objective sleep parameters, with minimal adverse consequences (Wofford et al., 2023; see also Chamine et al., 2018). Moreover, a recent study has demonstrated the efficacy of self-administered hypnotherapy in enhancing sleep quality (Snyder et al., 2023; see also Elkins, 2024), which might be explained by a reduction in self-reported cognitive and somatic pre-sleep arousal from pre- to post-intervention (Alldredge et al., 2024). However, basic research on the use and effectiveness of hypnotic suggestions to

manipulate objective sleep parameters is limited, constraining the understanding of the underlying mechanisms.

A series of experimental studies in our laboratory has investigated the potential of hypnotic suggestions to increase the amount of SWS and sleep depth (Cordi et al., 2014, 2015, 2020; Cordi & Rasch, 2021). In those studies, healthy participants listened to an audio tape consisting of either hypnotic suggestions specifically designed to increase SWS and sleep depth, or a neutral control text before falling asleep. The results showed that, in medium-to-high hypnotisable subjects, hypnotic suggestions to deepen sleep increased the duration of SWS of ca. 65% in a 90-min nap (Cordi et al., 2014) and 11% in nighttime sleep (Cordi et al., 2020). In addition, the pre-sleep hypnotic suggestions also significantly increased the depth of sleep as indicated by an increased power in the SWA frequency band during sleep. These effects were specific to SWS, as no other sleep stage duration (e.g., N2, REM) was altered. Several control conditions were conducted and refuted the possibilities that the positive effects of hypnotic suggestions were due to demand characteristics, a generalising relaxing effect of the hypnotic tape, or other differences in the audio tapes such as intonation or speed (Cordi et al., 2014). Most interestingly, in another study using a similar procedure, the hypnosis-induced increase in SWS was also accompanied by a highly significant increase in the release of growth hormone during a midday nap (Besedovsky et al., 2022). This finding is particularly noteworthy given the established association between SWS and growth hormone release, which is thought to support the regeneration and recovery function of sleep (Chennaoui et al., 2020; Van Cauter & Plat, 1996). It is important to note however that these effects were only observed in medium-to-high hypnotisable subjects, suggesting that hypnotisability is a key factor that influences the effectiveness of hypnotic interventions.

Taken together, these findings suggest that pre-sleep hypnotic suggestions can remain active or be reactivated during ongoing sleep. Hypnosis appears to reduce psychophysiological arousal and sleep-hindering processes during wakefulness, including worries, ruminations and negative thoughts, thereby facilitating sleep onset (e.g., Alldredge et al., 2024; Wofford et al., 2023). However, the deepening of sleep by hypnotic suggestions discussed above go one step further: suggestions given before sleep can influence the sleep stage of SWS which occurs several minutes to hours after sleep onset and after the end of the hypnosis itself, and this effect seems to be unrelated to the general relaxing properties of the hypnosis procedure (Cordi et al., 2014). Thus, hypnotic suggestions to deepen sleep seem to act in a posthypnotic manner and during a sleeping state which is characterised by reduced consciousness. These results suggest

that hypnotic suggestions to sleep deeper given before sleep can reactivate concepts of relaxation and deep sleep during sleep, thereby enhancing sleep depth and quality. This interpretation aligns with the MemoSleep hypothesis which posits that reactivation of sleep-related cognitive representations during sleep can shape ongoing sleep physiology. This idea is supported by a study from our laboratory which activated the concept of relaxation during NREM by presenting relaxing words, such as “sleep” or “relax” (Beck, Loretz, et al., 2021): the presentation of relaxing words during sleep increased the duration of deep sleep, as well as the power in the SWA frequency band, improved subjective sleep quality and slowed cardiac activity compared with the night with control words (Beck, Loretz, et al., 2021; Koroma et al., 2024). These findings indicate that the reactivation of sleep- and relaxation-related concepts during sleep can modulate the associated physiological responses, positively influencing sleep regulatory systems allowing for deeper sleep.

However, existing research on hypnotic modulation of sleep has exclusively focused on SWS, leaving open the question of whether similar mechanisms extend to other sleep stages occurring later in the sleep cycle. In particular, no study to date has explored whether hypnosis can be used to selectively modulate REM sleep. Given the central role of REM sleep in emotional processing, memory integration and dreaming, exploring whether hypnotic suggestions delivered before sleep can influence REM sleep represents a crucial next step within the MemoSleep framework. If cognitive information encoded before sleep can indeed be reactivated during REM sleep, similarly to what has been shown for SWS, this would open a novel avenue for targeted modulation of REM-sleep-dependent processes. Moreover, if hypnosis can be used to selectively increase REM sleep, this would offer a unique opportunity to further investigate the potential functions of REM sleep, including its role in emotional processing discussed in previous sections. These considerations directly motivate the aims of the present dissertation, which are outlined in the following section.

2.7. Aims of the present dissertation

The theoretical background presented above highlights how sleep can be shaped by cognitions and pre-sleep states. However, the mechanisms by which cognitive activity influence sleep are not fully understood. Addressing this gap is essential for the advancement of theory and the development of targeted interventions for sleep disturbances. Grounded in the MemoSleep hypothesis, this dissertation presents four studies that systematically investigate

how cognitive processes before and during sleep influence sleep physiology, dream content, and subjective experience.

Study I investigates how binge-watching suspenseful TV series, with and without cliffhangers, affect sleep. It was predicted that suspenseful series would impair sleep through an increased cognitive pre-sleep arousal, and that cliffhangers would amplify this effect by creating unresolved cognitive tension caused by unfinished narratives. This study provides the first controlled laboratory evidence testing the effects of specific media content on sleep. Additionally, it directly tests one prediction of the MemoSleep hypothesis, namely that wake-related embodied cognitions, such as suspense and tension, activated before sleep remain active or are reactivated during sleep, thereby shaping its course and physiology.

Study II examines whether the reactivation of cognitions during sleep, as proposed in the MemoSleep hypothesis, can be observed in dream content, focusing on the effects of pre-sleep and anticipated post-sleep stress on early and late. Using a large sample and systematically collected dream reports, this study offers a fine-grained test of whether different types of stress (rumination vs. anticipation) are incorporated into dreams at different times across the night. In doing so, it extends previous results from our laboratory from a nap paradigm to full-night sleep, providing a detailed investigation of the temporal dynamics of stress incorporation in dreams.

Study III shifts focus to positive cognitive activity, addressing a critical gap in insomnia models that largely overlook its role. It was postulated that activating the concept of relaxation before sleep improves sleep quality and physiology, an effect that potentially biased a previous study from our laboratory where stress was compared to relaxation. By introducing a neutral control condition, this study aims to clarify the true scope of stress effects, highlighting the significance of sleep-promoting cognitions and their therapeutic potential for improving sleep.

Finally, **Study IV** tests whether pre-sleep hypnotic suggestions and circadian manipulation can modulate REM sleep parameters in morning and midday naps. Representing the first direct attempt to use hypnosis to experimentally enhance REM sleep, this study directly tests a central assumption of the MemoSleep hypothesis, namely that sleep-related cognitions can be reactivated during sleep and activate the associated physiological responses. In addition, it advances the broader understanding of REM sleep functions by exploring its role in emotional processing. Due to its novelty, this study provides valuable methodological innovation and explores new possibilities for targeted cognitive interventions to modulate sleep.

Overall, this dissertation aims to make contributions on multiple levels. Theoretically, it is designed to advance and refine the MemoSleep hypothesis, by integrating findings from diverse paradigms to clarify the role of cognitive processes in shaping sleep. Methodologically, it demonstrates the value of controlled laboratory designs, systematic dream analysis and the use of novel interventions such as hypnosis. Practically, the findings aim to inform strategies for improving sleep health by examining the impact of specific digital media consumption habits, highlighting the potential of sleep-promoting cognition and exploring new cognitive-based approaches to improve sleep health. Taken together, these studies provide a comprehensive, multilevel analysis of the dynamic interplay between cognition and sleep, offering new insights into how cognitive processes shape sleep and dreams.

3. Study I

Pre-sleep arousal induced by suspenseful series and cliffhangers have only minor effects on sleep: A sleep laboratory study

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3.1. Abstract

Pre-sleep arousal impairs sleep. Therefore, watching suspenseful TV series before sleep is not recommended as they increase arousal. In particular, the consumption of multiple episodes of the same suspenseful TV series in one sitting – termed binge-watching – could lead to large increases in physiological arousal delaying sleep onset. Furthermore, abrupt endings during critical scenes – termed cliffhangers – result in unfinished story lines, which further increase cognitive arousal and could negatively impact sleep architecture and the number of awakenings. However, the effects of binge-watching and cliffhangers on objective sleep parameters are still unknown.

Here we tested in a controlled sleep-laboratory setting whether pre-sleep arousal induced by watching 3–4 episodes of a suspenseful TV series has negative effects on sleep in 50 healthy young participants (39 females, mean age = 22.62 ± 2.60 (SD)). Watching a neutral TV series served as a control condition, according to a within-subject design. In one group of participants, the suspenseful TV series ended with a cliffhanger. In the other group, the same TV series ended where no ongoing action was interrupted. Pre-sleep arousal was measured both subjectively with the self-reported level of stress and objectively with the mean heart rate and cortisol level. As expected, suspenseful TV series induced higher cognitive and physiological pre-sleep arousal than neutral control TV series, with highest values for TV series with cliffhangers. In spite of the high pre-sleep arousal, participants fell asleep faster after watching the suspenseful compared with the neutral TV series ($F_{(1,48)} = 4.89, p = 0.032, \eta^2 = 0.09$). Sleep architecture and the number of awakenings remained unaffected. However, in the first two sleep cycles, heart rate was still higher after watching suspenseful TV series ($F_{(1,48)} = 6.76, p = 0.012, \eta^2 = 0.12$). And only after cliffhangers, objective sleep quality – measured as the ratio between slow-wave and beta activity during sleep – was lower than in the other conditions (interaction effect, $F_{(1,48)} = 5.05, p = 0.029, \eta^2 = 0.10$).

Our results speak against large impairments of pre-sleep watching of multiple episodes of suspenseful TV series and cliffhangers on sleep quality and architecture. However, unfinished narratives might induce more subtle changes in oscillatory power during sleep, possibly reflecting ongoing cognitive processing during sleep.

Keywords: binge-watching, cliffhangers, sleep, sleep quality.

3.2. Introduction

Pre-sleep arousal is a critical factor explaining sleep disturbances as it extends sleep onset latency, increases wake after sleep onset and changes sleep architecture (e.g., reduction in slow-wave sleep [SWS]). Particularly in insomnia patients, high levels of arousal (sometimes also referred as “hyperarousal”) are strongly related to the development and maintenance of sleep disturbances and most theories on insomnia include arousal as central concept (Harvey et al., 2005; Ong et al., 2018; Perlis et al., 1997). For example, in the “Hyperarousal model of insomnia”, Riemann et al., (2010) describe the development from acute to chronic insomnia in a framework of interacting components on the cognitive-behavioural level and the neurobiological level. In that model, poor sleep would result from cognitive-emotional processes that are dysfunctional and over-aroused. Accordingly, when those cognitive-emotional processes are controlled and functional, for example in people with high resilience, it allows to benefit from restorative sleep (Sadeghi-Bahmani & Brand, 2022). Along these lines, pre-sleep arousal includes physiological and cognitive aspects: Physiological arousal refers to the sympathetic system leading to somatic changes, e.g., increased heart rate and cortisol levels. In contrast, cognitive arousal refers to negative and occupying thoughts like worries and rumination. Physiological and cognitive arousal interact, but can also occur in parallel or independent of each other (Cohen et al., 2000; Hjortskov et al., 2004; Oldehinkel et al., 2011; Schlotz et al., 2008).

Also in healthy individuals, pre-sleep arousal is suspected to be a cause for sleeping difficulties, and it is commonly recommended to avoid arousing activities before bedtime (Bonnet & Arand, 2010; Riemann et al., 2010). One common pre-sleep activity in young healthy adults is watching suspenseful TV series using streaming services. For example, the streaming portal Netflix offers video on demand and streaming and has over 220 million users worldwide (netflix.com). Streaming services offer a more flexible way of television and allow the user to watch the desired content whenever they want (Granow et al., 2018). This opportunity has led to the development of watching multiple episodes of a TV series in a row in one sitting, a phenomenon termed binge-watching (Merikivi et al., 2020). In a recent survey by Exelmans and Van den Bulck (2017), 32% of binge-viewing participants reported bad sleep quality. Furthermore, a higher frequency of binge-viewing was associated with frequency of insomnia symptoms and increased daytime fatigue. The association between binge-watching and sleep quality was mainly explained by increases in cognitive arousal after viewing multiple episodes in one sitting, possibly due to stronger cognitive involvement in the storyline. In

contrast, physiological arousal was a weaker predictor. However, no objective sleep data was acquired in this study.

As streaming services have an interest in keeping viewers watching, episodes typically have open endings in critical scenes, leaving the viewers uncertain about how the story will develop. TV series with such cliffhangers leave audience in full of suspense and probably further increase cognitive arousal (Michlin, 2011). Unfinished narratives and tasks are known to induce tension for completeness (Ovsiankina, 1928) leading also to enhanced memory for unfinished tasks which is known as the Zeigarnik Effect (Zeigarnik, 1927; Baumeister & Bushman, 2014; Syrek & Antoni, 2014). As proposed by the cognitive-emotional model of insomnia (e.g., Harvey, 2002; Harvey et al., 2005), cliffhangers can be expected to further impair sleep due to the increased cognitive arousal produced by the unresolved tension that needs resolution (Flayelle et al., 2019). However, the effects of cliffhangers on sleep are still unknown.

To fill this important scientific gap, we tested the effects of binge-watching a suspenseful TV series with or without cliffhangers on sleep in healthy young participants in the sleep laboratory. Following Exelmans and Van den Bulck (2017), we predicted that watching a suspenseful TV series will increase pre-sleep arousal and delay objective sleep onset. In addition, we hypothesised that TV series with cliffhangers further increase pre-sleep arousal and have a more negative impact on sleep than TV series without cliffhangers. In particular, according to the cognitive-emotional model that links cognitive pre-sleep arousal to a poorer sleep quality (Harvey, 2002; Harvey et al., 2005), we predicted that cliffhangers, due to the unfinished narrative and increased rumination, also impair ongoing sleep processes (i.e., a higher number of awakenings and decreased depth of sleep).

3.3. Methods

Participants

Sixty-three healthy French-speaking individuals took part in all sessions of the study. Seven participants were excluded due to invalid EEG signals and six had to be excluded due to insufficient sleep in at least one of the two experimental nights (<6 h). The final sample consisted of 50 young adults (39 females, mean age = 22.62 ± 2.60 [mean (M) $\pm$ standard deviation (SD)], age range: 18–28 years).

Participants were recruited through an advertisement 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 – and the Cantonal Board of the Canton de Vaud (CH) approved the study (Project-ID: 2019-449), and all participants gave written informed consent prior to participating. The study was conducted in accordance with the Declaration of Helsinki.

Design and procedure

We conducted an experiment with one within-subject factor (suspenseful TV series vs. non-suspenseful control TV series) and one between-subject factor (cliffhanger vs. no cliffhanger). Each participant spent one adaptation night in the sleep laboratory of the University of Fribourg, which was followed by two experimental nights. On the latter, participants either watched a suspenseful TV series (suspense condition) or a non-suspenseful documentary TV series (control condition), according to a crossover design. The order of the two conditions was balanced across participants. In addition to the within-subject comparison between the suspenseful TV series and the non-suspenseful control documentary, the presence of cliffhangers at the end of the TV series was varied between subjects to test the effects of cliffhangers on sleep. One group of participants ($n = 22$) saw the suspenseful TV series with a cliffhanger at the end (“cliff” group). For the other group of participants ($n = 28$), the ending of the TV series was interrupted at a point where the ongoing action had been completed (“no cliff” group). Participants were randomly assigned to one of the two groups and blinded regarding the group they were assigned to. The study was a part of a larger study examining the effects of TV series and cliffhangers on arousal and other parameters independent of sleep (Wirz et al., 2022).

Both experimental sessions started at 6.30 p.m. and were spaced one week apart from each other. Each session started with the attachment of electrodes for recordings of electroencephalography (EEG), electromyography (EMG), electrooculography (EOG), and electrocardiography (ECG). Afterwards, participants watched the respective TV series, which included three to four complete episodes with a total duration of approximately 3 h. In both

experimental sessions, participants completed standardised questionnaires (see Questionnaires section) before and after the binge-watching session. At four different time-points (before the start of the viewing session, after two episodes, after the viewing session and in the morning), saliva samples were collected. After 7.5 h of sleep, participants were woken up. At this point, subjective sleep quality and mood were assessed (see Figure 1A, for a summary of the experimental design and procedure).

Media content

We used four different TV series selected based on their suspenseful content (How to Get Away with Murder, Orphan Black, Sense8 and The Sinner). In a screening questionnaire, participants described their media consumption habits and indicated which TV series they had already seen. Participants were assigned to one of the four TV series, making sure that they had not seen it before. In the control condition, we used a documentary TV series (Islands of the Future) about neutral energy projects. This documentary TV series contained no suspenseful content nor cliffhangers and showed no continuity between the different episodes. All TV series were presented on a 24-inch computer screen while the participants were sitting in a chair.

To examine the effects of cliffhangers on sleep, two versions of the last episode of each selected TV series were created cutting the narration at a different time point: one version ended abruptly during a critical scene (“cliff”) and one version was interrupted at a point where the ongoing action had been completed in order to end the TV series in a calm situation (“no cliff”). Therefore, the content of the TV series did not differ between the groups, but the duration was slightly changed (mean duration overall = 173 ± 2.85 min; mean duration “cliff” = 173 ± 3.04 min; mean duration “no cliff” = 172 ± 2.97 min [$M \pm SD$]). From a questionnaire completed at the end of the TV series, seven items were used to create a subscale assessing the degree of suspense (see Appendix for the items; Cronbach's alpha = 0.88). According to this score of suspense, the TV series were rated as significantly more suspenseful than the control documentary (main effect of condition (suspense vs. control): $F_{(1, 47)} = 322.04$, $p < 0.001$, $\eta^2 = 0.87$) for both groups (“cliff”, “no cliff”). On a scale from 1 (= not suspenseful) to 5 (= very suspenseful), the mean score for the control documentary was 2.10 ± 0.48 and the mean score for the TV series all together was 3.85 ± 0.44 [$M \pm SD$] (The Sinner: 3.62 ± 0.32 ; Sense8: 3.80 ± 0.56 ; Orphan Black: 4.09 ± 0.39 ; How to Get Away with Murder: 3.91 ± 0.34). For more information on the effects of the TV series and cliffhangers on enjoyment, arousal and intention to continue watching see Wirz et al. (2022).

Questionnaires

Before entering the study, participants were asked to fill out a questionnaire including questions on personal information (e.g., age, education), personality and habits regarding series consumption and binge-watching (e.g., frequency, number of hours, motivations, identification to characters, etc.).

During the first adaptation night, subjective sleep quality, sleep disturbances and chronotype were assessed using the French versions of the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) and the Morningness-Eveningness-Questionnaire (MEQ; Griefahn et al., 2001; Taillard et al., 2004).

Mood and stress were assessed before and after the binge-watching session, as well as in the morning. The questionnaire used was composed of four different sub-questionnaires: the Multidimensional Mood State Questionnaire (MDBF; Steyer et al., 1997), the Positive and Negative Affective Schedule (PANAS; Watson et al., 1988), three questions from the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) and a stress scale from 0 (= totally relaxed) to 100 (= highest anxiety ever felt). In addition, a questionnaire was specifically created for this study to assess the emotions associated with the series (e.g., appreciation of the series, identification and attachment to the characters, transport into the universe of the series, will to continue watching, etc.; see also Wirz et al., 2022). This questionnaire was filled out directly after watching the TV series. Mood data was missing for one participant, resulting in a sample size of 49 participants.

Subjective sleep quality was measured in the morning with the sleep quality subscale of the SF-A/R (Görtelmeyer, 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). Items from the question “How did you sleep last night?” were also independently analysed: deep, good, relaxed, agitated, uniformly, calm, and ample. Those items were rated on a scale from 1 (= not at all) to 5 (= very much) (see also Beck et al., 2021). In addition, subjective sleep onset latency (SOL), subjective wake after sleep onset (WASO), subjective number of awakenings (NWAK) were also analysed. Data for subjective sleep quality was missing for 5 participants, resulting in a sample size of 45 participants in this analysis.

At the end of the experiment, participants were asked about the aim of the study and their understanding of the concept of “binge-watching” in an open question format.

Cortisol

The production of the cortisol hormone can be used as a physiological indicator for arousal, as it is thought to result from the experience of mild psychological stressors (Kirschbaum & Hellhammer, 1989; Lovallo & Buchanan, 2017). Level of cortisol was measured via saliva samples using salivette collection tubes (Sarstedt AG, Sevelen, Switzerland). In both experimental sessions, saliva samples were taken before the start of the TV series (sample 1, used as baseline sample), after two episodes of the TV series (sample 2), at the end of the TV series (sample 3) and in the morning directly after waking up (sample 4) (see Figure 1A). After the saliva collection, salivettes were stored in the fridge at 5°C for two days maximum and then sent to a laboratory for analysis. Level of salivary cortisol are reported in nmol/l (nanomole per litre). Cortisol data was missing for one participant, resulting in a sample size of 49 participants for this analysis.

Polysomnographic recordings and analysis of sleep architecture

Electroencephalographic (EEG) data was recorded using a 32-channels Easycap Net (Easycap GmbH, Herrsching) with a BrainAmp amplifier (Brain Products, Gilching, Germany), at a sampling rate of 500 Hz. The 32 used channels were the following, based on the international 10–20 system: Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fpz, AFz, Fz, Cz, CPz, Pz, FC1, FC2, FC5, FC6, CP1, CP2, CP5, CP6, M1, M2. FCz was used as a physical reference and AFz as a ground electrode. Two electrodes were used to collect electrooculographic (EOG) data, three chin electrodes were used to collect electromyogram (EMG) data and two electrodes for electrocardiogram (ECG) data. Impedances were kept below 20 kΩ.

Following the AASM guidelines (Iber et al., 2007), electrodes were re-referenced to the 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). For sleep analysis, an automated and validated sleep scoring algorithm was used (The SIESTA Group Schlafanalyse GmbH, Vienna; Caldart et al., 2020). The algorithm provides the analysis of sleep according to standard AASM criteria. In addition,

it provides a microstructural analysis of sleep including arousal indices and an analysis of stage shifts from different sleep stages.

The analyses of objective sleep parameters were carried out on the total sleep time (TST) as well as on the first two sleep cycles, as we were expecting that the pre-sleep manipulation would mainly impact the first half of the night (Takahashi & Arito, 1994; Wuyts et al., 2012).

Analysis of Sleep Cycles

A cycle analysis was performed with the SleepCycles package for R (Blume & Cajochen, 2021) which follows the criteria of Feinberg and Floyd (1979). These criteria separate NREM and REM periods. A NREM period (NREMP) starts with N1 with a minimal duration of 15 min. NREMP with a duration longer than 120 min excluding waketime can be split in two parts. Those periods can include waketime but no epochs of REM sleep. An epoch of REM sleep following a NREMP starts a REM period (REMP) automatically when it is longer than 5 min. The first REM is an exception as its duration can be less than 5 min. A new cycle starts with the first N3 episode following a phase of more than 12 min with any other stage than N3 (Jenni & Carskadon, 2004; Kurth et al., 2010; Rudzik et al., 2020). For each cycle, the amount of N1, N2, N3, REM and WASO was calculated as well as the duration of each cycle.

Analysis of spectral power

EEG data was pre-processed 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 the averaged mastoids. Only the data from the first two cycles was analysed, segmented for NREM-REM sleep (N2, N3, REM).

Data was segmented in 30s epochs of NREM-REM sleep (N2, N3, REM) based on the results of the sleep scoring. Then, data was segmented into equally sized segments of 2048 data points (4s) with 102 points overlapping. Artefacts were rejected automatically, and three criteria were used to select the segments to keep: (1) a maximum difference in EMG activity $<150 \mu\text{V}$ in both EMG channels, (2) a maximum voltage step in all EEG channels $<50 \mu\text{V/ms}$, and (3) a maximum difference in EEG activity $<500 \mu\text{V}$ in all EEG channels. The number of removed segments were manually checked for each artefact rejection step. Based on the number of removed segments, heavy EMG artefacts were identified and dropped if necessary. An automatic artefact rejection was chosen to have standardised criteria for all data sets, although

it does not guarantee that small artefacts are correctly rejected. To ensure the quality of the artefact rejection, each data set was also visually checked. Moreover, the criteria for the automatic artefact rejection used in the present study have already been used and proved efficient in our previous studies (e.g., Ackermann et al., 2015; Beck et al., 2021; Cordi et al., 2019). We used the SleepTrip toolbox (Weber, 2021) for Matlab (Mathworks, Natick) to calculate the average power values (μV^2) for different frequency bands: slow-wave activity (SWA; 0.5–4.5 Hz), theta activity (4.5–8 Hz), alpha activity (8–11 Hz), slow spindles (11–13 Hz), fast spindles (13–15 Hz) and beta activity (15–30 Hz) in the main EEG channels (F3, F4, C3, C4, P3, P4, O1, O2) (see Combertaldi & Rasch, 2020). In addition, we calculated the ratio between SWA and beta activity as this measure is associated with objective sleep quality (Cordi et al., 2019; Maes et al., 2014). Data was further analysed using RStudio version 1.4.1717.

Analysis of ECG

Electrocardiogram (ECG) was analysed using Kubios HRV Premium 3.4.3 (Kubios, Oy, Kuopio). The ECG signal for pre-sleep (from LightsOff to the first signs of N1) and for the first two cycles were exported in EDF+ format using BrainVision Analyzer Version 2.2 (Brain Products 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 (Kogler et al., 2015). Furthermore, Kubios provides an index to analyse the tone of the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS). Those two indices were used to evaluate an appropriate measure for physiological stress. The PNS-index is a PNS tone index based on mean RR whereas the SNS-index is an SNS tone index to evaluate stress which is based on mean HR (Tarvainen et al., 2014).

Statistical analyses

Statistical analyses were performed using RStudio version 1.4.1717. Data are presented as means $\pm$ standard errors. All variables were analysed using repeated-measures analysis of variance (rmANOVA) including the within-subject factor condition (suspense, control) and the between-subjects factor group (cliff, no cliff). For oscillatory power during sleep, the within-subject factors hemisphere (left, right) and topography (frontal, central, parietal, occipital) were

added when applicable (SWA, SWA/Beta ratio). Exploratory post-hoc tests for interactions and main effects consisted of uncorrected paired Student's *t*-tests. In case of statistically significant results, effect sizes are reported with partial eta squared (η^2 ; small effect: $\eta^2 \leq 0.06$; medium effect: > 0.06 – 0.14 ; large effect: ≥ 0.14) for main effects and interactions and Cohen's *d* for *t*-tests (small effect: $d \leq 0.2$; medium effect: > 0.2 – 0.8 ; large effect: ≥ 0.8).

Associations were explored using Pearson product-moment correlations. The level of significance was set to $p \leq 0.05$.

Data availability

Datasets analysed for the current study are available online on <https://osf.io/3stgh>.

3.4. Results

Manipulation check: effects of suspenseful TV series and cliffhangers on pre-sleep arousal

We first analysed whether our manipulation of TV series content (suspenseful TV series vs. non-suspenseful control documentary) resulted in the desired differences on pre-sleep arousal. On the objective level, we analysed the mean HR during the sleep onset period (from LightsOff to the first sign of N1) and the level of cortisol measured after watching the TV series. Regarding HR, only the cliffhanger group exhibited a higher HR after watching the suspenseful TV series (63.17 ± 1.45 bpm) during the sleep onset period, compared to the control condition (58.77 ± 1.27 bpm; $t_{(21)} = -2.90$, $p = 0.009$, $d = 0.46$). No difference was observed in the “no-cliff” group (59.56 ± 0.91 bpm vs. 60.95 ± 1.01 bpm; $t_{(27)} = 1.34$, $p = 0.193$, $d = 0.21$) (see Figure 1B). The interaction condition (series vs. control) x group (cliff vs. no-cliff) was significant ($F_{(1, 48)} = 10.55$, $p = 0.002$, $\eta^2 = 0.18$). The main effect condition was not significant ($p = 0.197$). For cortisol measures after the end of TV series watching, a significant interaction between condition and group was again observed: cortisol values were higher after watching suspenseful TV series compared with non-suspenseful TV series in the cliffhanger group, while the pattern was reversed in the group without cliffhangers ($F_{(1, 47)} = 4.51$, $p = 0.039$, $\eta^2 = 0.09$). The main effects were not significant (both p -values > 0.434 , see Figure 1C). For the three other cortisol samples, no main effect nor interaction effect were found (all p -values > 0.120). On the subjective level, participants rated their level of stress on a scale from 0 (= totally relaxed) to 100 (= highest anxiety ever felt). Participants reported higher stress levels after watching the suspenseful TV series compared to the non-suspenseful documentary (respectively 26.29 ± 2.77

vs. 15.49 ± 1.72 , main effect of condition: $F_{(1, 47)} = 20.62, p < 0.001, \eta^2 = 0.30$). Highest pre-sleep stress levels were reported after watching the TV series with the cliffhanger (32.05 ± 3.39), which significantly differed from stress ratings after watching the non-suspenseful documentary ($16.32 \pm 1.77, t_{(21)} = -3.98, p < 0.001, d = 0.83$). In the group without cliffhangers, the difference was also significant ($t_{(26)} = -2.36, p = 0.026, d = 0.53$). The interaction between the factors condition and group showed a statistical trend ($F_{(1, 47)} = 3.51, p = 0.067, \eta^2 = 0.07$, see Figure 1D), indicating that the difference between the suspenseful TV series and the control tended to be bigger in the “cliff” group than in the “no cliff” group. Thus, our manipulation check was successful: binge-watching a suspenseful TV series resulted in significantly increased objective arousal in the “cliff” group and subjective arousal in both the “cliff” and “no-cliff” group before sleep. In addition, cliffhangers tended to increase pre-sleep arousal on the subjective and objective levels (see Table 1).

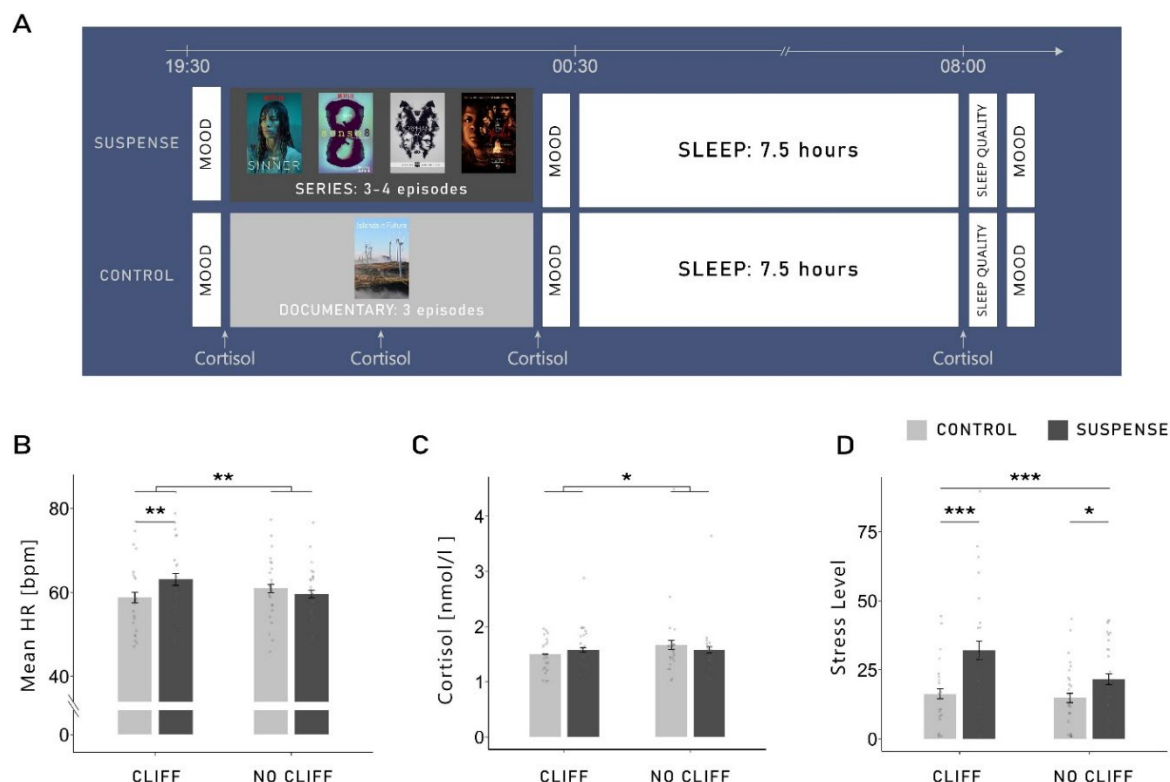


Figure 1: Experimental procedure and manipulation checks. A) Procedure: Healthy young participants watched 3 h of either a suspenseful TV series or a control non-suspenseful documentary in the evening before sleep in a cross-over design. They were then allowed to sleep for a full night of sleep (7.5 h). For one group of participants, the suspenseful TV series was ending with a cliffhanger before sleep (“cliff” group; $n = 22$); for the other group, the suspenseful TV series was manipulated to not end with a cliffhanger before sleep (“no cliff” group; $n = 28$). Sleep was measured using polysomnography including 32 EEG channels. **B) Mean Heart Rate (HR) in beats per minute (bpm) during the sleep onset period:** in the “cliff” group, participants had a higher HR while falling asleep after watching the suspenseful TV series (dark grey) as compared to the control documentary (light grey; $t_{(21)} = -2.90$, $p = 0.009$); no difference was observed in the “no cliff” group ($t_{(27)} = 1.34$, $p = 0.193$). The group $\times$ condition interaction was significant ($F_{(1, 48)} = 10.55$, $p = 0.002$). **C) Cortisol level after the series:** Cortisol values were higher after watching the suspenseful TV series compared with the non-suspenseful control TV series in the “cliff” group, while the pattern was reversed in the “no cliff” group ($F_{(1, 47)} = 4.51$, $p = 0.039$). **D) Subjective stress level:** participants reported higher stress levels after watching the suspenseful TV series compared to the non-suspenseful documentary (main effect of condition: $F_{(1, 47)} = 20.62$, $p < 0.001$). The highest pre-sleep stress levels were reported after watching the TV series with the cliffhanger. Means $\pm$ Standard Errors of the Means (SEM) are indicated. *: $p < 0.05$. **: $p \leq 0.01$. ***: $p \leq 0.001$.

Subjective Sleep Parameters

Next, we analysed whether the increased arousal before and during sleep caused by binge-watching a suspenseful TV series resulted in impaired subjective sleep quality. In contrast to our expectations, and despite the observed increases in pre-sleep arousal after watching suspenseful TV series, we observed no significant impairment of subjective sleep quality (SQ; all p -values > 0.266 , see Figure 2A). No significant effects were found on the other

subjective measures (e.g., subjective sleep onset latency (SOL; see Figure 2B), wake after sleep onset (WASO) and the number of awakenings (NWAK); all p -values > 0.231 ; see Table 1). Additional exploratory analyses revealed that participants felt that their sleep was more agitated after watching a suspenseful TV series ending with a cliffhanger, which was not the case in the “no cliff” group (group $\times$ condition: $F_{(1, 43)} = 4.25$, $p = 0.045$, $\eta^2 = 0.09$) (see Figure 2C). No effects were found on the other self-assessment of how they slept (e.g., deep, good, relaxed, uniformly, calm, ample; all p -values > 0.154).

Objective Sleep Parameters

Also on the objective level, the results did not confirm our initial hypothesis. Watching suspenseful TV series before sleep did not significantly decrease sleep efficiency (all p -values > 0.181 ; see Figure 2D). For WASO and NWAK as well, no significant differences were observed (all p -values > 0.545 , see Table 1).

For objective SOL, the results even showed an opposite pattern compared to our expectation: after watching a suspenseful TV series, participants fell asleep faster (11.67 ± 1.36 min) compared with the non-suspenseful documentary (15.64 ± 1.97 min; main effect condition: $F_{(1, 48)} = 4.89$, $p = 0.032$, $\eta^2 = 0.09$). At a descriptive level, participants in the “cliff” group even had the shortest SOL in the suspenseful TV series condition (10.00 ± 1.29 min), although the interaction was not significant ($p > 0.509$; see Figure 2E and Table 1).

Regarding overall sleep architecture, we observed no significant effect of watching a suspenseful TV series on TST or percentage of N1, N2, or rapid eye-movement (REM) sleep relative to the TST. Only for slow-wave sleep (SWS), the percentage of SWS (relative to the TST) appeared to be lower in the TV series condition with cliffhanger ($30.12 \pm 1.09\%$) compared to the control condition ($31.62 \pm 1.11\%$). The opposite pattern occurred in the “no cliff” group (suspense: $34.10 \pm 1.47\%$; control: $32.08 \pm 1.63\%$). This effect trended in the expected direction ($F_{(1, 48)} = 3.60$, $p = 0.064$, $\eta^2 = 0.07$; see Figure 2F and Table 1). Interestingly, this interaction effect was significant when focusing on the first two sleep cycles (our main analysis window for sleep oscillations; $F_{(1, 48)} = 6.31$, $p = 0.015$, $\eta^2 = 0.12$). Post-hoc pairwise comparisons revealed that only the difference in the “no cliff” group was significant ($t_{(27)} = -2.14$, $p = 0.041$, $d = 0.41$), but not in the “cliff” group ($p = 0.16$; see Figure 3A and Table 1). SWS latency and REM latency and the cyclic structure of sleep remained unaffected by our

manipulation (all p -values > 0.18). We also did not observe any effects of suspenseful TV series on the number of arousals during sleep (see Table 1).

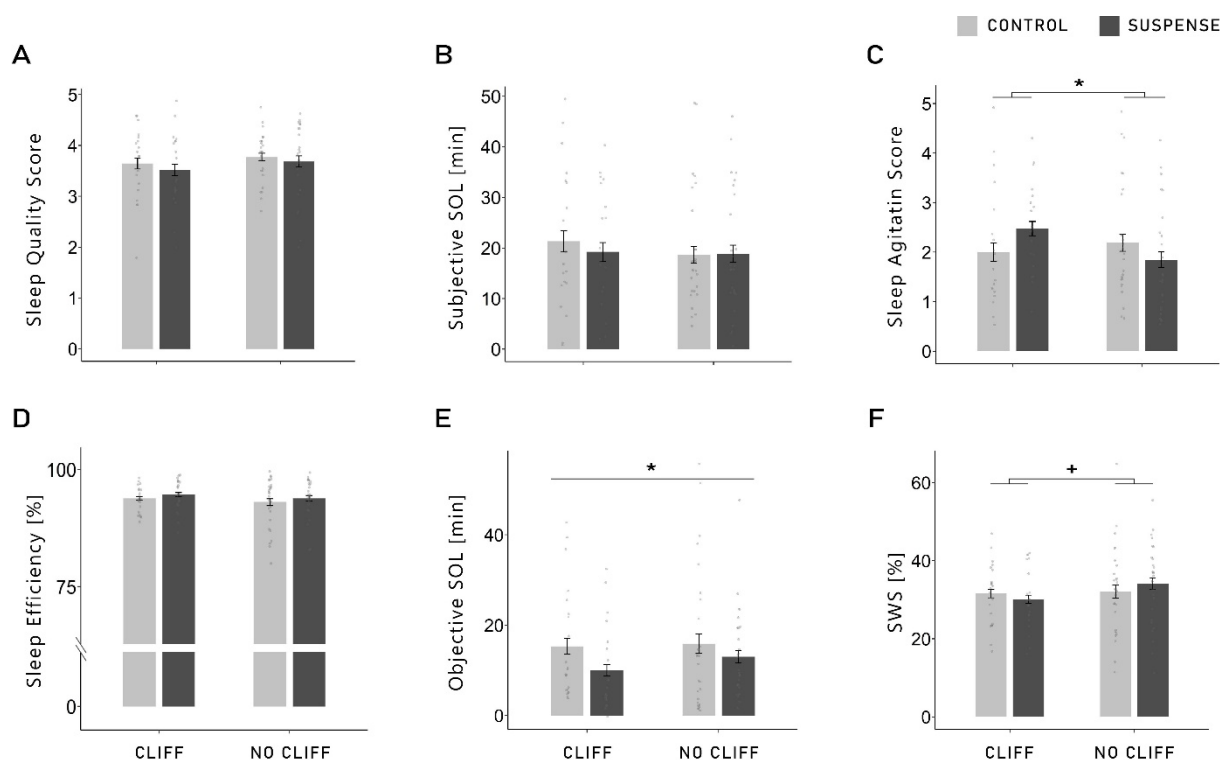


Figure 2: Subjective and objective sleep parameters after watching a suspenseful TV series (dark grey) or a non-suspenseful control documentary (light grey) in “cliff” and “no cliff” groups. Subjective parameters are based on subjective ratings in the SF-A/R (Görmeyer, 2011); objective values are based on polysomnographic recordings. **A) Subjective Sleep Quality (SQ):** subjective SQ was not impaired after watching suspenseful TV series (all p -values > 0.266). **B) Subjective Sleep Onset Latency (SOL) in minutes:** no significant changes were observed (all p -values > 0.488). **C) Subjective Sleep Agitation Score:** a more agitated sleep was reported after watching a suspenseful TV series in the “cliff” group, while this was not the case in the “no cliff” group (interaction: $F_{(1, 43)} = 4.25$, $p = 0.045$). **D) Objective Sleep Efficiency (SE; %):** watching suspenseful TV series before sleep did not significantly decrease SE (all p -values > 0.181). SE represents the percentage of time spent asleep while in bed (the amount of time spent asleep (in minutes) is divided by the total amount of time in bed (in minutes)). **E) Objective Sleep Onset Latency (SOL) in minutes:** participants fell asleep faster after watching a suspenseful TV series compared to the non-suspenseful documentary (main effect of condition: $F_{(1, 48)} = 4.89$, $p = 0.032$). The shortest SOL was observed in the “cliff” group, after the suspenseful TV series. **F) Percentage of Slow-Wave Sleep (SWS) relative to the Total Sleep Time (TST):** in the “cliff” group, percentage of SWS was lower in the suspense condition compared to the control condition, while the opposite pattern was observed in the “no cliff” group. This interaction showed a statistical trend ($F_{(1, 48)} = 3.60$, $p = 0.064$). Means $\pm$ Standard Errors of the Means (SEM) are indicated. *: $p < 0.05$. **: $p \leq 0.01$. ***: $p \leq 0.001$. +: $p < 0.07$.

Table 1: Values and analyses on Total Sleep Time

	Cliffhangers		No cliffhangers		Main effect of condition			Interaction effect		
	Suspense	Control	Suspense	Control	F	p	η^2	F	p	η^2
Subjective Sleep Parameters										
Sleep Quality	3.52 ± 0.11	3.64 ± 0.11	3.68 ± 0.11	3.77 ± 0.07	1.27	0.266	0.03	0.04	0.836	<0.01
SOL [min]	19.21 ± 1.85	21.32 ± 2.11	18.85 ± 1.70	18.65 ± 1.63	0.23	0.634	0.01	0.49	0.488	0.01
WASO [min]	12.63 ± 1.91	10.79 ± 1.73	7.50 ± 1.70	8.08 ± 1.54	0.13	0.720	<0.01	0.94	0.337	0.02
NWAK	1.53 ± 0.16	1.47 ± 0.19	1.38 ± 0.19	1.58 ± 0.16	0.14	0.707	<0.01	0.26	0.610	0.01
Sleep Depth	3.68 ± 0.15	3.53 ± 0.17	3.77 ± 0.16	3.92 ± 0.13	0.01	0.905	<0.01	0.70	0.409	0.02
Sleep Agitation	2.47 ± 0.14	2.00 ± 0.19	1.85 ± 0.16	2.19 ± 0.17	0.00	>0.999	<0.01	4.25	0.045*	0.09
Objective Sleep Parameters										
Sleep Efficiency [%]	94.67 ± 0.49	93.81 ± 0.38	93.82 ± 0.59	93.02 ± 0.74	1.84	0.181	0.04	0.00	0.961	<0.01
SOL [min]	10.00 ± 1.29**	15.32 ± 1.74	12.98 ± 1.41	15.89 ± 2.17	4.89	0.032*	0.09	0.44	0.509	0.01
WASO [min]	14.00 ± 1.92	12.61 ± 1.25	14.73 ± 1.96	15.52 ± 1.80	0.01	0.931	<0.01	0.30	0.584	0.01
N1 [%]	7.38 ± 0.58	6.66 ± 0.37	7.28 ± 0.58	7.62 ± 0.52	0.07	0.799	<0.01	1.11	0.298	0.02
N2 [%]	40.95 ± 0.95	40.08 ± 0.73	39.20 ± 1.22	39.10 ± 1.21	0.25	0.616	0.01	0.19	0.661	<0.01
N3 [%]	30.12 ± 1.10	31.62 ± 1.11	34.10 ± 1.47 ^a	32.08 ± 1.63	0.26	0.610	0.01	3.60	0.064 ^a	0.07
REM [%]	21.55 ± 0.64	21.65 ± 0.65	19.42 ± 0.63	21.20 ± 0.72	1.77	0.190	0.04	1.14	0.291	0.02
TST [min]	422.77 ± 2.21	422.05 ± 1.74	420.89 ± 2.86	418.61 ± 1.74	0.27	0.603	0.01	0.06	0.801	<0.01
SWS Latency [min]	17.57 ± 1.10	17.32 ± 1.32	14.63 ± 1.25	15.98 ± 1.36	0.14	0.711	<0.01	0.21	0.650	<0.01
REM Latency [min]	92.50 ± 5.18	96.91 ± 4.29	96.41 ± 6.41	97.70 ± 6.37	0.14	0.709	<0.01	0.05	0.828	<0.01
Arousals										
Arousals in TST	136.23 ± 10.29	137.05 ± 9.15	139.11 ± 9.27	128.64 ± 8.89	0.74	0.392	0.02	0.77	0.384	0.02
Arousals in NREM	122.45 ± 10.33	123.77 ± 8.69	126.82 ± 8.95	117.71 ± 8.62	0.52	0.473	0.01	0.68	0.412	0.01
Arousals in REM	13.77 ± 1.06	13.27 ± 1.12	12.29 ± 1.40	10.93 ± 1.34	0.34	0.561	0.01	0.06	0.801	<0.01
Arousal Index (TST)	19.40 ± 1.47	19.46 ± 1.27	19.92 ± 1.33	18.61 ± 1.32	0.59	0.446	0.01	0.55	0.463	0.01
Arousal Index NREM	21.80 ± 1.65	22.34 ± 1.50	22.54 ± 1.58	21.59 ± 1.62	0.08	0.782	<0.01	0.47	0.495	0.01
Arousal Index REM	9.31 ± 0.71	8.92 ± 0.79	9.13 ± 1.13	7.30 ± 0.71	1.19	0.281	0.02	0.42	0.519	0.01

Notes: Subjective parameters are based on subjective ratings in the SF-A/R (Göttele, 2011). Objective values are based on polysomnographic recordings. Non-rapid eye movement sleep (NREM), stage 1, 2, 3 sleep (N1, N2, N3), 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 measured in minutes [min] and percentages indicate partial percentage of TST [%]. Analysis with an automatic sleep scoring algorithm (the SIESTA Group Schlafanalyse GmbH, Vienna) provides the number of arousals and arousal indexes. The number of arousals as well as the arousal indexes were analysed for total sleep time (TST), NREM and REM sleep. Values are Means (M) ± Standard Error of Mean (SEM). * indicates $p \leq 0.05$, ** indicates $p \leq 0.01$, *** indicates $p \leq 0.001$, ^a indicates $p \leq 0.09$. Significant results are highlighted in bold. η^2 represent 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.

Effect of cliffhangers on arousal and oscillatory power during sleep in the first two sleep cycles

As watching suspenseful TV series affected heart rate (HR) in the period of falling asleep, we examined HR also during the first two sleep cycles (our main time window of analysis for the sleep oscillations; mean duration = 198.98 ± 7.01 minutes; see Table 2). During the first two sleep cycles in the “cliff” group, HR was significantly higher (60.11 ± 1.24 beats per minute (bpm)), compared with the control documentary (56.89 ± 0.98 bpm; $t_{(21)} = -2.54$, $p = 0.019$, $d = 0.41$). The difference was not significant in the “no cliff” group ($t_{(27)} = -0.94$, $p = 0.357$, $d = 0.12$; see Figure 3B and Table 2). However, the interaction showed only a statistical trend ($F_{(1, 48)} = 3.27$, $p = 0.077$, $\eta^2 = 0.06$), while the main effect of condition was significant ($F_{(1, 48)} = 6.76$, $p = 0.012$, $\eta^2 = 0.12$). Thus, arousal differences caused by watching a suspenseful TV series were maintained during the first half of sleep and tended to be the highest for participants who watched a suspenseful TV series ending with a cliffhanger.

In addition to sleep architecture, we analysed the effects of watching suspenseful TV series with or without cliffhangers on oscillatory power in different frequency bands (slow-wave activity (SWA; 0.5–4.5 Hz), theta (4.5–8 Hz), alpha (8–11 Hz), slow spindle (11–13 Hz), fast spindle (13–15 Hz) and beta band (15–30 Hz)). We observed lower power after watching a suspenseful TV series vs. non-suspenseful control in the “cliff” group in SWA, theta and alpha frequency bands, while this was not the case in the “no cliff” group (see Table 2): For these three frequency bands, the interaction between the factors condition and group were significant (SWA: $F_{(1, 48)} = 4.27$, $p = 0.044$, $\eta^2 = 0.08$; theta: $F_{(1, 48)} = 7.80$, $p = 0.007$, $\eta^2 = 0.14$; alpha: $F_{(1, 48)} = 7.47$, $p = 0.009$, $\eta^2 = 0.13$). In the other frequency bands (beta, slow spindles, fast spindles), the interaction did not reach significance (all p -values > 0.826). A main effect of condition was observed in the fast spindle band, indicating that, in both groups (“cliff” and “no cliff”), a higher power was measured in the suspense condition (“cliff”: 0.27 ± 0.02 ; “no cliff”: 0.27 ± 0.03), compared to the control condition (“cliff”: 0.25 ± 0.02 ; “no cliff”: 0.25 ± 0.03 ; $F_{(1, 48)} = 5.49$, $p = 0.023$, $\eta^2 = 0.09$). We observed no main effect of condition in the other frequency bands (all p -values > 0.183 ; see Table 2). No interactions were found between the factors topography and condition for any of the frequencies analysed (all p -values > 0.153), revealing that the respective power did not differ in location between the two conditions. Similarly, the three-way interaction between the factors topography, condition and group was not significant (all p -values > 0.162).

Regarding the ratio between power in the SWA band and the beta band (SWA/beta ratio), which is considered an indicator of sleep quality (Cordi et al., 2019), the interaction between condition, group and hemisphere (left, right) was significant ($F_{(1, 48)} = 5.05$, $p = 0.029$, $\eta^2 = 0.10$). Therefore, separate analysis for each hemisphere were conducted, revealing that this

effect was mainly driven by the right hemisphere. Indeed, the interaction between condition and group was significant in the right hemisphere ($F_{(1, 48)} = 4.86, p = 0.032, \eta^2 = 0.09$), but not in the left hemisphere ($F_{(1, 48)} = 2.77, p = 0.103, \eta^2 = 0.05$). In both hemispheres, the difference between conditions and groups showed the same pattern: in the “cliff” group, the ratio was lower in the suspense condition compared to the control condition, while the opposite was observed in the “no cliff” group. Post-hoc pairwise t -tests only showed a statistical trend in the right hemisphere for the “cliff” group ($t_{(21)} = 1.91, p = 0.069, d = 0.33$), while the other t -tests showed no significance (all p -values > 0.135 ; see Figure 3C and D, and Table 2). Similarly to the other frequencies, no interactions were found between the factors topography and condition (all p -values > 0.205), nor between the factors topography, condition and group (all p -values > 0.337).

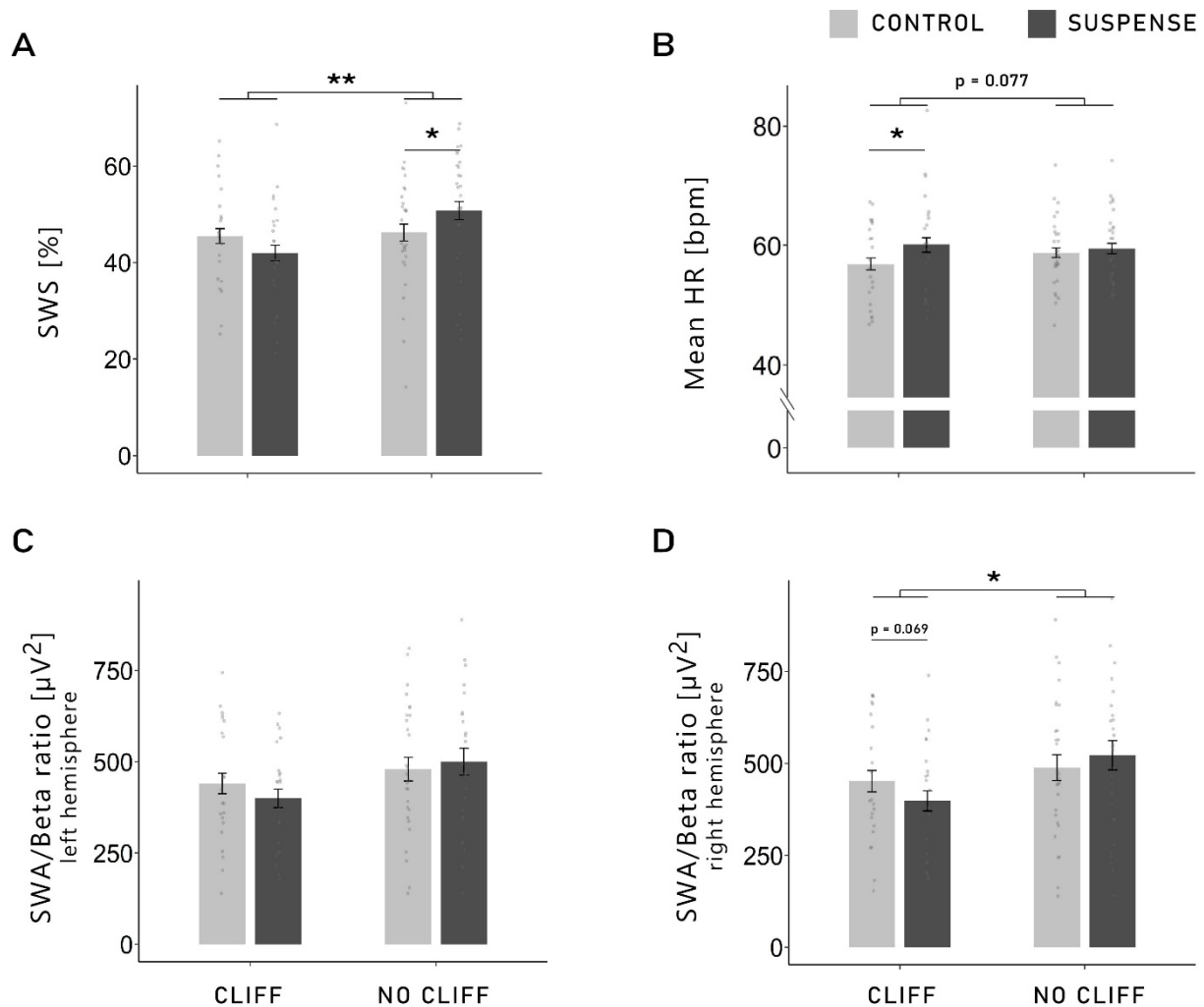


Figure 3: Analyses on the first two sleep cycles. **A) Percentage of Slow-Wave Sleep (SWS)** relative to the total time in the first two sleep cycles: in the “cliff” group, the percentage of SWS was lower in the suspense condition compared to the control condition, while the opposite pattern was observed in the “no cliff” group (interaction: $F_{(1, 48)} = 6.31$, $p = 0.015$). **B) Mean Heart Rate (HR) in beats per minute (bpm) in the first two sleep cycles:** in the “cliff” group, HR was significantly higher in the suspenseful series condition compared with the non-suspenseful control condition ($t_{(21)} = -2.54$, $p = 0.019$). The difference was not significant in the “no cliff” group ($t_{(27)} = 0.94$, $p = 0.357$). The interaction only showed a statistical trend ($F_{(1, 48)} = 3.27$, $p = 0.077$). **Ratio between power in the SWA band and the beta band (SWA/beta ratio) in microvolts (μV^2) in the left (C) and in the right (D) hemisphere:** in both hemispheres, the differences between conditions and groups showed the same pattern: in the “cliff” group, the ratio was lower in the suspenseful TV series condition compared to the non-suspenseful control condition, while the opposite was observed in the “no cliff” group. The group $\times$ condition interaction was significant only in the right hemisphere ($F_{(1, 48)} = 4.86$, $p = 0.032$). Means $\pm$ Standard Errors of the Means (SEM) are indicated. *: $p < 0.05$. **: $p \leq 0.01$. ***: $p \leq 0.001$.

Table 2: Values and analyses in the first two sleep cycles

	Cliffhangers		No cliffhangers		Main effect of condition			Interaction effect		
	Suspense	Control	Suspense	Control	F	p	η^2	F	p	η^2
Sleep Cycles										
Number of Cycles	4.95 ± 0.14	4.77 ± 0.11	4.93 ± 0.12	4.78 ± 0.10	1.37	0.247	0.03	0.01	0.905	<0.01
Mean Cycle Duration [min]	91.31 ± 4.75	90.28 ± 4.81	89.07 ± 4.39	93.54 ± 4.90	0.55	0.464	0.01	0.70	0.407	0.01
Mean Duration Cycle 1	99.84 ± 5.30	105.61 ± 4.29	97.07 ± 4.84	104.39 ± 6.09	1.08	0.304	0.02	0.01	0.905	<0.01
Mean Duration Cycle 2	102.09 ± 5.19	91.57 ± 3.90	95.96 ± 2.93	99.63 ± 4.59	0.26	0.615	0.01	1.90	0.174	0.04
Mean Duration Cycle 1 and 2	201.93 ± 8.41	197.18 ± 6.34	193.04 ± 5.18	204.02 ± 8.08	0.22	0.643	<0.01	0.80	0.375	0.02
Objective Sleep Parameters										
WASO [%]	1.73 ± 0.19	1.78 ± 0.29	1.76 ± 0.29	2.01 ± 0.36	0.25	0.621	0.01	0.09	0.762	<0.01
N1 [%]	7.19 ± 0.59	6.28 ± 0.42	6.29 ± 0.57	6.88 ± 0.54	0.02	0.903	<0.01	1.57	0.216	0.03
N2 [%]	32.39 ± 1.38	30.89 ± 1.11	27.43 ± 1.36	28.48 ± 1.24	0.00	0.954	<0.01	1.28	0.264	0.03
N3 [%]	41.97 ± 1.64	45.49 ± 1.52	50.75 ± 1.85*	46.23 ± 1.74	0.38	0.540	0.01	6.31	0.015*	0.12
REM [%]	16.71 ± 1.08	15.55 ± 1.01	13.77 ± 0.97	16.39 ± 0.84	0.66	0.421	0.01	2.53	0.118	0.05
Heart Rate Variability (HRV)										
Mean HR [bpm]	60.11 ± 1.24*	56.89 ± 0.98	59.46 ± 0.87	58.77 ± 0.83	6.76	0.012*	0.12	3.27	0.077 ^a	0.06
SNS index	-1.05 ± 0.13*	-1.35 ± 0.09	-1.19 ± 0.09	-1.23 ± 0.08	4.68	0.036*	0.09	3.00	0.090 ^a	0.06
PNS index	1.54 ± 0.23	1.95 ± 0.22	1.52 ± 0.19	1.52 ± 0.15	1.30	0.259	0.03	1.76	0.191	0.04
Oscillatory Power [μV^2]										
SWA	12.09 ± 1.04	13.41 ± 1.18	18.26 ± 1.97	16.73 ± 1.80	0.16	0.687	<0.01	4.27	0.044*	0.08
Theta	0.84 ± 0.05	0.89 ± 0.06	1.15 ± 0.08	1.07 ± 0.07	0.74	0.395	0.02	7.80	0.007**	0.14
Alpha	0.46 ± 0.05	0.49 ± 0.05	0.57 ± 0.06	0.53 ± 0.05	0.75	0.391	0.02	7.47	0.009**	0.13
Beta	0.03 ± 0.002	0.03 ± 0.002	0.04 ± 0.003	0.03 ± 0.003	2.85	0.098	0.06	0.02	0.880	<0.01
Slow Spindles	0.34 ± 0.03	0.34 ± 0.03	0.32 ± 0.03	0.32 ± 0.03	0.00	0.965	<0.01	0.05	0.826	<0.01
Fast Spindles	0.27 ± 0.02	0.25 ± 0.02	0.27 ± 0.03	0.25 ± 0.02	5.49	0.023*	0.10	0.04	0.839	<0.01
SWA/Beta ratio right	397.66 ± 27.39	451.66 ± 29.00	521.96 ± 39.91	488.32 ± 34.96	0.06	0.804	<0.01	4.86	0.032*	0.09
SWA/Beta ratio left	399.79 ± 25.76	440.77 ± 28.05	500.61 ± 36.84	479.77 ± 32.54	0.12	0.732	<0.01	2.77	0.103	0.05

Notes: Objective values are based on polysomnographic recordings. Sleep cycles are calculated using the "SleepCycle" R-package (Blume & Cajochen, 2021) based on the criteria of Feinberg & Floyd (1979). Non-rapid eye movement (NREM)-sleep, stage 1, 2 and 3 sleep (N1, N2, N3), rapid eye movement sleep (REM), wake after sleep onset (WASO) are reported in percentages [%] relative to the total time in the first two sleep cycles. Heart rate (HR, in beats per minute (bpm)), sympathetic nervous system (SNS)- and parasympathetic nervous system (PNS)- indexes (provided by Kubios Oy, Kuopio)) calculated during the first two sleep cycles were used as an objective measure. Oscillatory power in the first two sleep cycles was calculated in different frequency bands and reported in microvolts. Values are Means (M) ± Standard Error of Mean (SEM). * indicates $p \leq 0.05$, ** indicates $p \leq 0.01$, *** indicates $p \leq 0.001$, ^a indicates $p \leq 0.09$. Significant results are highlighted in bold. η^2 represent 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.

Correlations

In a follow-up analysis, we further investigated whether the increased stress level and mean HR while falling asleep were correlated to the results found in the sleep parameters. Therefore, correlation analyses were performed. For each variable, the difference between the values from the suspenseful TV series condition and the non-suspenseful control condition were calculated (suspense – control). We were specifically interested in the effect of subjective and objective arousal measures on sleep onset latency (SOL), as SOL was significantly reduced after watching the suspenseful TV series compared to the control condition.

Of note, higher differences in subjective arousal before sleep correlated negatively with differences in objective sleep latency measures, particularly in the “cliff” group ($r = -0.48$, $p = 0.023$) and on a descriptive level also in the “no cliff” group ($r = -0.11$, $p = 0.592$). The two correlations did not significantly differ ($z = -1.36$, $p = 0.175$). Thus, more subjective arousal in the suspense vs. control conditions appeared to predict shorter SOL in the suspense vs. control conditions (see Figure 4A). For the “cliff” group, the same negative association was descriptively observed also for objective arousal (mean heart rate; $r = -0.33$, $p = 0.136$). However, the “no cliff” group showed a significant positive association, with higher heart rate differences predicting longer SOL differences ($r = 0.51$, $p = 0.005$). The two correlations were highly significantly different from each other ($z = -2.98$, $p = 0.003$; see Figure 4B). Thus, cliffhangers in TV series appear to influence associations between objective pre-sleep arousal measures and SOL, resulting in the unexpected reduction of SOL after watching TV series with cliffhangers.

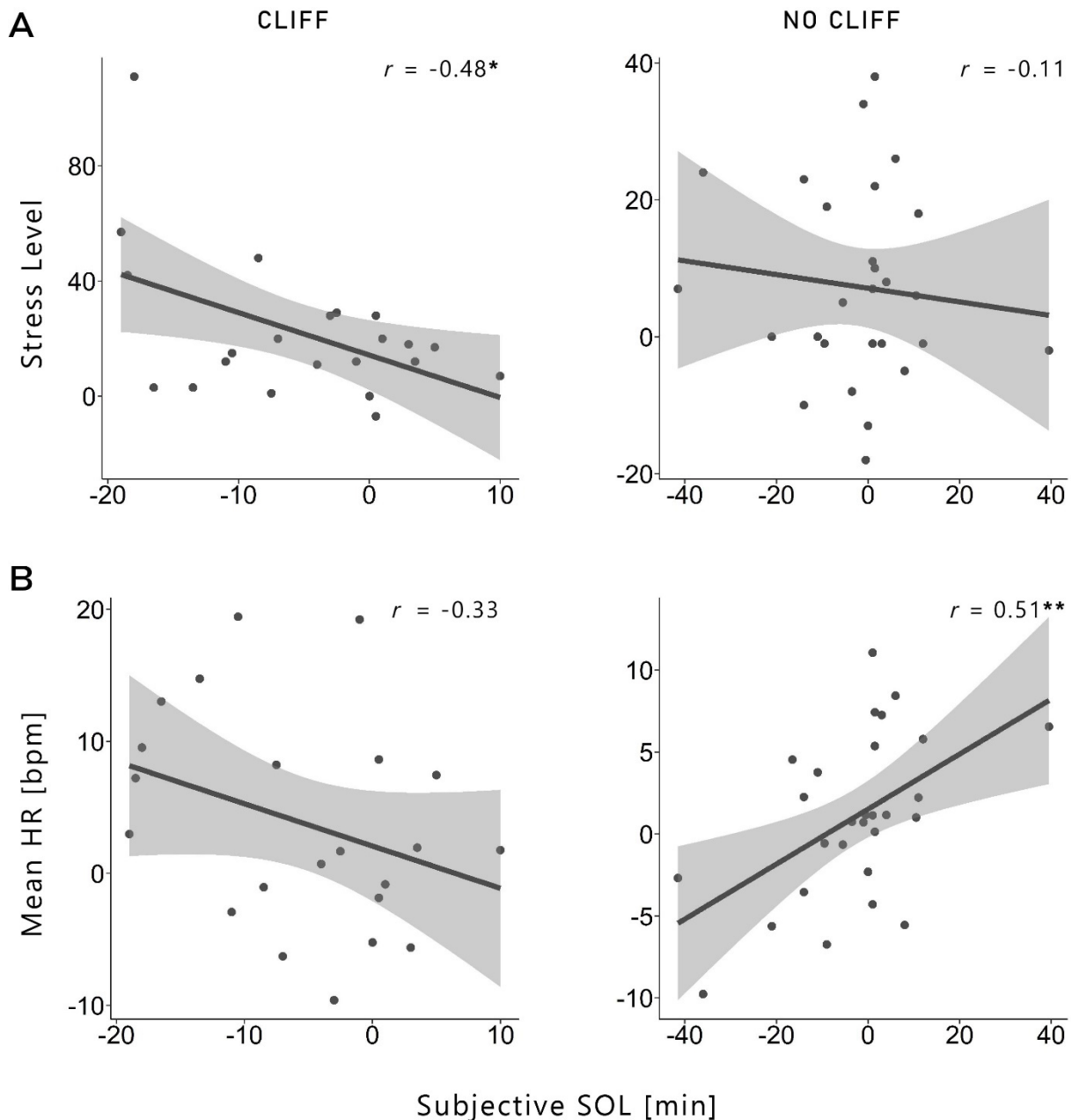


Figure 4: Correlations between subjective and objective pre-sleep stress and objective Sleep Onset Latency (SOL; in minutes) in the “cliff” and “no cliff” groups. For each variable, the difference between the values from the suspense condition and the control condition were calculated (suspense – control). **A) Correlation between differences in subjective pre-sleep stress level and SOL.** More subjective arousal in the suspense vs. control conditions predicted shorter SOL in the suspense vs. control conditions, specifically in the “cliff” group (left). The two correlations were however not significantly different from each other ($z = -1.36, p = 0.175$). **B) Correlation between differences in objective pre-sleep stress (mean Heart Rate) and SOL.** In the “cliff” group (left), more objective arousal in the suspense vs. control conditions predicted shorter SOL in the suspense vs. control conditions, while the opposite pattern was observed in the “no cliff” group. The two correlations were significantly different from each other ($z = -2.98, p = 0.003$). *: $p < 0.05$. **: $p \leq 0.01$.

3.5. Discussion

In this study, we examined the impact of watching 3 h of a suspenseful TV series with and without cliffhangers on subsequent objective and subjective sleep quality in the sleep laboratory. We hypothesised that binge-watching a suspenseful TV series before sleep would negatively impact subjective and objective parameters of sleep and that this impact would be even stronger for TV series ending with a cliffhanger. In contrast to our expectations, we observed only minor effects of watching suspenseful TV series on subsequent sleep: Objective sleep parameters like sleep efficiency, total sleep time, wake after sleep onset and proportion of sleep stages N1, N2 and REM sleep all remained unaffected by our experimental manipulation. In fact, sleep onset latency (SOL) showed the opposite result pattern: participants fell asleep faster after watching 3 h of a suspenseful TV series compared to watching 3 h of a non-suspenseful control documentary. Subjective sleep quality scores were also comparable across the different experimental conditions.

This unexpected result pattern cannot be explained by missing arousal before sleep. Participants generally indicated significantly higher arousal levels after watching the suspenseful TV series compared to the non-suspenseful control documentary. However, heart rate during the period of falling asleep and cortisol levels were only increased after watching suspenseful TV series with cliffhangers. Still, participants in the cliffhanger group as well fell asleep faster after watching the suspenseful TV series vs. the non-suspenseful control documentary. Thus, we have to conclude that arousal induced by suspenseful TV series with or without cliffhanger does not lead to impairments in neither objective nor subjective sleep quality in healthy young adults.

In previous studies, physiological pre-sleep arousal had been correlated with negative effects on SOL (Beck et al., 2023; Heath et al., 2018; Higuchi et al., 2005; Tang & Harvey, 2004), TST (Broman & Hetta, 1994; Landolt et al., 1995; Tang & Harvey, 2004), sleep efficiency (Landolt et al., 1995; Winzeler et al., 2014) or subjective sleepiness (Higuchi et al., 2005). Also greater cognitive arousal has been associated with prolonged SOL both in adults (Takano et al., 2014; Wicklow & Espie, 2000; Wuyts et al., 2012) and in adolescents (Harbard et al., 2016; Hiller et al., 2014). Similarly, pre-sleep arousal specifically induced by media use before sleep has been shown to prolong sleep onset (Dworak et al., 2007; Harbard et al., 2016; Higuchi et al., 2005; Loft & Cameron, 2014). Some authors have suggested that the use of media (watching TV, playing video games, using computers, using mobile phones, or listening to music) before sleep would contribute to a greater cognitive arousal (mental activation such

as thoughts and worries), which increases the difficulty to fall sleep (Harbard et al., 2016). The results of our study do not support this conclusion, as participants fell asleep faster after watching the suspenseful TV series, despite an increased pre-sleep arousal. We could speculate that watching the TV series was more interesting and involving than watching the documentary, which might have led to boredom after the documentary, which is known to elicit negative affective states such as frustration, sadness or anger (Van Tilburg & Igou, 2012). If the documentary was not interesting or exciting for the subjects, it might have elicited those negative affective states which might have delayed sleep onset, similarly to ruminations or repetitive thoughts, without increasing pre-sleep arousal. Several studies have found that repetitive thought results in a lower sleep quality (Guastella & Moulds, 2007; Thomsen et al., 2003; Yeh et al., 2015; Zoccola et al., 2009). This is also in line with studies showing that cognitive arousal without an emotional component led to a prolonged SOL (Wuyts et al., 2012) and that a cognitive arousal eliciting anxiety led to a decreased SOL (Tang & Harvey, 2004). However, in this case, the association between pre-sleep mental activity and sleep onset latency is probably more complex and cannot simply be explained by increases in pre-sleep arousal, as the exact content of the pre-sleep mentation might be relevant.

Our results are also not in line with the findings of a survey reported by Exelmans and Van den Bulck (2017) who showed that the negative effects of binge-watching on subjective sleep quality were mediated by pre-sleep arousal. However, the setting of this study was quite different: In the survey, participants reported on their usual binge-watching habits and their subjective arousal and sleep quality level over a period of a month in their home settings. Our study took place in the highly controlled environment of a sleep laboratory using polysomnographic recordings. Most importantly, participants watched TV series for 3 h in all our experimental conditions. Thus, we have no data on objective and subjective sleep quality of our participants when they did not watch anything before sleep. While sleep quality was generally still high in our sample, we cannot exclude that participants would sleep even better when they would have not watched anything before going to sleep, or even used the time to perform more relaxing activities. In a previous study, we have shown that 30 min progressive muscle relaxation before sleep decreased sleep onset latency compared to 30 min of social media use (Combertaldi et al., 2021). Thus, we would expect that no or even relaxing pre-sleep activities would have shortened sleep latency and increased sleep quality also in our sample. However, that was not the primary goal of the study. Importantly in a real-life setting, pre-sleep media use (and specifically binge watching of multiple TV series) decreases the time available

for sleep, as people delay their sleep onset with typically fixed awaking times the next morning due to school or work schedules. By decreasing time available for sleep, media use and binge-watching clearly has negative effects on sleep, which was not tested in the current study. In addition, here we studied only one occasion of 3 h binge-watching, while in real-life, binge-watching can occur more repeatedly or even chronically. In a recent survey which focused on binge-watching habits over longer time periods (i.e., a month), it has been shown that chronic excessive binge-watching behaviours are related to poor sleep and that those behaviours were partly explained by emotional dysregulation (Alfonsi et al., 2022). Similarly, the survey done by Exelmans and Van den Bulck (2017) reported sleep problems in habitual binge-watchers, which were mediated by pre-sleep arousal. These survey results differ from the minor effects of one binge-watching occasion on sleep measured in the sleep laboratory reported in our study. It might be possible that the effects of habitual binge-watching behaviours on sleep are stronger compared to the effects of one occasion of binge-watching, raising the possibility of “trait-state” differences of these effects. As we did not include a group of habitual binge-watchers in our laboratory experiment, future studies are needed to examine the effects of binge-watching habits on objective sleep parameters.

In our study, we were also specifically interested in the effects of cliffhangers on subsequent sleep. As TV series with such cliffhangers leave audience in full of suspense (Michlin, 2011) and because unfinished narratives and tasks are known to induce tension for completeness (Ovsiankina, 1928; e.g., Zeignarik Effect; Zeigarnik, 1927; Baumeister & Bushman, 2014; Syrek & Antoni, 2014), we expected sleep effects to be larger for TV series with cliffhangers compared to TV series without cliffhangers. In fact, already before sleep, suspenseful TV series with cliffhangers increased heart rate and cortisol levels compared to the non-suspenseful documentary, while this effect was not observed in the group without cliffhanger. Further, subjective arousal levels also tended to be larger with cliffhangers. While cliffhangers had no strong additional effect on subsequent sleep, participants reported to be more agitated after sleep when they had watched TV series with cliffhangers. In addition, we observed a trend for less slow-wave sleep (SWS) after TV series with cliffhangers compared to TV series without cliffhangers. This trend was significant when restricting the analysis to the first two cycles of sleep, and was accompanied by a reduction in the slow-wave/beta ratio, particularly over the right hemisphere. Similarly, slow-wave, theta and alpha power were reduced after suspenseful TV series with cliffhangers compared to the non-suspenseful documentary, which was not observed in the group watching TV series without cliffhangers.

During the first two sleep cycles, heart rate continued to be higher after watching suspenseful TV series with cliffhangers compared to the non-suspenseful documentary, which we did not observe in the no cliffhanger group.

Taken together, suspenseful TV series ending with a cliffhanger appear to have lasting effects on cognitive and physiological arousal that are detectable at least during the first two sleep cycles. These increases in arousal decrease the amount of deep sleep (SWS) and characteristic sleep oscillations (SWA/beta ratio). A possible explanation for these findings is that cognitive arousal induced before sleep remains active during the first sleep periods and reduces sleep depth. We have previously suggested that the content of pre-sleep cognitive activity might be spontaneously reactivated during subsequent sleep (Cordi et al., 2020), similarly to the assumed reactivation of memories during sleep (Rasch & Born, 2013; Wilson & McNaughton, 1994). This repeated reactivation of pre-sleep cognitive content during sleep could activate associated physiological arousal networks and wake-promoting brain regions thereby reducing sleep depth. In line with this hypothesis, we have recently shown that activating cognitive concepts of relaxation during sleep by presenting word cues increased the time spent in slow-wave sleep and induced event-related increases in slow oscillatory power (Beck et al., 2021). Thus, the suspense associated with the open endings after watching TV series with cliffhangers could have been spontaneously reactivated during sleep, thereby activating physiological arousal processes and reducing sleep depth. Our finding of an increased heart rate during the first two sleep cycles supports this notion. Future studies are needed to examine whether targeted reactivation of the suspenseful open endings using associated word cues could decrease sleep depth even further.

An alternative explanation is that after watching TV series with cliffhangers, the suspense associated with open endings increased physiological arousal already before sleep, which then simply remained increased throughout the first two sleep cycles. For this explanation, we do not need the assumption of a reactivation of cognitive content during sleep. We consider this explanation unlikely due to two reasons: First, sleep onset was not increased by increases in physiological arousal before sleep. Thus, the induced pre-sleep physiological arousal was apparently not strong enough to disturb sleep onset processes. In fact, it even facilitated sleep onset, as indicated by the negative correlation between increased heart rate and sleep onset latency in the cliffhanger group. Second, the time course of a sustained physiological arousal responses is typically in the range of 30–60 min after the stressful event (see e.g., Beck et al., 2023). We have recently shown that sleep alterations after a pre-sleep

stressor are detectable only up to 30–60 minutes (Beck et al., 2023). As we observe the effects over two sleep cycles (ca. three hours), it appears to be unlikely that the reported changes in sleep after cliffhangers can be explained by a sustained physiological stress response induced by cliffhangers. Note also that 3 h watching of a suspenseful TV series vs. a non-suspenseful documentary should create a much larger difference in our physiological arousal system compared to watching TV series with or without cliffhangers, which probably mostly affects cognitive aspects of arousal. However, this remains a speculation, as the current study does not allow to clearly separate between cognitive and physiological aspects of arousal.

Our study has several limitations. First, as a control condition, we chose to present a non-suspenseful documentary TV series, because we were mainly interested in the effects of suspense and cliffhangers, and not in the effects of watching *per se*. However, our non-suspenseful documentary might not have been “neutral” as it could have elicited boredom, anger, or frustration. Moreover, as the control condition also implies watching multiple episodes before sleep, we did not have a condition without pre-sleep manipulation. Thus, our design does not provide a comparison with “normal” sleep without binge-watching, which would have enabled to examine also the time-consuming effects of watching multiple TV series at bedtime. Furthermore, our study did include only healthy young participants which were all good sleepers. Thus, our results cannot be generalised to participants with sleeping difficulties or sleep disorders. Furthermore, we did not specifically include a group with a high habitual level of binge-watching, who might differ in several dimensions from the sample included here (Starosta et al., 2021). Furthermore, we did not look at the addictive component of binge-watching, which might be relevant in understanding the link between binge-watching and sleep in real-life settings (Ort et al., 2021).

In sum, our results indicate that watching 3 h of a suspenseful TV series has only minor effects on subjective and objective sleep parameters in young healthy adults compared to watching 3 h of a non-suspenseful documentary. However, TV series ending with cliffhangers can increase aspects of arousal and can reduce the recovery function of sleep, e.g., by decreasing sleep depth and associated brain oscillations in the first two cycles of sleep. We conclude that unfinished cognitive content encountered before sleep should be seen as problematic. To promote sleep, we recommend reducing the use of cliffhangers in TV series, or at least offer options to close the story lines before going to sleep or stop the episode before the cliffhanger. Cliffhangers are used by streaming services to encourage users to continue watching, which delays bedtime even further, which clearly can have detrimental effects on sleep. Thus, while

watching suspenseful TV series before sleep did not impair sleep quality in our study, we would still recommend to restrict the time of media use to allow for sufficient, age-adequate sleep opportunities, which are important for optimal health and cognitive functioning.

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3.6. References

- Ackermann, S., Hartmann, F., Papassotiropoulos, A., de Quervain, D. J. F., & Rasch, B. (2015). No Associations between Interindividual Differences in Sleep Parameters and Episodic Memory Consolidation. *Sleep*, 38(6), 951–959. <https://doi.org/10.5665/sleep.4748>
- Alfonsi, V., Varallo, G., Scarpelli, S., Gorgoni, M., Filosa, M., De Gennaro, L., Musetti, A., & Franceschini, C. (2022). ‘This is the last episode’: The association between problematic binge-watching and loneliness, emotion regulation, and sleep-related factors in poor sleepers. *Journal of Sleep Research*, n/a(n/a), e13747. <https://doi.org/10.1111/jsr.13747>
- Baumeister, R. F., & Bushman, B. J. (2014). *Social Psychology and Human Nature (3rd edition)*. Belmont.
- Beck, J., Loretz, E., & Rasch, B. (2021). Exposure to relaxing words during sleep promotes slow-wave sleep and subjective sleep quality. *Sleep*, 44(11), zsab148. <https://doi.org/10.1093/sleep/zsab148>
- Beck, J., Loretz, E., & Rasch, B. (2023). Stress dynamically reduces sleep depth: Temporal proximity to the stressor is crucial. *Cerebral Cortex*, bhac055. <https://doi.org/10.1093/cercor/bhac055>
- Blume, C., & Cajochen, C. (2021). ‘SleepCycles’ package for R - A free software tool for the detection of sleep cycles from sleep staging. *MethodsX*, 8, 101318. <https://doi.org/10.1016/j.mex.2021.101318>
- Bonnet, M. H., & Arand, D. L. (2010). Hyperarousal and insomnia: State of the science. *Sleep Medicine Reviews*, 14(1), 9–15. <https://doi.org/10.1016/j.smrv.2009.05.002>
- Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1), 49–59. [https://doi.org/10.1016/0005-7916\(94\)90063-9](https://doi.org/10.1016/0005-7916(94)90063-9)
- Broman, J.-E., & Hetta, J. (1994). Perceived pre-sleep arousal in patients with persistent psychophysiologic and psychiatric insomnia. *Nordic Journal of Psychiatry*, 48(3), 203–207. <https://doi.org/10.3109/08039489409081360>
- Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, 28(2), 193–213. [https://doi.org/10.1016/0165-1781\(89\)90047-4](https://doi.org/10.1016/0165-1781(89)90047-4)
- Caldart, C. S., Sanchez, R. E. A., Ben-Hamo, M., Beck, A. I., Weil, T. A., Perez, J. G., Kalume, F., Brunton, B. W., & de la Iglesia, H. O. (2020). *Sleep Identification Enabled by Supervised Training Algorithms (SIESTA): An open-source platform for automatic sleep staging of rodent polysomnographic data* [Preprint]. Neuroscience. <https://doi.org/10.1101/2020.07.06.186940>
- Cohen, S., Hamrick, N. M. S., Rodriguez, M. S., Feldman, P. J., Rabin, B. S., & Manuck, S. B. (2000). The stability of and intercorrelations among cardiovascular, immune, endocrine, and psychological reactivity. *Annals of Behavioral Medicine*, 22(3), 171–179. <https://doi.org/10.1007/BF02895111>
- Combataldi, S. L., Ort, A., Cordi, M., Fahr, A., & Rasch, B. (2021). Pre-sleep social media use does not strongly disturb sleep: A sleep laboratory study in healthy young participants. *Sleep Medicine*, 87, 191–202. <https://doi.org/10.1016/j.sleep.2021.09.009>
- Combataldi, S. L., & Rasch, B. (2020). Healthy Sleepers Can Worsen Their Sleep by Wanting to Do so: The Effects of Intention on Objective and Subjective Sleep Parameters. *Nature and Science of Sleep*, 12, 981–997. <https://doi.org/10.2147/NSS.S270376>
- Cordi, M. J., Ackermann, S., & Rasch, B. (2019). Effects of Relaxing Music on Healthy Sleep. *Scientific Reports*, 9(1), 9079. <https://doi.org/10.1038/s41598-019-45608-y>
- Cordi, M. J., Rossier, L., & Rasch, B. (2020). Hypnotic Suggestions Given Before Nighttime Sleep Extend Slow-Wave Sleep as Compared to a Control Text in Highly Hypnotizable Subjects. *International Journal of Clinical and Experimental Hypnosis*, 68(1), 105–129. <https://doi.org/10.1080/00207144.2020.1687260>
- Dworak, M., Schierl, T., Bruns, T., & Strüder, H. K. (2007). Impact of Singular Excessive Computer Game and Television Exposure on Sleep Patterns and Memory Performance of School-aged Children. *Pediatrics*, 120(5), 978–985. <https://doi.org/10.1542/peds.2007-0476>
- Exelmans, L., & Van Den Bulck, J. (2017). Binge Viewing, Sleep, and the Role of Pre-Sleep Arousal. *Journal of Clinical Sleep Medicine*, 13(08), 1001–1008. <https://doi.org/10.5664/jcsn.6704>

- Feinberg, I., & Floyd, T. C. (1979). Systematic Trends Across the Night in Human Sleep Cycles. *Psychophysiology*, 16(3), 283–291. <https://doi.org/10.1111/j.1469-8986.1979.tb02991.x>
- Flayelle, M., Maurage, P., Vögele, C., Karila, L., & Billieux, J. (2019). Time for a plot twist: Beyond confirmatory approaches to binge-watching research. *Psychology of Popular Media Culture*, 8(3), 308–318. <https://doi.org/10.1037/ppm0000187>
- Görtelmeyer, R. (2011). *SF-A/R und SF-B/R - Schlaffragebogen A und B*. Hogrefe.
- Granow, V. C., Reinecke, L., & Ziegele, M. (2018). Binge-Watching and Psychological Well-Being: Media Use Between Lack of Control and Perceived Autonomy. *Communication Research Reports*, 35(5), 392–401. <https://doi.org/10.1080/08824096.2018.1525347>
- Griefahn, B., Kunemund, C., Bröde, P., & Mehnert, P. (2001). Zur Validität der deutschen Übersetzung des Morningness-Eveningness-Questionnaires von Horne und Östberg. *Somnologie*, 5(2), 71–80. <https://doi.org/10.1046/j.1439-054X.2001.01149.x>
- Guastella, A. J., & Moulds, M. L. (2007). The impact of rumination on sleep quality following a stressful life event. *Personality and Individual Differences*, 42(6), 1151–1162. <https://doi.org/10.1016/j.paid.2006.04.028>
- Harbard, E., Allen, N. B., Trinder, J., & Bei, B. (2016). What's Keeping Teenagers Up? Prebedtime Behaviors and Actigraphy-Assessed Sleep Over School and Vacation. *Journal of Adolescent Health*, 58(4), 426–432. <https://doi.org/10.1016/j.jadohealth.2015.12.011>
- Harvey, A. G. (2002). A cognitive model of insomnia. *Behaviour Research and Therapy*, 40(8), 869–893. [https://doi.org/10.1016/s0005-7967\(01\)00061-4](https://doi.org/10.1016/s0005-7967(01)00061-4)
- Harvey, A. G., Tang, N. K. Y., & Browning, L. (2005). Cognitive approaches to insomnia. *Clinical Psychology Review*, 25(5), 593–611. <https://doi.org/10.1016/j.cpr.2005.04.005>
- Heath, M., Johnston, A., Dohnt, H., Short, M., & Gradisar, M. (2018). The role of pre-sleep cognitions in adolescent sleep-onset problems. *Sleep Medicine*, 46, 117–121. <https://doi.org/10.1016/j.sleep.2018.03.002>
- Higuchi, S., Motohashi, Y., Liu, Y., & Maeda, A. (2005). Effects of playing a computer game using a bright display on presleep physiological variables, sleep latency, slow wave sleep and REM sleep. *Journal of Sleep Research*, 14(3), 267–273. <https://doi.org/10.1111/j.1365-2869.2005.00463.x>
- Hiller, R. M., Lovato, N., Gradisar, M., Oliver, M., & Slater, A. (2014). Trying to fall asleep while catastrophising: What sleep-disordered adolescents think and feel. *Sleep Medicine*, 15(1), 96–103. <https://doi.org/10.1016/j.sleep.2013.09.014>
- Hjortskov, N., Garde, A. H., Ørbæk, P., & Hansen, Å. M. (2004). Evaluation of salivary cortisol as a biomarker of self-reported mental stress in field studies. *Stress and Health*, 20(2), 91–98. <https://doi.org/10.1002/smi.1000>
- Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). *The AASM manual for the scoring of sleep and associated events rules, terminology and technical specifications* (American Academy of Sleep Medicine).
- Jenni, O. G., & Carskadon, M. A. (2004). Spectral Analysis of the Sleep Electroencephalogram During Adolescence. *Sleep*, 27(4), 774–783. <https://doi.org/10.1093/sleep/27.4.774>
- Kirschbaum, C., & Hellhammer, D. H. (1989). Salivary Cortisol in Psychobiological Research: An Overview. *Neuropsychobiology*, 22, 150–169.
- Kogler, L., Müller, V.I., Chang, A., Eickhoff, S.B., Fox, P.T., Gur, R.C., & Derntl, B. (2015). Psychosocial versus physiological stress—Meta-analyses on deactivations and activations of the neural correlates of stress reactions. *NeuroImage*, 119, 235–251. <https://doi.org/10.1016/j.neuroimage.2015.06.059>
- Kurth, S., Jenni, O. G., Riedner, B. A., Tononi, G., Carskadon, M. A., & Huber, R. (2010). Characteristics of sleep slow waves in children and adolescents. *Sleep*, 33(4), 475–480. <https://doi.org/10.1093/sleep/33.4.475>
- Landolt, H.-P., Werth, E., Borbély, A. A., & Dijk, D.-J. (1995). Caffeine intake (200 mg) in the morning affects human sleep and EEG power spectra at night. *Brain Research*, 675(1–2), 67–74. [https://doi.org/10.1016/0006-8993\(95\)00040-W](https://doi.org/10.1016/0006-8993(95)00040-W)
- Loft, M., & Cameron, L. (2014). The importance of sleep: Relationships between sleep quality and work demands, the prioritization of sleep and pre-sleep arousal in day-time employees. *Work & Stress*, 28(3), 289–304. <https://doi.org/10.1080/02678373.2014.935523>

- Lovallo, W. R., & Buchanan, T. W. (2017). Stress hormones in psychophysiological research: Emotional, behavioral, and cognitive implications. In *Handbook of psychophysiology, 4th ed* (pp. 465–494). Cambridge University Press.
- Maes, J., Verbraecken, J., Willemsen, M., De Volder, I., van Gastel, A., Michiels, N., Verbeek, I., Vandekerckhove, M., Wuyts, J., Haex, B., Willemsen, T., Exadaktylos, V., Bulckaert, A., & Cluydts, R. (2014). Sleep misperception, EEG characteristics and autonomic nervous system activity in primary insomnia: A retrospective study on polysomnographic data. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, 91(3), 163–171. <https://doi.org/10.1016/j.ijpsycho.2013.10.012>
- Merikivi, J., Bragge, J., Scornavacca, E., & Verhagen, T. (2020a). Binge-watching Serialized Video Content: A Transdisciplinary Review. *Television & New Media*, 21(7), 697–711. <https://doi.org/10.1177/1527476419848578>
- Michlin, M. (2011). More, More, More: Contemporary American TV Series and the Attractions and Challenges of Serialization As Ongoing Narrative. *Mise Au Point*, 3. <https://doi.org/10.4000/map.927>
- Oldehinkel, A. J., Ormel, J., Bosch, N. M., Bouma, E. M. C., Van Roon, A. M., Rosmalen, J. G. M., & Riese, H. (2011). Stressed out? Associations between perceived and physiological stress responses in adolescents: The TRAILS study. *Psychophysiology*, 48(4), 441–452. <https://doi.org/10.1111/j.1469-8986.2010.01118.x>
- Ong, J. C., Xia, Y., Smith-Mason, C. E., & Manber, R. (2018). A Randomized Controlled Trial of Mindfulness Meditation for Chronic Insomnia: Effects on Daytime Symptoms and Cognitive-Emotional Arousal. *Mindfulness*, 9(6), 1702–1712. <https://doi.org/10.1007/s12671-018-0911-6>
- Ort, A., Wirz, D. S., & Fahr, A. (2021). Is binge-watching addictive? Effects of motives for TV series use on the relationship between excessive media consumption and problematic viewing habits. *Addictive Behaviors Reports*, 13, 100325. <https://doi.org/10.1016/j.abrep.2020.100325>
- Ovsiankina, M. (1928). Untersuchungen zur Handlungs- und Affektpsychologie: VI. Die Wiederaufnahme unterbrochener Handlungen. *Psychologische Forschung*, 11(1), 302–379.
- Perlis, M., Giles, D. E., Mendelson, W. B., Bootzin, R. R., & Wyatt, J. K. (1997). Psychophysiological insomnia: The behavioural model and a neurocognitive perspective. *Journal of Sleep Research*, 6(3), 179–188. <https://doi.org/10.1046/j.1365-2869.1997.00045.x>
- Rasch, B., & Born, J. (2013). About Sleep's Role in Memory. *Physiological Reviews*, 93(2), 681–766. <https://doi.org/10.1152/physrev.00032.2012>
- Riemann, D., Spiegelhalder, K., Feige, B., Voderholzer, U., Berger, M., Perlis, M., & Nissen, C. (2010). The hyperarousal model of insomnia: A review of the concept and its evidence. *Sleep Medicine Reviews*, 14(1), 19–31. <https://doi.org/10.1016/j.smr.2009.04.002>
- Rudzik, F., Thiesse, L., Pieren, R., Héritier, H., Eze, I. C., Foraster, M., Vienneau, D., Brink, M., Wunderli, J. M., Probst-Hensch, N., Rössli, M., Fulda, S., & Cajochen, C. (2020). Ultradian modulation of cortical arousals during sleep: Effects of age and exposure to nighttime transportation noise. *Sleep*, 43(7), zsz324. <https://doi.org/10.1093/sleep/zsz324>
- Sadeghi-Bahmani, D., & Brand, S. (2022). Sleep Medicine Reviews “Stay hungry, stay foolish, stay tough and sleep well!”; why resilience and mental toughness and restoring sleep are associated | Elsevier Enhanced Reader. *Sleep Medicine Reviews*, 62, 101618. <https://doi.org/10.1016/j.smr.2022.101618>
- Schlotz, W., Kumsta, R., Layes, I., Entringer, S., Jones, A., & Wüst, S. (2008). Covariance Between Psychological and Endocrine Responses to Pharmacological Challenge and Psychosocial Stress: A Question of Timing. *Psychosomatic Medicine*, 70(7), 787–796. <https://doi.org/10.1097/PSY.0b013e3181810658>
- Starosta, J., Izydorczyk, B., & Wontorczyk, A. (2021). Anxiety-Depressive Syndrome and Binge-Watching Among Young Adults. *Frontiers in Psychology*, 12, 689944. <https://doi.org/10.3389/fpsyg.2021.689944>
- Steyer, R., Schwenkmezger, P., Notz, P., & Eid, M. (1997). *The multidimensional mental state questionnaire: Manual*. (Göttingen).
- Syrek, C. J., & Antoni, C. H. (2014). Unfinished tasks foster rumination and impair sleeping—Particularly if leaders have high performance expectations. *Journal of Occupational Health Psychology*, 19(4), 490–499. <https://doi.org/10.1037/a0037127>

- Taillard, J., Philip, P., Chastang, J.-F., & Bioulac, B. (2004). Validation of Horne and Ostberg Morningness-Eveningness Questionnaire in a Middle-Aged Population of French Workers. *Journal of Biological Rhythms*, 19(1), 76–86. <https://doi.org/10.1177/0748730403259849>
- Takahashi, M., & Arito, H. (1994). Suppression of electroencephalogram A power density during non-rapid eye movement sleep as a result of a prolonged cognitive task prior to sleep onset. *European Journal of Applied Physiology and Occupational Physiology*, 68(3), 274–280.
- Takano, K., Sakamoto, S., & Tanno, Y. (2014). Repetitive Thought Impairs Sleep Quality: An Experience Sampling Study. *Behavior Therapy*, 45(1), 67–82. <https://doi.org/10.1016/j.beth.2013.09.004>
- Tang, N. K. Y., & Harvey, A. G. (2004). Effects of Cognitive Arousal and Physiological Arousal on Sleep Perception. *Sleep*, 27(1), 69–78. <https://doi.org/10.1093/sleep/27.1.69>
- Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, 113(1), 210–220. <https://doi.org/10.1016/j.cmpb.2013.07.024>
- Thomsen, D. K., Yung Mehlsen, M., Christensen, S., & Zachariae, R. (2003). Rumination—Relationship with negative mood and sleep quality. *Personality and Individual Differences*, 34(7), 1293–1301. [https://doi.org/10.1016/S0191-8869\(02\)00120-4](https://doi.org/10.1016/S0191-8869(02)00120-4)
- Van Tilburg, W. A. P., & Igou, E. R. (2012). On boredom: Lack of challenge and meaning as distinct boredom experiences. *Motivation and Emotion*, 36(2), 181–194. <https://doi.org/10.1007/s11031-011-9234-9>
- Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, 54(6), 1063–1070. <https://doi.org/10.1037/0022-3514.54.6.1063>
- Weber Frederik-D-Weber. (2021). *Frederik-D-Weber/sleeptrip* [MATLAB]. <https://github.com/Frederik-D-Weber/sleeptrip> (Original work published 2019)
- Wicklow, A., & Espie, C. A. (2000). Intrusive thoughts and their relationship to actigraphic measurement of sleep: Towards a cognitive model of insomnia. *Behaviour Research and Therapy*, 38(7), 679–693. [https://doi.org/10.1016/S0005-7967\(99\)00136-9](https://doi.org/10.1016/S0005-7967(99)00136-9)
- Wilson, M. A., & McNaughton, B. L. (1994). Reactivation of Hippocampal Ensemble Memories During Sleep. *Science*, 265(5172), 676–679. <https://doi.org/10.1126/science.8036517>
- Winzeler, K., Voellmin, A., Schäfer, V., Meyer, A. H., Cajochen, C., Wilhelm, F. H., & Bader, K. (2014). Daily stress, presleep arousal, and sleep in healthy young women: A daily life computerized sleep diary and actigraphy study. *Sleep Medicine*, 15(3), 359–366. <https://doi.org/10.1016/j.sleep.2013.09.027>
- Wirz, D. S., Ort, A., Rasch, B., & Fahr, A. (2022). The role of cliffhangers in serial entertainment: An experiment on cliffhangers' effects on enjoyment, arousal, and intention to continue watching. *Psychology of Popular Media*. <https://doi.org/10.1037/ppm0000392>
- Wuyts, J., De Valck, E., Vandekerckhove, M., Pattyn, N., Bulckaert, A., Berckmans, D., Haex, B., Verbraecken, J., & Cluydts, R. (2012). The influence of pre-sleep cognitive arousal on sleep onset processes. *International Journal of Psychophysiology*, 83(1), 8–15. <https://doi.org/10.1016/j.ijpsycho.2011.09.016>
- Yeh, Z.-T., Wung, S.-K., & Lin, C.-M. (2015). Pre-sleep Arousal as a Mediator of Relationships Among Worry, Rumination, and Sleep Quality. *International Journal of Cognitive Therapy*, 8(1), 21–34. <https://doi.org/10.1521/ijct.2015.8.1.21>
- Zeigarnik, B. (1927). Das Behalten erledigter und unerledigter Handlungen. *Psychologische Forschung*, 9, 1–85.
- Zoccola, P. M., Dickerson, S. S., & Lam, S. (2009). Rumination Predicts Longer Sleep Onset Latency After an Acute Psychosocial Stressor. *Psychosomatic Medicine*, 71(7), 771–775. <https://doi.org/10.1097/PSY.0b013e3181ae58e8>

3.7. Appendix

From a questionnaire completed at the end of the TV series, the seven following items were used to create a subscale assessing the degree of suspense.

- 1) A la fin de chaque épisode, j'étais curieux·se de savoir la suite.
- 2) Lorsqu'un épisode se terminait, je voulais vraiment visionner le prochain.
- 3) J'ai continué à regarder le prochain épisode, uniquement car l'étude le demandait.
- 4) Cela me frustre de ne pas savoir comment l'histoire continue.
- 5) Je suis très excité·e de voir comment l'histoire continue.
- 6) Je veux vraiment voir le prochain épisode de la série pour savoir comment cela continue.
- 7) Cela me rend nerveux·se de ne pas connaître la fin de l'histoire.

The answering scale was the following: 'pas du tout', 'un peu', 'moyennement', 'beaucoup', 'tout à fait'.

4. Study II

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

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4.1. 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.

Key words: dreams, stress, cognition, anticipated stress

4.2. 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 & Rohleder, 2019; Bellingrath et al., 2013; Janson & 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 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 & 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.

4.3. Methods

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).

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 8 h and a maximum of 9 h 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 Figure 1A for a summary of the experimental procedure). Before and after the tasks, participants completed standardised questionnaires (see “Questionnaires” section).

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 Figure 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 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.

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://greenergames.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.

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 (Görtelmeyer, 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.

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.

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).

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 $<150\ \mu\text{V}$ in both EMG channels, (2) a maximum voltage step in all EEG channels $<50\ \mu\text{V}/\text{ms}$, (3) a maximum difference in EEG activity $<500\ \mu\text{V}$ in all EEG channels, and (4) a minimum activity in EEG $>0.5\ \mu\text{V}$ 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., Baseltgia et al., 2023; Beck et al., 2023) and the number of removed segments was manually checked.

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).

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 $p < 0.05$.

4.4. Results

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: $F_{1,53} = 63.76$, $p < 0.001$, $\eta^2 = 0.28$). The interaction between the factors group and condition was also significant ($F_{1,53} = 18.64$, $p < 0.001$, $\eta^2 = 0.10$), indicating that the difference was bigger in the pre-sleep group (stress: 5.23 ± 0.50 ; relax: 1.65 ± 0.24 ; $t_{25} = -7.49$, $p < 0.001$, $d = 1.47$) compared to the post-sleep group (stress: 4.62 ± 0.36 ; relax: 3.55 ± 0.32 ; $t_{28} = -3.08$, $p = 0.005$, $d = 0.57$; see Figure 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 > 0.295 ; see Figure 1C). In addition, we observed no difference neither in cognitive nor somatic subjective pre-sleep arousal (all p -values > 0.325). 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: $F_{1,53} = 174.85$, $p < 0.001$, $\eta^2 = 0.56$). The interaction between group and condition was significant ($F_{1,53} = 6.69$, $p = 0.012$, $\eta^2 = 0.05$) indicating that the difference was higher in the pre-sleep group (stress: 5.83 ± 0.36 ; relax: 1.70 ± 0.20 ; $t_{25} = -11.47$, $p < 0.001$, $d = 2.25$) than in the post-sleep group (stress: 4.61 ± 0.38 ; relax: 1.83 ± 0.21 ; $t_{28} = -7.41$, $p < 0.001$, $d = 1.38$). 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: $F_{1,53} = 54.73$, $p < 0.001$, $\eta^2 = 0.22$). We observed no main effect of group, nor interaction (both p -values > 0.603).

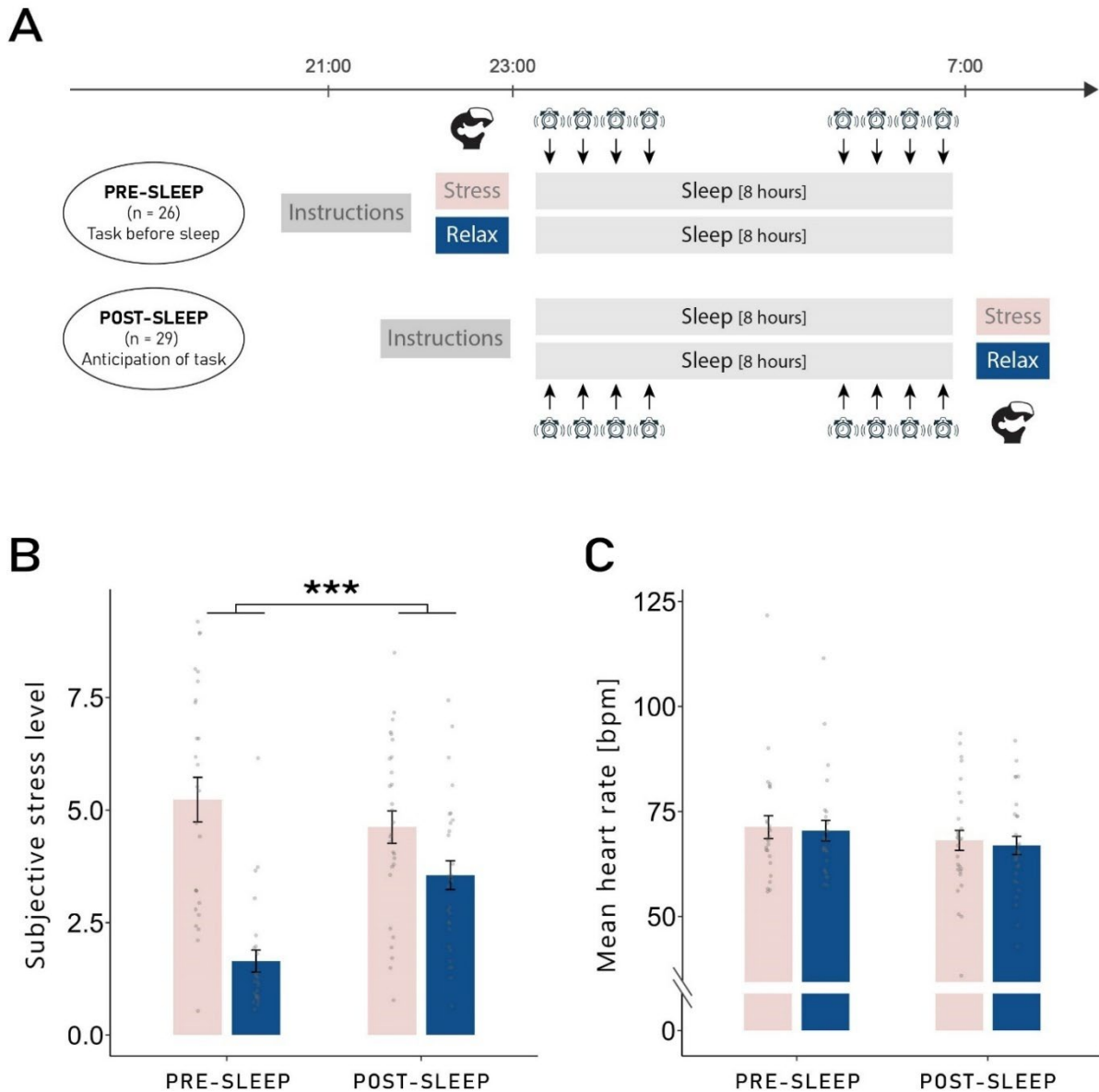


Figure 1: A) Experimental procedure. One group of participants performed either a stress or a relaxation task directly before sleep (maximum 20 min before bed; pre-sleep group, $n = 26$); while another group was informed before sleep that the stress or relaxation task will occur in the morning (post-sleep 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: $F_{1,53} = 63.76$, $p < 0.001$, $\eta^2 = 0.28$). The difference was bigger in the pre-sleep group, compared to the post-sleep group (group x condition interaction: $F_{1,53} = 18.64$, $p < 0.001$, $\eta^2 = 0.10$). **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 > 0.295). Means $\pm$ standard errors of the means are indicated. ***: $p \leq 0.001$.

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 > 0.082 , 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 ($F_{1,612.88} = 3.89$, $p = 0.049$). 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 ($t_{78.9} = 3.45$, $p < 0.001$). 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; $p = 0.124$; 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 ; $F_{1,53.82} = 7.84$, $p = 0.007$). 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 ; $F_{1,612.88} = 60.66$, $p < 0.001$). No other interactions were observed (all p -values > 0.640). 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).

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 Figure 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 > 0.784 ; see Table 1 and Figure 2A).

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

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 x sleep period interaction: $F_{1,79,249} = 9.49, p = 0.003$). 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 ; $t_{78.4} = 2.64, p = 0.010$). 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 ; $t_{85.5} = -1.82, p = 0.073$). Moreover, the difference between conditions also varied depending on the groups, irrespective of the sleep period (condition x group interaction: $F_{1,81,397} = 6.73, p = 0.011$). 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 ; $t_{83.6} = -1.97, p = 0.052$). However, the opposite pattern (stress: 1.70 ± 0.27 ; relax: 1.14 ± 0.26) was not significant in the post-sleep group (estimate difference: 0.56 ± 0.33 ; $t_{84.2} = 1.70, p =$

0.092). The three-way interaction was not significant ($p = 0.407$; see Figure 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 ($\chi^2_{(8)} = 7.73$, $p = 0.460$), 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 ; $t_{75.9} = -0.41$, $p = 0.687$; post-sleep group: 0.82 ± 0.31 ; $t_{87.3} = 1.39$, $p = 0.168$). 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 ; $t_{80.7} = -3.03$, $p = 0.003$) and in the post-sleep group (estimated difference: -0.95 ± 0.47 ; $t_{87.3} = -2.02$, $p = 0.047$; see Figure 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 ; $t_{29.2} = 4.19$, $p < 0.001$; see Figure 2B and Table 3). Unexpectedly, in the pre-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 ; $t_{38.3} = -3.12$, $p = 0.003$). 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 > 0.257).

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.

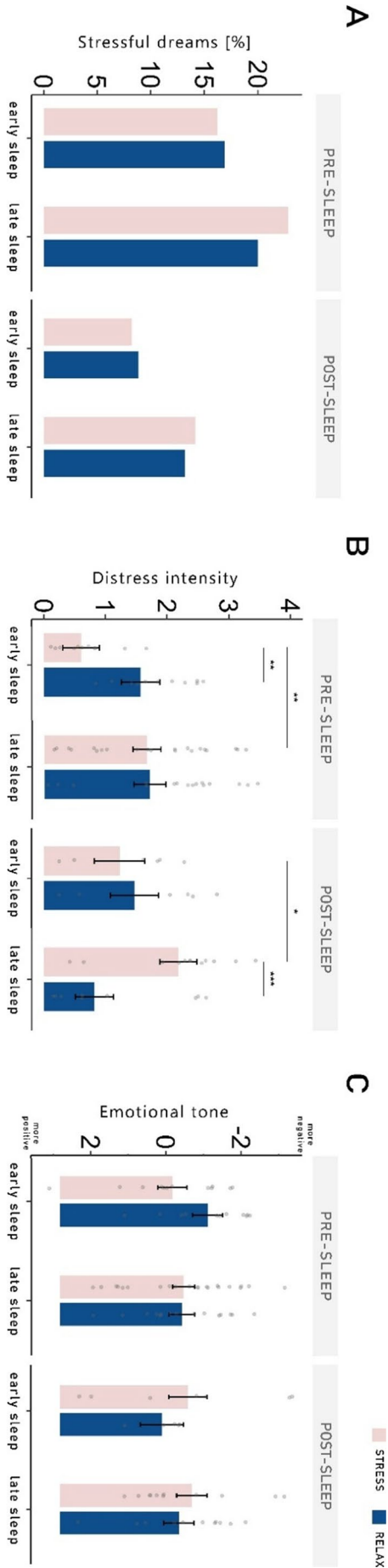


Figure 2: A) Overall percentages of stressful dreams in the pre-sleep group and the post-sleep group for both sleep periods. No difference was found between both conditions (stress, relax) in either group and sleep period (all $\chi^2 < 0.075$, all p -values > 0.784). **B) Intensity of evoked distress 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 > 0.168). 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 ($t_{80.7} = -3.03$, $p = 0.003$); in the post-sleep group, the late dreams were significantly more intense compared to the early dreams ($t_{87.3} = -2.02$, $p = 0.047$). Moreover, in the late sleep of the post-sleep group, the distress intensity was significantly higher in the stress condition ($t_{29.2} = 4.19$, $p < 0.001$), while the opposite was found in the early sleep period of the pre-sleep group ($t_{38.3} = -3.12$, $p = 0.003$). **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 > 0.132). Estimated Marginal Means (EMM) $\pm$ their standard errors are shown. ***: $p \leq 0.001$; **: $p \leq 0.01$.

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 > 0.097 ; see Figure 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 ($F_{1,561.49} = 12.35, p < 0.001$). 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: $-0.48 \pm 0.19, t_{559} = -2.51, p = 0.012$; early dreams, post-sleep group: estimated difference: $-0.61 \pm 0.20, t_{566} = -3.00, p = 0.003$; late dreams, post-sleep group: estimated difference: $-0.14 \pm 0.19, t_{561} = -0.76, p = 0.450$). 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 ($0.44 \pm 0.17; t_{559} = 2.14, p = 0.033$; see Figure 3 and Table 3). The main effect of sleep period as well as its interaction with the factor group were significant (both p -values < 0.006). 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 ($\chi^2_{(8)} = 5.12, p = 0.745$), 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 ($1.05 \pm 0.16; t_{558} = -5.22, p < 0.001$; see Figure 3). The other differences were not significant (all p -values > 0.148).

The emotional intensity was analysed in a similar way, and only a main effect of the sleep period was observed ($F_{1,555.09} = 10.43, p = 0.001$), 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 Figure S2). No other main effect or interaction were observed (all p -values > 0.170).

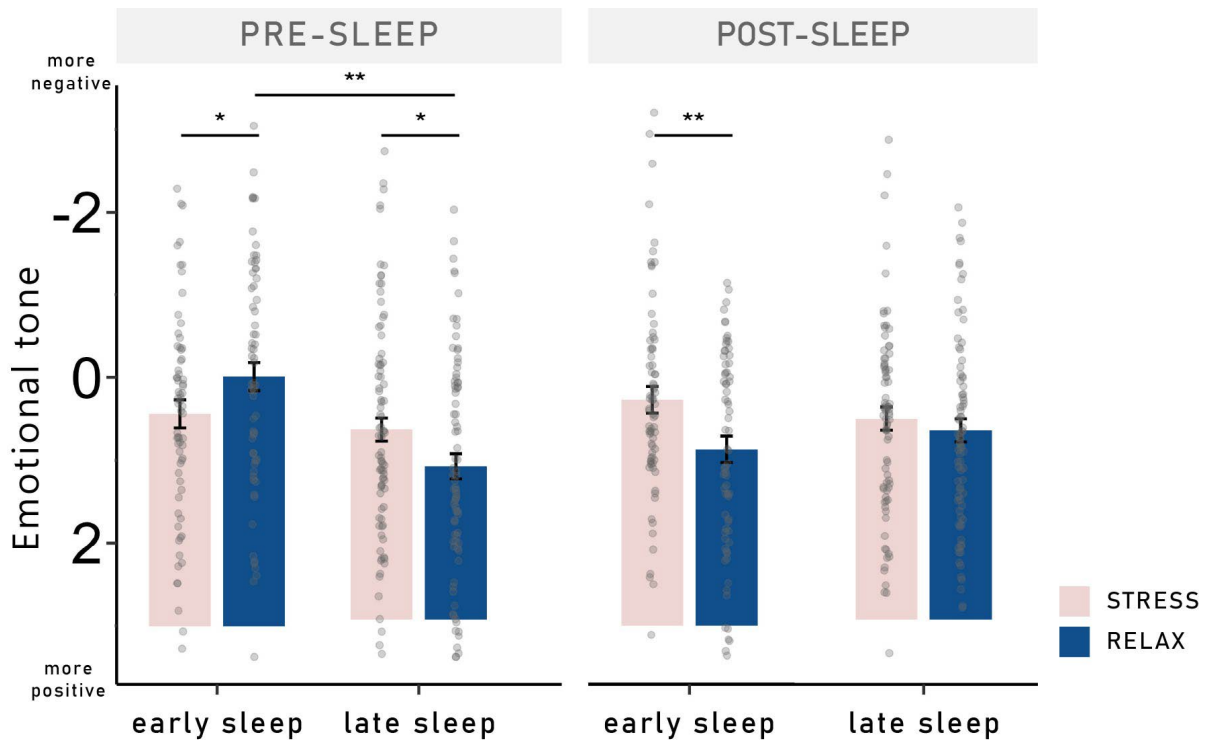


Figure 3: Self-reported emotional tone (positive – negative) of all the dreams in both groups and both sleep periods. The three-way interaction was highly significant ($F_{1,561.49} = 12.35, p < 0.001$). In three of the conditions, the results followed the expected pattern of a more negative emotional 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 ($t_{559} = 2.14, p = 0.033$). 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 ($t_{558} = -5.22, p < 0.001$). The other differences were not significant (all p -values > 0.148). Estimated marginal means (EMM) $\pm$ their standard errors are represented. **: $p \leq 0.01$; *: $p \leq 0.05$.

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	0.072 ^a	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	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	0.053 ^a	0.04	0.850	7.48	0.006	12.35
Late sleep	0.58 ± 0.15	1.05 ± 0.16	0.44 ± 0.15	0.59 ± 0.15							<0.001
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	0.007	60.66	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: $p < 0.075$.

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 > 0.771). No difference was found in subjective SOL either (all p -values > 0.440). 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 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 ($F_{1,53} = 6.19, p = 0.016, \eta^2 = 0.04$). 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; $t_{25} = 2.42, p = 0.023, d = 0.47$), while no difference was observed in the post-sleep group (stress: 17.38 ± 1.29 ; relax: 16.59 ± 0.92 ; $p = 0.638$). We also observed a significant main effect of condition ($F_{1,53} = 4.34, p = 0.042, \eta^2 = 0.03$), 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: $F_{1,46} = 3.72, p = 0.060, \eta^2 = 0.03$; percentage: $F_{1,46} = 3.19, p = 0.081, \eta^2 = 0.02$) 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 ; $t_{22} = -2.17, p = 0.041, d = 0.45$; percentage: 16.77 ± 0.58 ; $t_{22} = -2.11, p = 0.047, d = 0.44$), while no difference was seen in the post-sleep group (both p -values > 0.516). 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 > 0.134 ; 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 > 0.372).

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 ± 0.98	17.77 ± 1.13	18.90 ± 1.00	18.79 ± 0.93	0.16	0.691	<0.01	0.46	0.499	<0.01	0.06	0.806	<0.01
Somatic PSA	13.62 ± 0.84	12.65 ± 0.69	13.21 ± 0.65	13.31 ± 0.72	0.64	0.426	<0.01	0.02	0.891	<0.01	0.99	0.325	<0.01
Sleep Quality	3.37 ± 0.15	3.40 ± 0.14	3.37 ± 0.15	3.35 ± 0.14	0.00	0.969	<0.01	0.02	0.890	<0.01	0.09	0.771	<0.01
SOL	26.96 ± 2.59	26.15 ± 2.50	24.31 ± 2.76	26.21 ± 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 ± 4.75	34.31 ± 5.49	34.10 ± 4.49	35.19 ± 4.78	0.33	0.567	<0.01	0.08	0.778	<0.01	0.06	0.804	<0.01
WASO [%]	14.94 ± 1.34	15.96 ± 1.36	13.57 ± 1.07	14.12 ± 1.16	0.61	0.438	<0.01	1.28	0.264	0.02	0.05	0.816	<0.01
N1 [%]	5.93 ± 0.41	5.80 ± 0.46	6.09 ± 0.47	5.80 ± 0.44	0.65	0.423	<0.01	0.02	0.890	<0.01	0.10	0.748	<0.01
N2 [%]	47.74 ± 0.97	48.77 ± 1.00	47.88 ± 0.95	46.90 ± 1.34	0.00	0.982	<0.01	0.44	0.509	<0.01	1.51	0.225	<0.01
SWS [%]	14.62 ± 0.77	14.88 ± 0.90	15.69 ± 0.89	15.90 ± 1.07	0.14	0.712	<0.01	0.83	0.368	0.01	0.00	0.966	<0.01
REM [%]	16.77 ± 0.84	14.59 ± 0.61	16.79 ± 0.97	17.26 ± 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 ± 3.55	459.30 ± 7.63	459.20 ± 5.61	468.04 ± 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 ± 1.17	25.50 ± 4.12	17.38 ± 1.77	16.59 ± 1.26	4.34	0.042*	0.03	2.32	0.134	0.03	6.19	0.016*	0.04
REM Latency [min]	118.98 ± 9.86	136.96 ± 9.51	118.48 ± 9.96	121.62 ± 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 (Kalmach et al., 2020). Subjective sleep quality and SOL are based on subjective ratings in the SF-A/R (Göertelmeyer, 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) ± Standard Error of Mean (SEM). * indicates $p < 0.05$, ^a indicates $p < 0.09$. 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.

4.5. 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 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 & 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 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 & 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 & Vohs, 2012), which might be reflected in dream emotions according to the dream continuity hypothesis (Schredl & 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 & Rohleder, 2019; Bellingrath et al., 2013; Janson & Rohleder, 2017). Thus, performing a stressful task directly before sleep will typically increase sleep latency and reduce sleep quality (Kim & 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 (Åkerstedt, 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 & 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 focused 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 & 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.

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4.6. References

- Ackermann, S., Cordi, M., La Marca, R., Seifritz, E., & Rasch, B. (2019). Psychosocial Stress Before a Nap Increases Sleep Latency and Decreases Early Slow-Wave Activity. *Frontiers in Psychology*, 10, 20. <https://doi.org/10.3389/fpsyg.2019.00020>
- Åkerstedt, T. (2006). Psychosocial stress and impaired sleep. *Scandinavian Journal of Work, Environment & Health*, 32(6), 493–501.
- Allen, A. P., Kennedy, P. J., Dockray, S., Cryan, J. F., Dinan, T. G., & Clarke, G. (2017). The Trier Social Stress Test: Principles and practice. *Neurobiology of Stress*, 6, 113–126. <https://doi.org/10.1016/j.ynstr.2016.11.001>
- Arnulf, I., Grosliere, L., Le Corvec, T., Golmard, J.-L., Lascols, O., & Duguet, A. (2014). Will students pass a competitive exam that they failed in their dreams? *Consciousness and Cognition*, 12.
- Baekeland, F., Resch, F., & Katz, D. (1968). Presleep Mentation and Dream Reports: I. Cognitive Style, Contiguity to Sleep, and Time of Night. *Archives of General Psychiatry*, 19(3), 300–311. <https://doi.org/10.1001/archpsyc.1968.01740090044005>
- Baselgia, S., Combertaldi, S. L., Fahr, A., Wirz, D. S., Ort, A., & Rasch, B. (2023). Pre-sleep arousal induced by suspenseful series and cliffhangers have only minor effects on sleep: A sleep laboratory study. *Sleep Medicine*, 102, 186–198. <https://doi.org/10.1016/j.sleep.2023.01.005>
- Beck, J., Loretz, E., & Rasch, B. (2021). Exposure to relaxing words during sleep promotes slow-wave sleep and subjective sleep quality. *Sleep*, 44(11), zsab148. <https://doi.org/10.1093/sleep/zsab148>
- Beck, J., Loretz, E., & Rasch, B. (2023). Stress dynamically reduces sleep depth: Temporal proximity to the stressor is crucial. *Cerebral Cortex*, bhac055. <https://doi.org/10.1093/cercor/bhac055>
- Becker, L., & Rohleder, N. (2019). Time course of the physiological stress response to an acute stressor and its associations with the primacy and recency effect of the serial position curve. *PLOS ONE*, 14(5), e0213883. <https://doi.org/10.1371/journal.pone.0213883>
- Bellingrath, S., Rohleder, N., & Kudielka, B. M. (2013). Effort–reward-imbalance in healthy teachers is associated with higher LPS-stimulated production and lower glucocorticoid sensitivity of interleukin-6 in vitro. *Biological Psychology*, 92(2), 403–409. <https://doi.org/10.1016/j.biopsycho.2012.12.003>
- Blagrove, M., Fouquet, N. C., Henley-Einion, J. A., Pace-Schott, E. F., Davies, A. C., Neuschaffer, J. L., & Turnbull, O. H. (2011). Assessing the Dream-Lag Effect for REM and NREM Stage 2 Dreams. *PLoS ONE*, 6(10), e26708. <https://doi.org/10.1371/journal.pone.0026708>
- Blanaru, M., Bloch, B., Vadas, L., Arnon, Z., Ziv, N., Kremer, I., & Haimov, I. (2012). The effects of music relaxation and muscle relaxation techniques on sleep quality and emotional measures among individuals with posttraumatic stress disorder. *Mental Illness*, 4(2), 59–65. <https://doi.org/10.4081/mi.2012.e13>
- Born, J., Hansen, K., Marshall, L., Mölle, M., & Fehm, H. L. (1999). Timing the end of nocturnal sleep. *Nature*, 397(6714), 29–30. <https://doi.org/10.1038/16166>
- Breger, L., Hunter, I., & Lane, R. W. (1971). The Effect of Stress on Dreams. *Psychological Issues*, 7(Monograph 27).
- Combertaldi, S. L., Wick, A. Z., & Rasch, B. (2022). The Intention to React to Sounds Induces Sleep Disturbances and Alters Brain Responses to Sounds during Sleep: A Pilot Study. *Clocks & Sleep*, 4(4), Article 4. <https://doi.org/10.3390/clockssleep4040044>
- Davis, J. L., & Wright, D. C. (2005). Case Series Utilizing Exposure, Relaxation, and Rescripting Therapy: Impact on Nightmares, Sleep Quality, and Psychological Distress. *Behavioral Sleep Medicine*, 3(3), 151–157. https://doi.org/10.1207/s15402010bsm0303_3
- Domhoff, G. W. (2017). The invasion of the concept snatchers: The origins, distortions, and future of the continuity hypothesis. *Dreaming*, 27(1), 14–39. <https://doi.org/10.1037/drm0000047>
- Eichenlaub, J.-B., Van Rijn, E., Phelan, M., Ryder, L., Gaskell, M. G., Lewis, P. A., Walker, M. P., & Blagrove, M. (2019). The Nature of Delayed Dream Incorporation ('dream-lag effect'): Personally significant events persist, but not major daily activities or concerns. *Journal of Sleep Research*, 28(1). <https://doi.org/DOI:%252010.1111/jsr.12697>
- Erdelyi, M. H. (2017). The continuity hypothesis. *Dreaming*, 27(4), 334–344. <https://doi.org/10.1037/drm0000063>

- Erlacher, D., Ehrlenspiel, F., & Schredl, M. (2011). Frequency of Nightmares and Gender Significantly Predict Distressing Dreams of German Athletes Before Competitions or Games. *The Journal of Psychology*, 145(4), 331–342.
- Fosse, R., Stickgold, R., & Hobson, J. A. (2001). The Mind in REM Sleep: Reports of Emotional Experience. *Sleep*, 24(8), 1–9. <https://doi.org/10.1093/sleep/24.8.1>
- Gackenbach, J., & Kuruvilla, B. (2008). The relationship between video game play and threat simulation dreams. *Dreaming*, 18(4), 236–256. <https://doi.org/10.1037/a0013782>
- Goldberg, Z., Thomas, K. G. F., & Lipinska, G. (2020). Bedtime Stress Increases Sleep Latency and Impairs Next-Day Prospective Memory Performance. *Frontiers in Neuroscience*, 14. <https://doi.org/10.3389/fnins.2020.00756>
- Görtelmeyer, R. (2011). *SF-A/R und SF-B/R - Schlaffragebogen A und B*. Hogrefe.
- Hein, E., Halonen, R., Wolbers, T., Makkonen, T., Kyllönen, M., Kuula, L., Kurki, I., Stepnicka, P., & Pesonen, A.-K. (2024). Does sleep promote adaptation to acute stress: An experimental study. *Neurobiology of Stress*, 29, 100613. <https://doi.org/10.1016/j.ynstr.2024.100613>
- Hoerl, C. (2015). Tense and the Psychology of Relief. *Topoi*, 34(1), 217–231. <https://doi.org/10.1007/s11245-013-9226-3>
- Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). *The AASM manual for the scoring of sleep and associated events rules, terminology and technical specifications* (American Academy of Sleep Medicine).
- Ikeda, H., & Hayashi, M. (2008). Electroencephalogram activity before self-awakening. *Sleep and Biological Rhythms*, 6(4), 256–259. <https://doi.org/10.1111/j.1479-8425.2008.00366.x>
- Janson, J., & Rohleder, N. (2017). Distraction coping predicts better cortisol recovery after acute psychosocial stress. *Biological Psychology*, 128, 117–124. <https://doi.org/10.1016/j.biopsycho.2017.07.014>
- Kaida, K., Nakano, E., Nittono, H., Hayashi, M., & Hori, T. (2003). The effects of self-awakening on heart rate activity in a short afternoon nap. *Clinical Neurophysiology*, 114(10), 1896–1901. [https://doi.org/10.1016/S1388-2457\(03\)00167-6](https://doi.org/10.1016/S1388-2457(03)00167-6)
- Kaida, K., Ogawa, K., Hayashi, M., & Hori, T. (2005). Self-Awakening Prevents Acute Rise in Blood Pressure and Heart Rate at the Time of Awakening in Elderly People. *Industrial Health*, 43(1), 179–185. <https://doi.org/10.2486/indhealth.43.179>
- Kalmbach, D. A., Buysse, D. J., Cheng, P., Roth, T., Yang, A., & Drake, C. L. (2020). Nocturnal cognitive arousal is associated with objective sleep disturbance and indicators of physiologic hyperarousal in good sleepers and individuals with insomnia disorder. *Sleep Medicine*, 71, 151–160. <https://doi.org/10.1016/j.sleep.2019.11.1184>
- Kim, E.-J., & Dimsdale, J. E. (2007). The Effect of Psychosocial Stress on Sleep: A Review of Polysomnographic Evidence. *Behavioral Sleep Medicine*, 5(4), 256–278. <https://doi.org/10.1080/15402000701557383>
- King, P. E., & Finn, A. N. (2017). A test of attention control theory in public speaking: Cognitive load influences the relationship between state anxiety and verbal production. *Communication Education*, 66(2), 168–182. <https://doi.org/10.1080/03634523.2016.1272128>
- Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The 'Trier Social Stress Test'—A Tool for Investigating Psychobiological Stress Responses in a Laboratory Setting. *Neuropsychobiology*, 28(1–2), 76–81.
- Kogler, L., Müller, V. I., Chang, A., Eickhoff, S. B., Fox, P. T., Gur, R. C., & Derntl, B. (2015). Psychosocial versus physiological stress—Meta-analyses on deactivations and activations of the neural correlates of stress reactions. *NeuroImage*, 119, 235–251. <https://doi.org/10.1016/j.neuroimage.2015.06.059>
- Lauer, C., Riemann, D., Lund, R., & Berger, M. (1987). Shortened REM Latency: A Consequence of Psychological Strain? *Psychophysiology*, 24(3).
- McDaniel, M. A., & Einstein, G. O. (2007). *Prospective Memory: An Overview and Synthesis of an Emerging Field*. SAGE Publications.
- Means, M. K., Lichstein, K. L., Epperson, M. T., & Johnson, T. (2000). Relaxation therapy for insomnia: Nighttime and day time effects. *Behaviour Research and Therapy*, 665–678.

- Nicassio, P. M., Mendlowitz, D. R., Fussell, J. J., & Petras, L. (1985). The phenomenology of the pre-sleep state: The development of the pre-sleep arousal scale. *Behaviour Research and Therapy*, 23(3), 263–271. [https://doi.org/10.1016/0005-7967\(85\)90004-X](https://doi.org/10.1016/0005-7967(85)90004-X)
- Perslev, M., Darkner, S., Kempfner, L., Nikolic, M., Jennum, P. J., & Igel, C. (2021). U-Sleep: Resilient high-frequency sleep staging. *Npj Digital Medicine*, 4(1), 72. <https://doi.org/10.1038/s41746-021-00440-5>
- Picard-Deland, C., Konkoly, K., Raider, R., Paller, K. A., Nielsen, T., Pigeon, W. R., & Carr, M. (2023). The memory sources of dreams: Serial awakenings across sleep stages and time of night. *Sleep*, 46(4), zsac292. <https://doi.org/10.1093/sleep/zsac292>
- Picard-Deland, C., Nielsen, T., & Carr, M. (2021). Dreaming of the sleep lab. *PLOS ONE*, 16(10), e0257738. <https://doi.org/10.1371/journal.pone.0257738>
- Riemann, D., Spiegelhalter, K., Feige, B., Voderholzer, U., Berger, M., Perlis, M., & Nissen, C. (2010). The hyperarousal model of insomnia: A review of the concept and its evidence. *Sleep Medicine Reviews*, 14(1), 19–31. <https://doi.org/10.1016/j.smrv.2009.04.002>
- Roussy, F., Raymond, I., Gonthier, I., Grenier, J., & De Koninck, J. (1998). Temporal references in manifest dream content: Confirmation of increased remoteness as the night progresses. *Sleep*, 21(285).
- Rusch, H. L., Rosario, M., Levison, L. M., Olivera, A., Livingston, W. S., Wu, T., & Gill, J. M. (2019). The effect of mindfulness meditation on sleep quality: A systematic review and meta-analysis of randomized controlled trials. *Annals of the New York Academy of Sciences*, 1445(1), 5–16. <https://doi.org/10.1111/nyas.13996>
- Schredl, M. (2003). *Continuity Between Waking and Dreaming: A Proposal for a Mathematical Model*. 14.
- Schredl, M. (2010). Dream content analysis: Basic principles. *International Journal of Dream Research*, 3(1), 65–73.
- Schredl, M., & Doll, E. (1998). Emotions in Diary Dreams. *Consciousness and Cognition*, 7(4), 634–646. <https://doi.org/10.1006/ccog.1998.0356>
- Schredl, M., & Reinhard, I. (2010). The Continuity between Waking Mood and Dream Emotions: Direct and Second-Order Effects. *Imagination, Cognition and Personality*, 29(3), 271–282. <https://doi.org/10.2190/IC.29.3.f>
- Siclari, F., Valli, K., & Arnulf, I. (2020). Dreams and nightmares in healthy adults and in patients with sleep and neurological disorders. *The Lancet Neurology*, 19(10), 849–859. [https://doi.org/10.1016/S1474-4422\(20\)30275-1](https://doi.org/10.1016/S1474-4422(20)30275-1)
- Sikka, P., Revonsuo, A., Sandman, N., Tuominen, J., & Valli, K. (2018). Dream emotions: A comparison of home dream reports with laboratory early and late REM dream reports. *Journal of Sleep Research*, 27(2), 206–214. <https://doi.org/10.1111/jsr.12555>
- Sikka, P., Valli, K., Virta, T., & Revonsuo, A. (2014). I know how you felt last night, or do I? Self- and external ratings of emotions in REM sleep dreams. *Consciousness and Cognition*, 25, 51–66. <https://doi.org/10.1016/j.concog.2014.01.011>
- Simon, K. C., McDevitt, E. A., Ragano, R., & Mednick, S. C. (2022). Progressive muscle relaxation increases slow-wave sleep during a daytime nap. *Journal of Sleep Research*, 31(5), e13574. <https://doi.org/10.1111/jsr.13574>
- Steyer, R. (1997). *Der Mehrdimensionale Befindlichkeitsfragebogen MDBF [Multidimensional mood questionnaire]*. (Hogrefe). Hogrefe.
- Sweeny, K., & Vohs, K. D. (2012). On Near Misses and Completed Tasks: The Nature of Relief. *Psychological Science*, 23(5), 464–468. <https://doi.org/10.1177/0956797611434590>
- Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, 113(1), 210–220. <https://doi.org/10.1016/j.cmpb.2013.07.024>
- Trenholme, I., Cartwright, R. D., & Greenberg, G. (1984). Dream dimension differences during a life change. *Psychiatry Research*, 12(1), 35–45. [https://doi.org/10.1016/0165-1781\(84\)90136-7](https://doi.org/10.1016/0165-1781(84)90136-7)
- Ueda, K., Nittono, H., Hayashi, M., & Hori, T. (2001). Spatiotemporal changes of slow wave activities before and after 14 Hz/12 Hz sleep spindles during stage 2 sleep. *Psychiatry and Clinical Neurosciences*, 55(3), 183–184. <https://doi.org/10.1046/j.1440-1819.2001.00817.x>

- Van Reeth, O., Weibel, L., Spiegel, K., Leproult, R., Dugovic, C., & Maccari, S. (2000). Interactions between stress and sleep: From basic research to clinical situations. *Sleep Medicine Reviews*, 4(2), 201–219. <https://doi.org/10.1053/smr.1999.0097>
- Verdone, P. (1965). Temporal Reference of Manifest Dream Content. *Perceptual and Motor Skills*, 20(3_suppl), 1253–1268. <https://doi.org/10.2466/pms.1965.20.3c.1253>
- Verga, L., D'Este, G., Cassani, S., Leitner, C., Kotz, S. A., Ferini-Strambi, L., & Galbiati, A. (2023). Sleeping with time in mind? A literature review and a proposal for a screening questionnaire on self-awakening. *PLOS ONE*, 18(3), e0283221. <https://doi.org/10.1371/journal.pone.0283221>
- Vytal, K. E., Cornwell, B. R., Letkiewicz, A. M., Arkin, N. E., & Grillon, C. (2013). The complex interaction between anxiety and cognition: Insight from spatial and verbal working memory. *Frontiers in Human Neuroscience*, 7, 93. <https://doi.org/10.3389/fnhum.2013.00093>
- Wamsley, E. J. (2022). Constructive episodic simulation in dreams. *PLOS ONE*, 17(3), e0264574. <https://doi.org/10.1371/journal.pone.0264574>
- Wamsley, E. J., Hirota, Y., Tucker, M. A., Smith, M. R., & Antrobus, J. S. (2007). Circadian and ultradian influences on dreaming: A dual rhythm model. *Brain Research Bulletin*, 71(4), 347–354. <https://doi.org/10.1016/j.brainresbull.2006.09.021>
- Wamsley, E. J., Trost, T., & Tucker, M. (2024). Memory updating in dreams. *SLEEP Advances*, 5(1), zpae096. <https://doi.org/10.1093/sleepadvances/zpae096>
- Weingarden, A. M. (1972). Persistence of carthexis: A requisite condition for the incorporation of recent experiences into dreams. *Dissertation Abstracts International*, 33(5-B), 2361–2362.
- Wuyts, J., De Valck, E., Vandekerckhove, M., Pattyn, N., Bulckaert, A., Berckmans, D., Haex, B., Verbraecken, J., & Cluydts, R. (2012). The influence of pre-sleep cognitive arousal on sleep onset processes. *International Journal of Psychophysiology*, 83(1), 8–15. <https://doi.org/10.1016/j.ijpsycho.2011.09.016>
- Xiao, C.-X., Lin, Y.-J., Lin, R.-Q., Liu, A.-N., Zhong, G.-Q., & Lan, C.-F. (2020). Effects of progressive muscle relaxation training on negative emotions and sleep quality in COVID-19 patients: A clinical observational study. *Medicine*, 99(47), e23185. <https://doi.org/10.1097/MD.00000000000023185>
- Zimmer, P., Buttlar, B., Halbeisen, G., Walther, E., & Domes, G. (2019). Virtually stressed? A refined virtual reality adaptation of the Trier Social Stress Test (TSST) induces robust endocrine responses. *Psychoneuroendocrinology*, 101, 186–192. <https://doi.org/10.1016/j.psyneuen.2018.11.010>

4.7. Supplementary material

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

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Supplementary Material: Dream Report Questionnaire

L'enregistreur vocal est activé et le participant est réveillé par l'interphone, en s'adressant à lui par son prénom. Dès que le participant réagit, la question suivante est posée :

« Qu'est-ce qui t'a traversé l'esprit avant de te réveiller ? »

S'il n'y avait pas de rêve, la question suivante est posée :

« As-tu l'impression d'avoir rêvé, même si tu ne te souviens pas du contenu ? »

☐ Non

☐ Oui

☐ Je ne sais pas

Si aucun rêve n'a été rappelé, le participant est maintenu éveillé pendant environ cinq minutes.

Si le participant se souvient de contenus de rêves :

« Ton rêve était-il plus long qu'une minute ? »

☐ Non

☐ Oui

☐ Je ne sais pas

« S'il te plaît, décris de manière aussi détaillée que possible tous les rêves que tu as eus avant de te réveiller »

*Il est conseillé de poser les questions jusqu'à **3 fois** :*

« Y avait-il autre chose ? »

Le récit du rêve est suivi de l'évaluation des émotions :

« Pour les prochaines questions, évalue les émotions de ton rêve en répondant Non, Un peu, Modérément ou Oui : »

- Des sentiments positifs ont-ils été exprimés dans le rêve ?

☐ Non ☐ Un peu

☐ Modérément

☐ Fortement

- Des sentiments négatifs ont-ils été exprimés dans le rêve ?

☐ Non ☐ Un peu

☐ Modérément

☐ Fortement

« Pour les prochaines questions, s'il te plaît note sur une échelle de 1 à 5 » :

1. Quelle était l'intensité de ton rêve ?

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

(1 = pas du tout intense / 5 = très intense)

2. Quelle était l'intensité de l'excitation provoquée par ton rêve ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = pas du tout d'excitation / 5 = beaucoup d'excitation)

3. Quelle était la valence de ton rêve ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = très négative / 3 = neutre / 5 = très positive)

4. À quel point as-tu eu l'impression de subir passivement les événements du rêve ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = pas du tout subi / 5 = tout à fait subi)

5. À quel point ton expérience onirique était-elle imagée / visuelle ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = pas du tout imagée / 5 = très imagée)

6. À quel point es-tu sûr.e que ton souvenir de ton rêve est complet ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = pas du tout sûr.e / 5 = tout à fait sûr.e)

7. À quel point étais-tu conscient.e que l'expérience du rêve n'était pas réelle ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

(1 = pas du tout conscient.e / 5 = tout à fait conscient.e)

8. À quel point avais-tu du contrôle sur le contenu de ton rêve ?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

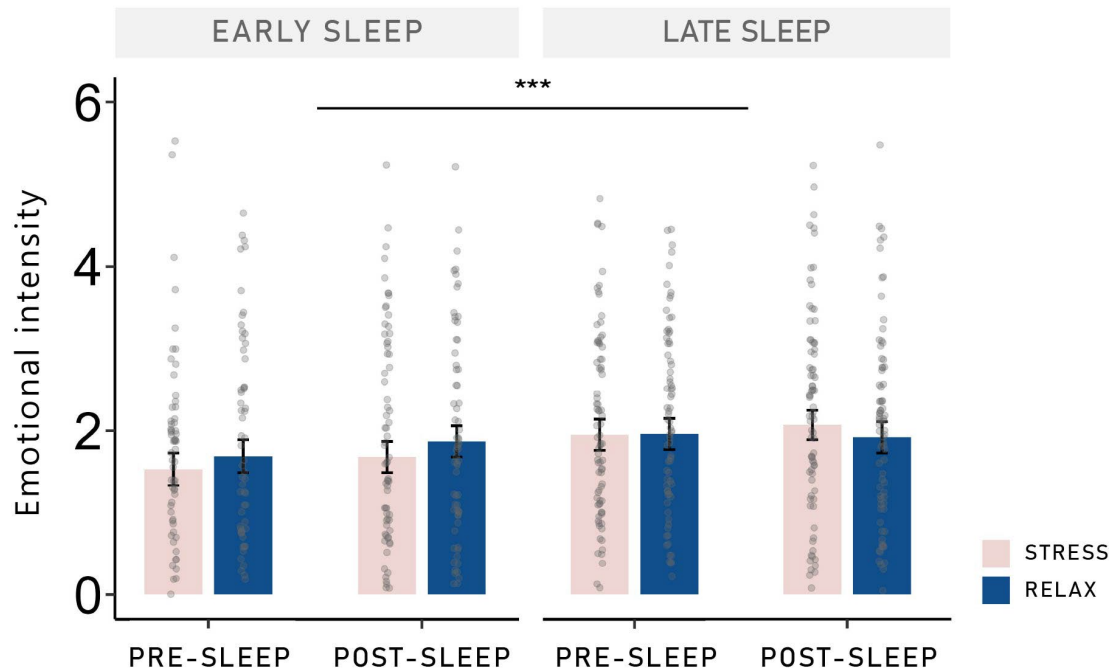
(1 = pas de contrôle / 5 = beaucoup de contrôle)

Table S1: Mean number of collected dream reports in both groups and both conditions, in the early and late sleep periods.

	Pre-sleep group		Post-sleep group		Main effect of condition			Main effect of group			Interaction		
	Stress	Relax	Stress	Relax	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2
Early sleep	2.85 ± 0.19	2.73 ± 0.19	2.93 ± 0.19	2.72 ± 0.15	1.09	0.302	<0.01	0.04	0.845	<0.01	0.09	0.768	<0.01
Late sleep	3.58 ± 0.10	3.27 ± 0.16	3.17 ± 0.13	3.10 ± 0.15	2.76	0.103	0.02	3.14	0.082	0.04	1.11	0.297	<0.01

Notes: Values are means ± standard error of the mean. 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 reflects a large effect.

Figure S2: Self-reported emotional intensity (positive + negative) of the stressful dreams in both groups and both sleep period. A main effect of the sleep period was observed ($F_{1,555.09} = 10.43, p = 0.001$), indicating that the emotional intensity was higher in the late sleep period compared to the early sleep period. No other main effect or interaction were observed (all p -values > 0.170). ***: $p < 0.001$.



5. Study III

Anticipation of stress and relaxation dynamically impacts sleep

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5.1. Abstract

Anticipation of stressful events can impair sleep quality. In a recent study, we reported that anticipating a stressful task before a nap led to negative changes in sleep parameters, particularly at the end of the nap. In our previous study, we compared stress anticipation with the anticipation of relaxation; thus, the observed effects may have been amplified by sleep quality improvements in the relaxation condition. In the current study, we aimed to replicate these findings using an alternative neutral control condition. The data from a newly collected sample ($n = 31$) were compared with the data from our previous study ($n = 33$) using identical analyses. The results reveal an opposite pattern from our previous study: participants in the neutral control condition showed poorer sleep (longer sleep onset latency, reduced slow-wave sleep, and lower SWA/beta ratio) compared to those anticipating stress. In a direct comparison of both studies, sleep parameters in the stress conditions were highly similar across the two studies, suggesting that the divergent outcomes are driven by differences in the control conditions. The temporal dynamic changes observed in our previous study could not be replicated. These findings highlight the importance of carefully considering control conditions in experimental sleep research and suggest that even “neutral” instructions can evoke anticipatory effects. Moreover, the observed benefits of anticipating post-sleep relaxation highlights opportunities for relaxation-based interventions to improve sleep quality.

5.2. Introduction

Psychosocial stress induces stress responses at both physiological and cognitive levels (Campbell & Ehler, 2012; Kogler et al., 2015), subsequently disrupting sleep (e.g., Tang & Harvey, 2004; Wuyts et al., 2012). Research findings have demonstrated that inducing psychosocial stress before sleep leads to prolonged sleep onset latency (SOL), greater sleep fragmentation, fewer deep sleep stages, and a decrease in objective measures of sleep quality (i.e., low-/high-frequency power ratio in electroencephalography (EEG) during non-rapid eye movement (NREM) sleep; Åkerstedt, 2006; Goldberg et al., 2020; Wuyts et al., 2012). Most of these changes are typically observed in the early sleep period, with the late sleep period typically remaining unaffected. In a recently conducted study by our group, our results showed that anticipating a stressful situation after sleep primarily affected later sleep periods (Beck et al., 2023). As one possible interpretation for this finding, we propose that cognitive arousal related to the upcoming event might either remain continuously active during sleep or is being reactivated towards the end of the sleep period in anticipation of the upcoming stressor. Such activation of cognitive arousal could, in turn, induce observed changes in physiological indicators during the late sleep period (e.g., changes in sleep parameters, heart rate, hormonal measures, etc.). The findings of our previous work support this notion, showing that activating the semantic concept of “relaxation” during NREM sleep promotes deeper sleep and lower cardiac activity (Beck et al., 2021; Koroma et al., 2024). By extension, we hypothesise that activating wake-related cognitions before sleep could elicit corresponding physiological responses associated with increased arousal and reduced sleep depth.

The results indicating that anticipation of a stressful situation mainly affected later sleep periods were obtained by comparing the anticipation of a stressful task (Trier Social Stress Test; TSST; Kirschbaum et al., 1993) to the anticipation of a relaxation task, both conducted in a virtual reality (VR) setting. It is thus possible that the detrimental effects on sleep observed in the anticipated stress condition may have been overestimated; since the anticipated relaxation task may have improved sleep parameters, it may have increased the contrast between conditions, thereby magnifying the effect of anticipated stress. To address this issue, we tested an additional group of participants who completed two nap sessions in our sleep laboratory. Under one condition, they underwent the exact same procedure of anticipated stress as in our previous study (Beck et al., 2023); in comparison, under the other condition, they were explicitly told before sleep that the session would end directly after waking up. The control condition – and the omission of an adaptation nap – were the only differences in the procedure

compared with the anticipation group in the study by Beck et al. (2023; Study I: anticipated stress vs. relaxation; see Figure 1A). The newly acquired data set (Study II: anticipated stress vs. neutral control) was compared with the data from Beck et al.'s study (2023), using the same analyses.

In the present study, we aimed to replicate and extend our previous study, in which we compared the anticipation of a stressful event with the anticipation of relaxation. Specifically, we sought to determine whether the previously observed effects of anticipated stress on sleep were influenced by the potentially beneficial effects of anticipating relaxation. To this end, we replicated the anticipated stress condition from our earlier work and added a neutral control condition as a comparison. In addition, we directly compared this new dataset to our previous study, to further investigate the temporal patterns of the influence of cognitive processes on sleep. To achieve these aims, 32 French- or German-speaking female subjects completed both sessions of the experiment. One subject was excluded due to technical problems during one session. The remaining 31 young female participants were compared to the 33 young female participants from Study I, resulting in a final sample of 64 individuals (mean age: 21.95 ± 2.46 [M $\pm$ SD]; age range: 18 – 30 years).

5.3. Results

Subjective and objective pre-sleep arousal

Subjective pre-sleep somatic arousal was significantly higher in Study II (16.39 ± 0.65) compared with Study I (12.30 ± 0.53 ; main effect of study: $F_{1,62} = 14.64$, $p < 0.001$, $\eta^2 = 0.16$; see Figure 1B). No main effect of condition nor interaction was observed (both p -values > 0.450). However, the opposite result was found for subjective pre-sleep cognitive arousal, whereby higher cognitive arousal was found in Study I (17.00 ± 0.69) compared with Study II (13.42 ± 0.54 ; main effect of study: $F_{1,62} = 10.31$, $p = 0.002$, $\eta^2 = 0.12$; see Figure 1C). No main effect of condition nor interaction was observed (both p -values > 0.117) and no difference was observed between both studies and both conditions (all p -values > 0.390) in objective arousal measured with the mean heart rate over the entire nap period (see Figure 1D). We further analysed the progression of heart rate across the nap period in segments of 15 minutes. Heart rate was comparable between both conditions across all timepoints for both studies (interaction between condition, time, and study: $F_{3,61,223.93} = 1.28$, $p = 0.280$, $\eta^2 < 0.01$; see Figure 1E-G).

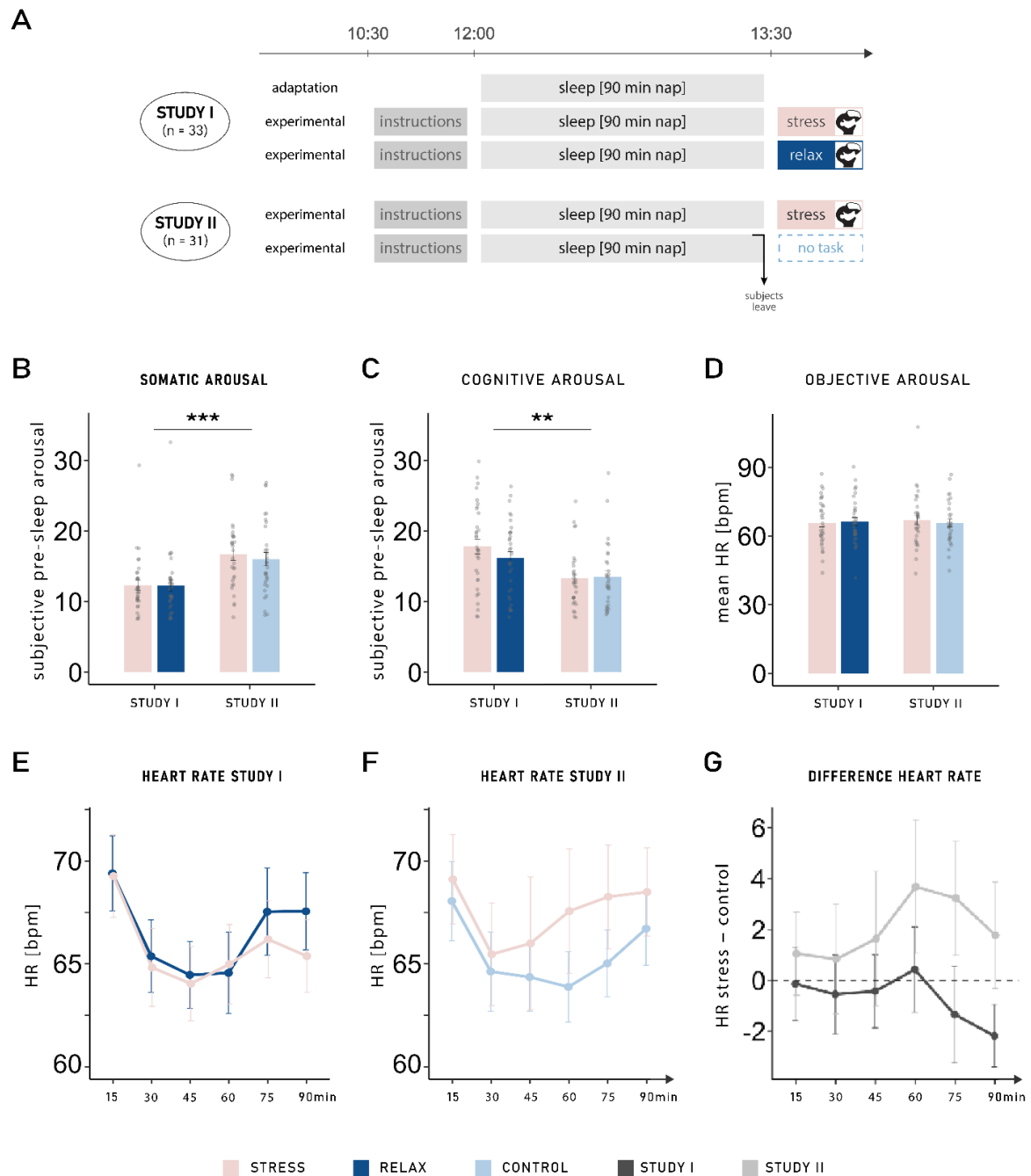


Figure 1: A) Experimental procedure. In Study I (Beck et al., 2023), participants either anticipated a stress or a relaxation task to occur after sleep ($n = 33$). In Study II, the relaxation task was replaced by a neutral control condition ($n = 31$). The anticipated stress condition was the same in both studies: a virtual reality version of the TSST. In the relaxation task, subjects were told to relax in a beautiful virtual reality environment; in comparison, in the neutral control condition, they were informed before sleep that no further task would be conducted upon awakening. While participants slept for an adaptation nap before both experimental naps in Study I, no adaptation nap was performed in Study II. **B) Subjective pre-sleep arousal:** participants reported higher somatic pre-sleep arousal in Study II compared with Study I (main effect of study: $F_{1,62} = 14.64$, $p < 0.001$, $\eta^2 = 0.16$), whereas the opposite result was found for **C) cognitive pre-sleep arousal** (main effect of study: $F_{1,62} = 10.31$, $p = 0.002$, $\eta^2 = 0.12$). **D) Mean heart rate (HR) in beats per minute (bpm) during the 90-min nap:** no difference was observed between either group or condition (all p -values > 0.390). **Progression of the mean heart rate across the nap period (15-min segments) in E) Study I and F) Study II,** in the stress and control conditions. **G) Progression of changes in heart rate (HR) from the stress to the control condition:** heart rate was comparable between both conditions across all time points for

both studies ($p = 0.280$). Means $\pm$ standard errors of the means are displayed. ***: $p \leq 0.001$; **: $p \leq 0.01$.

Sleep architecture

We observed general differences between Study I and Study II, independent of the experimental conditions. The main effect of study indicates that participants overall spent more time in sleep stage N3 in Study I (17.39 ± 1.81 min) compared with Study II (11.60 ± 1.42 min; $F_{1,62} = 4.61$, $p = 0.036$, $\eta^2 = 0.05$), and less time in sleep stage N2 (Study I: 27.50 ± 1.51 min; Study II: 34.58 ± 1.40 min; $F_{1,62} = 8.96$, $p = 0.004$, $\eta^2 = 0.09$). Furthermore, time spent in N1 was higher in Study I (12.20 ± 1.06 min) compared with Study II (7.45 ± 0.57 min; $F_{1,62} = 9.90$, $p = 0.003$, $\eta^2 = 0.11$; see Table 1 for percentages values). These differences between studies remained when we restricted the analyses on the second experimental sessions (all p -values < 0.038), excluding the possibility that they are due to the lack of adaptation in Study II.

We observed two main effects of condition that reached the level of a statistical trend. In both studies, objectively measured time awake (wake after sleep onset; WASO) was increased in the stress condition (6.53 ± 1.10 min) compared with the relaxation/control conditions (4.01 ± 0.73 min; $F_{1,62} = 3.81$, $p = 0.055$, $\eta^2 = 0.03$). In addition, participants tended to show a reduced percentage of N2 sleep in the stress condition ($41.26 \pm 2.10\%$) compared with the relaxation/control conditions ($45.15 \pm 2.27\%$; $F_{1,62} = 3.55$, $p = 0.064$, $\eta^2 = 0.01$). Subjective sleep quality and subjective sleep onset latency (SOL) were not affected by the conditions as no significant results were observed in either study (all p -values > 0.096).

We also observed several significant interactions between the factors study and condition, all of which followed the same pattern. For example, a significant interaction was observed for objective SOL ($F_{1,62} = 7.71$, $p = 0.007$, $\eta^2 = 0.03$). Post hoc pairwise t -tests revealed that the SOL was significantly shorter in the relaxation condition of Study I (12.94 ± 1.74) compared with the neutral control condition of Study II (19.15 ± 1.88 ; $t_{61.27} = -2.43$, $p = 0.018$, $d = 0.608$). This difference was not found when comparing both stress conditions (Study I: 16.76 ± 2.57 ; Study II: 15.76 ± 1.67 ; $p = 0.746$; see Figure 2A). No main effect was observed (both p -values > 0.308). The same interaction was also observed for the amount of SWS (minutes: $F_{1,62} = 6.43$, $p = 0.014$, $\eta^2 = 0.03$; percentage: $F_{1,62} = 5.68$, $p = 0.020$, $\eta^2 = 0.03$): comparing the two control conditions, participants of Study I spent more time in SWS in the relaxation condition (19.80 ± 2.56 min) compared to participants of Study II in the neutral control (9.40 ± 1.71 min; $t_{55.12} = 3.38$, $p = 0.001$, $d = 0.833$). Again, this difference was not

observed when comparing both stress conditions (Study I: 14.97 ± 2.52 ; Study II: 13.79 ± 2.23 ; $p = 0.727$; see Figure 2B and Table 1). No other effect was observed in objective sleep variables (all p -values > 0.110 ; see Table 1).

Objective sleep quality was also measured with the SWA/beta power ratio in NREM sleep over the frontal electrodes. Two participants were excluded from this analysis due to values larger than 3 SD above the mean. A significant interaction was once again observed between study and condition ($F_{1,60} = 4.07$, $p = 0.048$, $\eta^2 = 0.02$), demonstrating the same pattern. The relaxation condition of Study I led to a significantly higher SWA/beta ratio (487.45 ± 40.61) compared with the neutral control condition of Study II (395.81 ± 33.63 ; $t_{53.31} = 2.21$, $p = 0.031$, $d = 0.554$). No difference was observed when comparing the stress conditions (Study I: 402.36 ± 35.64 ; Study II: 395.81 ± 33.63 ; $t_{59.93} = 0.09$, $p = 0.925$, $d = 0.024$; see Figure 2C and Table 2). Therefore, while both stress conditions exhibited similar sleep parameters, differences were observed in the control conditions: the relaxation condition led to objectively improved sleep quality (decreased SOL, more time spent in SWS, and increased SWA/beta power ratio) compared with the neutral control condition. Comparisons between conditions (stress vs. relaxation/control) within studies are presented in Supplementary Table S1.

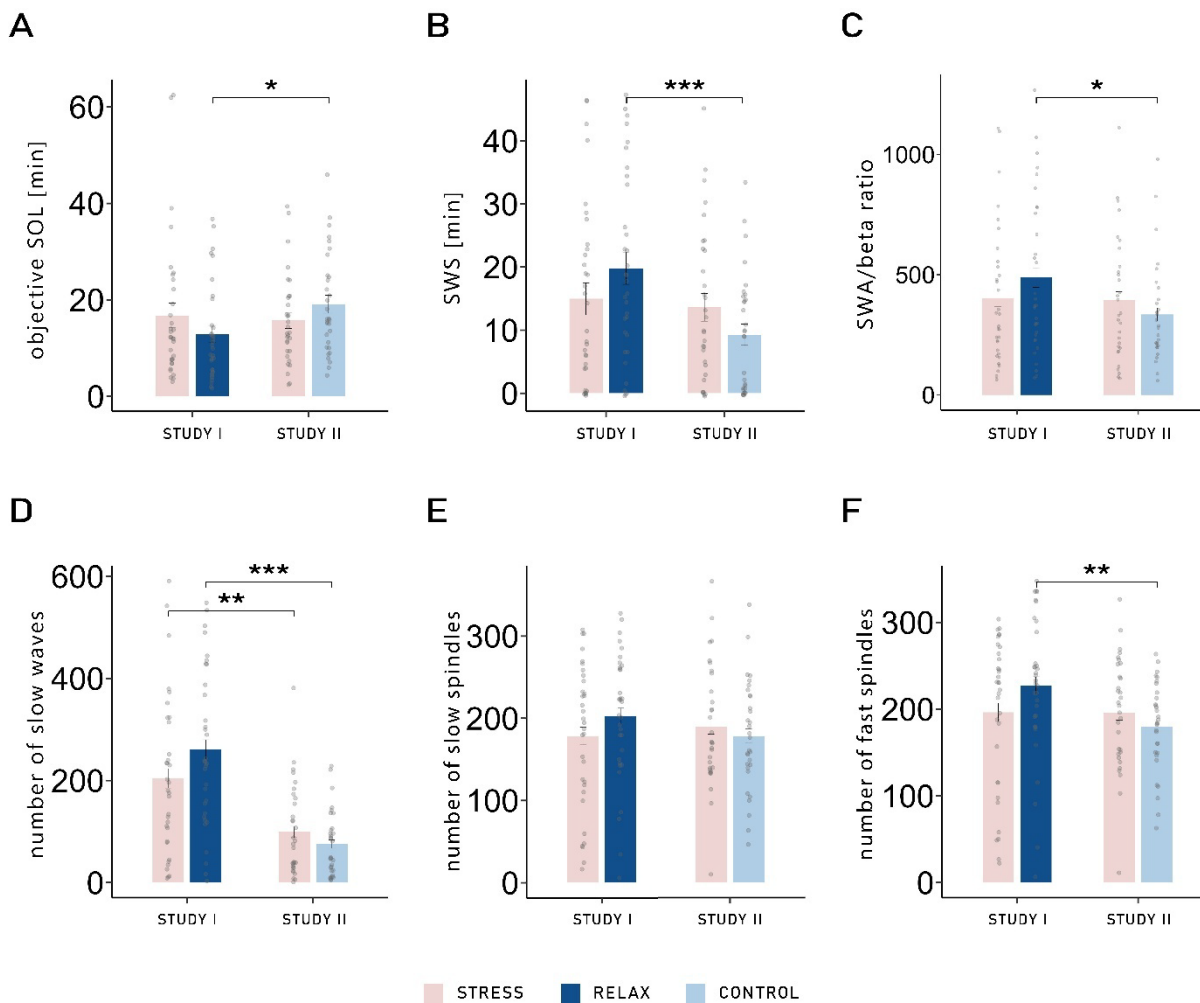


Figure 2: A) Objective sleep onset latency: sleep onset latency was significantly longer in the neutral control condition of Study I compared with the relaxation condition of Study II ($t_{61.27} = -2.43$, $p = 0.018$, $d = 0.608$). This difference was not found when comparing both stress conditions ($p = 0.746$). **B) Time spent in slow wave sleep (SWS) in minutes:** comparing the two control conditions, participants of Study I spent more time in SWS in the relaxation condition compared to participants of Study II in the neutral control condition ($t_{55.12} = 3.38$, $p = 0.001$, $d = 0.833$). This difference was not observed when comparing both stress conditions ($p = 0.727$). **C) Ratio between slow wave activity (SWA) and beta activity during NREM sleep, in the frontal area:** the relaxation condition of Study I led to a significantly higher SWA/beta power ratio compared with the neutral control condition of Study II ($t_{53.31} = 2.21$, $p = 0.031$, $d = 0.554$). No difference was found when comparing the stress conditions of both studies ($p = 0.925$). **D) Number of slow waves (SWs) in the frontal area:** more SWs were observed in Study I compared with Study II. However, the difference was bigger between both control conditions ($t_{43.04} = 6.32$, $p < 0.001$, $d = 1.544$), compared with the difference between both stress conditions ($t_{51.73} = 3.34$, $p = 0.002$, $d = 0.823$). A similar pattern was found for **E) the number of slow spindles in the frontal area;** however, the differences between conditions across studies were not significant (both p -values > 0.185). **F) Number of fast spindles in the parietal area:** the control conditions differed significantly, with more fast spindles observed in the relaxation condition of Study I compared with the neutral control condition of Study II ($t_{53.88} = 2.79$, $p = 0.007$, $d = 0.688$). However, the stress conditions did not differ across studies ($p = 0.961$). Means $\pm$ standard errors of the means are displayed. *: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$.

Table 1: Subjective and objective sleep parameters in the stress and relaxation/neutral control conditions, in both studies.

	Study I		Study II		Main effect of study		Main effect of condition		Interaction effect	
	Anticipated Stress vs. Relaxation		Anticipated Stress vs. Neutral Control		p	η^2	p	η^2	p	η^2
	Stress	Control	Stress	Control						
Subjective Sleep Parameters										
Cognitive PSA	17.82 ± 1.03	16.18 ± 0.91	13.32 ± 0.72	13.52 ± 0.83	0.002	0.12	0.214	<0.01	0.117	<0.01
Somatic PSA	12.33 ± 0.70	12.27 ± 0.80	16.74 ± 0.90	16.03 ± 0.94	<0.001	0.16	0.450	<0.01	0.524	<0.01
Sleep Quality	3.56 ± 0.14	3.57 ± 0.13	3.71 ± 0.12	3.65 ± 0.11	0.416	<0.01	0.785	<0.01	0.729	<0.01
SOL	23.18 ± 1.93	20.45 ± 1.97	25.16 ± 1.97	22.58 ± 1.70	0.352	<0.01	0.096	0.02	0.963	<0.01
Objective Sleep Parameters										
SOL [min]	16.76 ± 2.57	12.94 ± 1.74	15.76 ± 1.67	19.15 ± 1.88	0.308	0.01	0.869	<0.01	0.007	0.03
WASO [%]	9.93 ± 2.63	5.74 ± 1.93	8.10 ± 1.54	6.79 ± 1.86	0.857	<0.01	0.163	0.01	0.463	<0.01
N1 [%]	20.05 ± 2.75	17.07 ± 2.22	9.63 ± 1.13	11.30 ± 1.49	0.003	0.11	0.595	<0.01	0.064 ^a	0.01
N2 [%]	37.82 ± 2.61	39.70 ± 2.57	44.92 ± 3.24	50.96 ± 3.55	0.015	0.07	0.064 ^a	0.01	0.324	<0.01
SWS [%]	20.55 ± 3.14	26.23 ± 3.20	18.40 ± 3.37	12.21 ± 2.28	0.024	0.05	0.918	<0.01	0.020	0.03
REM [%]	11.64 ± 1.71	11.27 ± 1.77	12.55 ± 2.17	12.37 ± 2.54	0.656	<0.01	0.882	<0.01	0.959	<0.01
TST [min]	63.67 ± 3.48	68.30 ± 3.16	64.81 ± 3.00	61.68 ± 2.96	0.472	<0.01	0.754	<0.01	0.110	0.01
WASO [min]	7.18 ± 1.89	3.36 ± 0.85	5.84 ± 1.05	4.69 ± 1.20	0.996	<0.01	0.055 ^a	0.03	0.297	<0.01
N1 [min]	13.14 ± 1.64	11.26 ± 1.35	7.35 ± 0.80	7.55 ± 0.82	0.003	0.11	0.335	<0.01	0.236	<0.01
N2 [min]	26.50 ± 2.21	28.50 ± 2.07	33.95 ± 2.37	35.21 ± 1.52	0.004	0.09	0.351	<0.01	0.831	<0.01
SWS [min]	14.97 ± 2.52	19.80 ± 2.56	13.79 ± 2.23	9.40 ± 1.71	0.036	0.05	0.903	<0.01	0.014	0.03
REM [min]	9.06 ± 1.38	8.74 ± 1.42	9.71 ± 1.70	9.45 ± 1.92	0.699	<0.01	0.844	<0.01	0.984	<0.01

Notes: Subjective parameters are based on subjective ratings in the PSAS, assessing pre-sleep arousal (PSA) and SF-A/R questionnaires, measuring subjective sleep quality and sleep onset latency (SOL). Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), SOL, SWS latency, REM sleep latency are measured in minutes, and percentages indicate partial percentage of total sleep time (TST). Values are means and standard errors of the mean. Significant results are highlighted in bold. ^a indicates $p < 0.07$. 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 reflects a large effect.

Table 2: SWA/beta power ratio and characteristics of slow waves, slow spindles and fast spindles in NREM sleep, in both conditions and both studies. The last columns refer to the interaction between condition and study in the analysis of 5-min segments, adding the factor time.

	Study I		Study II		Main effect of study		Main effect of condition		Interaction effect		In 5-min segments: interaction effect	
	Anticipated Stress vs. Relaxation	Control	Anticipated Stress vs. Neutral	Control	p	η^2	p	η^2	p	η^2	p	η^2
SWA/beta ratio in frontal area												
Slow waves in frontal area												
Count	402.36 ± 35.64	487.45 ± 40.61	395.81 ± 33.63	334.60 ± 27.12	0.187	0.02	0.743	<0.01	0.048	0.02	0.018	0.01
Amplitude	203.94 ± 18.90	260.82 ± 19.00	99.31 ± 11.25	75.42 ± 8.09	<0.001	0.26	0.255	<0.01	0.007	0.03	0.005	<0.01
Density	138.27 ± 4.30	144.79 ± 4.31	83.75 ± 2.19	83.14 ± 2.02	<0.001	0.54	0.237	<0.01	0.154	<0.01	0.005	<0.01
Duration	2.29 ± 0.14	2.63 ± 0.14	1.02 ± 0.10	0.83 ± 0.07	<0.001	0.42	0.538	<0.01	0.023	0.02	0.005	<0.01
Up-slope	1.25 ± 0.01	1.25 ± 0.01	1.70 ± 0.01	1.73 ± 0.01	<0.001	0.94	0.050	0.01	0.033	0.01	0.011	<0.01
Down-slope	381.44 ± 14.44	386.66 ± 14.67	109.94 ± 2.98	109.31 ± 2.83	<0.001	0.73	0.771	<0.01	0.711	<0.01	0.027	<0.01
	-365.17 ± 11.88	-388.86 ± 13.86	-102.99 ± 2.97	-102.55 ± 2.76	<0.001	0.77	0.065 ^a	<0.01	0.056 ^a	<0.01	0.011	<0.01
Slow spindles in frontal area												
Count	178.36 ± 10.70	202.70 ± 9.68	190.00 ± 9.48	178.21 ± 8.55	0.703	<0.01	0.523	<0.01	0.069 ^a	0.01	0.034	<0.01
Amplitude	30.56 ± 0.73	30.77 ± 0.86	28.44 ± 0.87	29.93 ± 0.99	0.349	0.01	0.210	<0.01	0.343	<0.01	0.078 ^a	<0.01
Density	2.25 ± 0.06	2.19 ± 0.05	2.17 ± 0.08	2.16 ± 0.06	0.647	<0.01	0.518	<0.01	0.600	<0.01	0.023	<0.01
Duration	0.87 ± 0.01	0.86 ± 0.01	0.84 ± 0.01	0.85 ± 0.01	0.284	0.02	0.845	<0.01	0.295	<0.01	0.048	<0.01
Fast spindles in parietal area												
Count	196.27 ± 10.69	227.27 ± 10.09	195.32 ± 8.32	179.84 ± 6.65	0.125	0.03	0.426	<0.01	0.019	0.03	0.022	<0.01
Amplitude	25.83 ± 0.73	25.81 ± 0.86	18.69 ± 0.74	19.20 ± 0.60	<0.001	0.27	0.547	<0.01	0.522	<0.01	0.023	<0.01
Density	2.50 ± 0.04	2.47 ± 0.04	2.22 ± 0.05	2.25 ± 0.06	0.004	0.11	0.882	<0.01	0.438	<0.01	0.016	<0.01
Duration	0.90 ± 0.01	0.90 ± 0.01	0.86 ± 0.01	0.87 ± 0.01	0.075 ^a	0.04	0.853	<0.01	0.242	<0.01	0.056 ^a	<0.01

Notes: Slow-wave and spindles detection was conducted with the default settings from SleepTrip toolbox on MATLAB R2024b. Prior to sleep spindles detection, individual slow and fast spindle frequency peaks were visually determined based on the NREM power spectrum of each dataset. Slow spindles peaks were determined in frontal channels (F3, F4) and fast spindles peaks in parietal channels (P3, P4) due to expected power maxima over those regions (Mölle et al., 2002). The algorithms used in SleepTrip are explained in detail in Beck et al. (2021) and Beck et al. (2023). Values are means and standard errors of the mean. Significant results are highlighted in bold. ^a indicates $p < 0.075$. 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 reflects a large effect.

Slow-waves and sleep spindles

We performed further analyses on different characteristics of single slow-waves (SWs) and slow spindles in frontal electrodes and fast spindles in parietal electrodes (count, density, duration, amplitude, and up- and down-slope). Firstly, it is important to note that in general, there were more SWs in Study I (232.38 ± 19.25) compared with Study II (87.36 ± 9.88) and that those SWs showed an increased density, amplitude, and down- and up-slope in Study I compared with Study II (all p -values for the main effect of study < 0.001). However, SWs were of longer duration in Study II (1.72 ± 0.01) compared with Study I (1.25 ± 0.01 ; main effect of study: $F_{1,62} = 1145.13$, $p < 0.001$, $\eta^2 = 0.94$). Similarly, participants of Study I showed an increased density ($F_{1,62} = 9.04$, $p = 0.004$, $\eta^2 = 0.11$) and amplitude ($F_{1,62} = 24.48$, $p < 0.001$, $\eta^2 = 0.27$) of fast spindles; however they tended to be of shorter duration ($F_{1,62} = 3.27$, $p = 0.075$, $\eta^2 = 0.04$) compared with Study II. Following the pattern observed in sleep parameters, the interaction between study and condition was significant for the number of SWs ($F_{1,62} = 7.92$, $p = 0.007$, $\eta^2 = 0.03$; see Figure 2D) and fast spindles ($F_{1,62} = 5.76$, $p = 0.019$, $\eta^2 = 0.03$; see Figure 2F) and showed a statistical trend for the number of slow spindles ($F_{1,62} = 3.42$, $p = 0.069$, $\eta^2 = 0.01$; see Figure 2E). Regarding the number of SWs, the difference in SWs between the relaxation and neutral control conditions was stronger (Study I: 260.82 ± 19.00 ; Study II: 75.42 ; $t_{43.04} = 6.32$, $p < 0.001$, $d = 1.544$) compared with the difference in SWs between both stress conditions (Study I: 203.94 ± 18.90 ; Study II: 99.31 ± 11.25 ; $t_{51.73} = 3.34$, $p = 0.002$, $d = 0.823$). The same pattern was observed for SW density (interaction: $F_{1,62} = 5.47$, $p = 0.023$, $\eta^2 = 0.02$) and their duration (interaction: $F_{1,62} = 4.73$, $p = 0.033$, $\eta^2 = 0.01$). While the post hoc pairwise t -tests were not significant in terms of the number of slow spindles (both p -values > 0.185), the fast spindles exhibited the same pattern as observed with the other variables. Indeed, the relaxation and neutral control conditions differed significantly, with more fast spindles observed in the relaxation condition of Study I (227.27 ± 10.09) compared with the neutral control condition of Study II (179.84 ± 6.65 ; $t_{53.88} = 2.79$, $p = 0.007$, $d = 0.688$). However, the stress conditions did not differ across studies (Study I: 196.27 ± 10.69 ; Study II: 195.32 ± 8.32 ; $p = 0.961$). The main effect of condition was significant only for the duration of SWs, with longer SWs observed in the control conditions (1.48 ± 0.03) compared with the stress conditions (1.46 ± 0.03 ; $F_{1,62} = 4.01$, $p = 0.050$, $\eta^2 = 0.01$), and showed a statistical trend for the down-slope of SWs, with bigger slopes in the control conditions (-250.18 ± 20.66) compared with the

stress conditions (-238.18 ± 18.66 ; $F_{1,62} = 3.52$, $p = 0.065$, $\eta^2 < 0.01$). No other differences were observed (all p -values > 0.125 ; see Table 2 for all values).

Dynamic changes of SWA/beta power ratio, slow-waves, and sleep spindles

The results almost uniformly indicate that anticipating a relaxation task after sleep seems to increase objective sleep quality. In Study I (anticipated stress vs. relaxation), the results showed that the anticipation of a task specifically impacted the late part of the nap (Beck et al., 2023). Therefore, we further explored whether there were dynamic changes in SWA/beta power ratio, slow-waves and spindles parameters (number, density, duration, and amplitude). We explored the progression of each variable, focusing on differences between conditions across both studies (see Figure 3A-D). Two participants were excluded from the analysis of the SWA/beta power ratio due to values larger than 3 SD of the mean in all electrodes. Among all variables, we observed a consistent pattern: the different conditions (stress vs. relaxation/neutral control) had distinct impacts on sleep in each study; however, there was no dynamic change across the nap period. This finding was supported by significant interactions between the factors condition (stress vs. relaxation/control) and study (Study I vs. Study II) in all variables (all p -values < 0.045 ; see Table 2) except for the amplitude of slow spindles and the duration of fast spindles, for which it showed a statistical trend (both p -values < 0.078). For all variables, the three-way interaction (condition, study, time) was not significant (all p -values > 0.195).

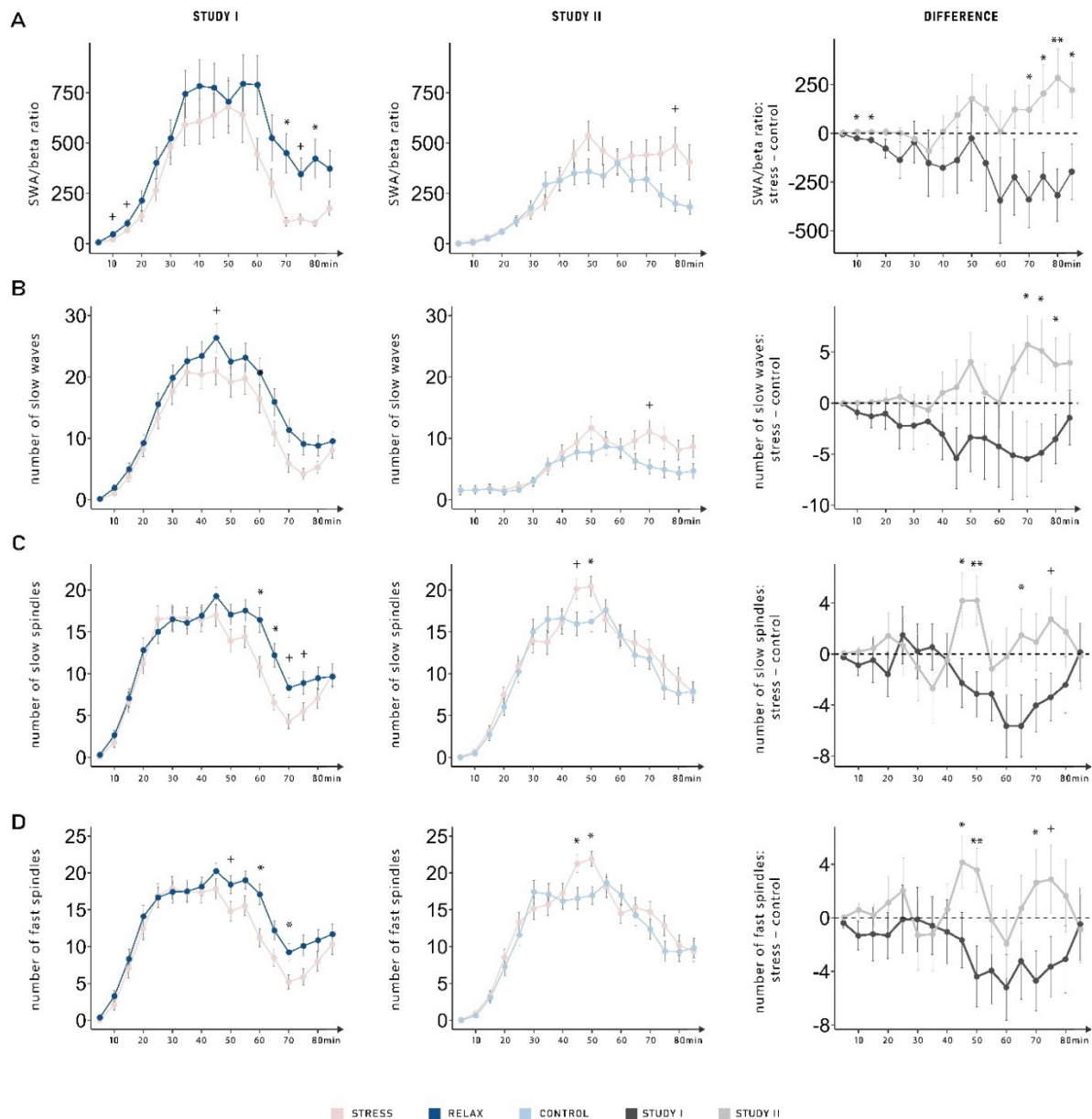


Figure 3: Dynamic changes in A) the ratio between slow wave activity (SWA) and beta activity, B) the number of slow waves, C) the number of slow spindles and D) the number of fast spindles. Among all variables, a consistent pattern was observed: the different conditions (stress vs. relaxation/control) had distinct impacts on sleep in each study; however, there was no significant dynamic change across the nap period (condition, study interactions; all p -values < 0.045). Data is shown as the means $\pm$ standard errors of the means averaged over 5-min segments for all conditions (stress, relaxation, and control). The left-hand column displays the data from Study I (anticipated stress vs. relaxation). The middle column displays the data from Study II (anticipated stress vs. neutral control). In the right-hand column, differences between the stress and the control (relaxation or neutral control) conditions are shown separately for Study I (dark grey) and Study II (light grey). **: $p \leq 0.01$; *: $p \leq 0.05$; +: $p \leq 0.08$.

5.4. Discussion

By introducing a new group, we aimed to replicate and extend the findings of Beck et al. (2023). More specifically, we aimed to clarify whether the disparity between the stress and relaxation conditions observed in our initial study could be attributed to a contrast effect (see Casey, 2022) stemming from the anticipation of relaxation. Interestingly, our results reveal an opposite pattern: participants exhibited worse sleep parameters (SOL, amount of SWS, and SWA/beta ratio) in the neutral condition compared with the anticipated stress condition. When directly comparing both studies, sleep parameters in the stress conditions were highly similar across the two studies, suggesting that the divergent outcomes are driven by differences in the control conditions: whereas anticipating relaxation appeared to promote sleep in Study I (anticipated stress vs. relaxation; Beck et al. 2023), the neutral control in Study II (anticipated stress vs. neutral control) was associated with poorer sleep quality. Previous studies on the effects of anticipated stress on sleep have shown mixed results: for example, Elder et al. (2018) observed no difference in objective and subjective sleep when subjects were anticipating cognitive demands the following day, in comparison to when they were expecting the following day to include only sedentary activities. In another study, in which the anticipation of two different levels of stress (high vs. low) was compared, the authors demonstrated discrepancies in sleep architecture between both levels, with no differences being identified in comparison to a neutral control condition (Sprajcer et al., 2018). This finding suggests that it may not be the anticipation of stress alone that disrupts sleep, but rather that the nature and valence of what is anticipated play a critical role in modulating pre-sleep cognitive and emotional states, subsequently shaping sleep architecture.

In our previous study, we reported the largest differences in sleep parameters (SWA/beta ratio, SWs, and spindles) towards the end of the nap period, closer to the anticipated stressor (Beck et al., 2023). This finding could not be replicated in our comparison with a neutral control condition, as no dynamic changes were observed. Sleep parameters appeared to be generally better across the entire nap period in the relaxation condition compared with the neutral control. However, the decrease in sleep parameters towards the end of the nap in anticipation of the stressor observed in Study I was not replicated in Study II. Overall, participants exhibited worse sleep parameters in Study II than in Study I (e.g., less SWS and fewer SWs), despite the high similarity in procedure (same environment and same instructions). This finding underscores the importance of within-subjects design in sleep research, as between-group differences may reflect individual variability, with sleep dynamics remaining

consistent within each study group. Importantly, this global difference does not account for the reversal in the pattern of condition effects. Specifically, the strongest contrast arises from the relaxation versus neutral control comparison, suggesting that the anticipation of relaxation exerts a measurable benefit on sleep. By contrast, while subtle differences in the progression of sleep were observed between the two stress conditions (Study I vs. Study II), their overall sleep architecture was not significantly different.

From the above findings, it can be concluded that, while participants from Study II slept less deeply overall, this factor alone cannot explain why the conditions led to an opposite pattern to the results observed in Study I. Differences in subjective pre-sleep arousal across studies provide a more plausible explanation: subjective somatic arousal was higher in Study II, while cognitive arousal was lower, regardless of conditions (stress or relaxation/control). These differences may reflect variations in how participants appraised the experimental context or perceived control over outcomes, aligning with literature sources suggesting that anticipatory appraisals influence both arousal and sleep (e.g., Kalmbach et al., 2020; Van Dalsen & Markus, 2018). The absence of heart rate differences suggests that subtle physiological changes accompany these anticipatory effects, even if they do not reach statistical significance.

It is important to note that, unlike in Study I, no adaptation nap was implemented in Study II. Although we attempted to control for potential confounding factors arising from this factor in our analyses, we cannot fully exclude the possibility that the lack of an adaptation nap influenced the observed results. A further point of caution concerns the distribution of chronotypes across the two datasets. All participants in both studies fell within the moderate chronotype range (i.e., moderately morning, neutral, moderately evening), with no extreme morning- or evening-type individuals. However, we observed slight differences across studies which may have contributed, at least in part, to the variability observed between them and should therefore be considered when interpreting cross-study comparisons. Moreover, as the present study included only female participants, potential influences of the menstrual cycle on sleep parameters should be considered. Although findings in the literature are inconsistent, studies in healthy young women generally report no major changes in objective sleep measures (e.g., SOL, sleep efficiency, SWS, or SWA) across the cycle, despite some variations in subjective sleep quality. The main cycle-related differences are typically observed in REM sleep, stage N2, and spindle activity (Baker & Lee, 2022; Driver et al., 2008; Shechter & Boivin, 2010). Thus, while menstrual cycle effects are likely minor overall, caution is warranted when interpreting our results, specifically on spindle activity.

To conclude, these findings highlight the importance of carefully considering control conditions in experimental sleep research, as “neutral” instructions may also carry anticipatory implications, significantly affecting sleep. Moreover, the observed benefits of anticipating post-sleep relaxation reinforce the potential of relaxation-based interventions. Relaxation techniques have already been shown to improve sleep quality by reducing both physiological and cognitive pre-sleep arousal (e.g., Blararu et al., 2012; De Niet et al., 2009; Liu et al., 2020). In previous studies, we posited that pre-sleep cognitive content may be spontaneously reactivated during subsequent sleep (Baselgia et al., 2023; Cordi et al., 2020), similarly to the reactivation of memories during sleep (e.g., Brodt et al., 2023; Rasch & Born, 2013). Such reactivations may in turn trigger associated physiological responses, thereby modulating sleep quality. Supporting this framework, presenting relaxation-related word cues during sleep has been shown to increase time spent in SWS, enhance slow oscillatory power and slow cardiac activity (Beck et al., 2021; Koroma et al., 2024). Moreover, anticipating a post-sleep relaxation may have shaped appraisal and subjective benefit, similarly to expectancy effects observed in placebo research (Stewart-Williams & Podd, 2004; Zhou et al., 2019). On the other hand, a neutral control condition may have elicited adverse feelings such as boredom or impacted mood due to speculations on the purpose of this condition. Together, these findings suggest that relaxation-oriented pre-sleep cognitive activity may improve sleep by engaging sleep-promoting neural networks through spontaneous reactivations during sleep.

5.5. Materials and Methods

Participants

A newly acquired data set (Study II) was compared with the data from the work of Beck et al. (2023; Study I). In Study II, thirty-two healthy French- or German-speaking female subjects completed both sessions of the experiment. One subject was excluded due to technical problems during one session. The remaining 31 young female participants (mean age: 21.58 ± 1.91 [M $\pm$ SD]) were compared to the 33 young female participants from Study I (mean age: 22.30 ± 2.87 [M $\pm$ SD]), resulting in a final sample of 64 individuals (mean age: 21.95 ± 2.46 [M $\pm$ SD]; age range: 18 – 30 years). The data set from our previous study (Beck et al., 2023) was collected from August 2019 to March 2020, and the new data set was collected from October 2023 to June 2024. Given the substantial overlap between these periods, potential seasonal effects, such as variations in natural light exposure, are unlikely to have had major influence on the results. All participants of both studies were of moderate chronotypes (i.e.,

moderately morning, neutral, moderately evening), with no extreme morning- or evening-type individuals. However, the distribution of moderate chronotypes differed significantly between the datasets (Fisher's Exact Test, $p = 0.047$): Study I included more moderately evening-type participants (30%), whereas Study II comprised a higher proportion of neutral-type participants (84%). This difference should be considered when interpreting cross-study comparisons, although the main pattern of results is unlikely to be fully explained by chronotype differences.

Participants were recruited via announcements posted at the University of Fribourg and shared on social media platforms. In return for their participation, they received course credits. Eligibility criteria included the absence of medication influencing sleep, as well as no history of neurological, psychiatric or sleep-related disorders. Individuals working night shift or who had travelled across time zones within the 6 weeks preceding the experiment were excluded. Participants were asked to refrain from consuming alcohol and caffeinated drinks on the day before and during the experimental sessions. The study protocol was approved by the Internal Review Board of the Department of Psychology (approval No. 475). All participants provided written informed consent prior to the study, which was conducted in accordance with the principles of the Declaration of Helsinki.

Design and procedure

Each participant participated in two experimental sessions including a 90 min nap in the sleep laboratory of the University of Fribourg. In one session, a stressful task was performed post-nap in a virtual reality environment, whereas in the other session, either a relaxation task in a virtual environment (Study I) or no task (Study II) was performed post-nap. The order of the conditions (stress or relaxation/control) was counterbalanced across participants according to a within-subject design. In addition, only participants from Study I completed an adaptation nap one week prior to the first experimental nap. In both studies, no sleep deprivation was applied before testing and participants adhered to their habitual sleep-wake rhythm.

Both experimental sessions started between 10:30 and 11:00 am and took place on the same day of the week, one week apart (except for one participant who had a four-week gap between both sessions due to illness). Both sessions started with the attachment of electrodes for recordings of electroencephalography (EEG), electromyography (EMG), electrooculography (EOG), and electrocardiography (ECG) data. Thereafter, participants received the instructions for the post-nap procedure (stressful task or relaxation/no task) and

then went to bed for a 90-min sleep opportunity. After 90 minutes, participants were woken up and their subjective sleep quality and mood were assessed. Upon awakening, participants either performed the stressful task or the relaxation task/no task (see Figure 1A for a summary of the experimental procedure). Participants completed standardised questionnaires (see *Questionnaires*) throughout the sessions.

Stressful tasks in virtual reality

The task and material used in the present manuscript 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). The stress and relaxation tasks were conducted using an HTC VIVE PRO head-mounted display (<https://www.vive.com>, accessed on the 6 October 2025).

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. The TSST is an established method to induce acute social stress in a laboratory setting (Allen et al., 2017) and induces a similar stress response, when conducted in virtual reality (Liszio et al., 2018; Zimmer et al., 2019). The TSST comprised two consecutive parts: a 5-min speech followed by a 5-min mental arithmetic task, both performed while standing in front of a panel of three university professors. In the first part, participants were instructed to deliver a persuasive 5-min speech explaining why they were the ideal candidate for their “dream job”. If they stopped talking before the end of the allotted 5 minutes, standardised questions were asked in accordance with the TSST manual. Immediately afterwards, participants were required to count backward from 2023 in steps of 17 for 5 minutes in front of the same jury panel. Whenever an error was made, they were instructed to restart the task from 2023. The same 15-min pre-recorded virtual reality video was used as in our previous study (Beck et al., 2023) and displayed using Skybox VR Player (<https://skybox.xyz/en/>, accessed on the 6 October 2025). Before sleep and again before performing the task, participants viewed on-screen instructions informing them that (1) their performance would be recorded via video and audio for subsequent behavioural and vocal analyses; (2) the task is scientifically recognised to elicit both psychological and physiological stress responses; (3) high performance on this task reflects strong stress resilience, whereas lower performance is associated with elevated risk for conditions such as cardiovascular disease, sleep problems, depression, and burnout; (4) results would be compared to peers of a similar age group, and participants demonstrating excellent performance in both the speech and

arithmetic segments would receive an additional compensation of 10 CHF; and (5) their contribution was essential for the success of the research project associated dissertations. Following the task, participants were verbally debriefed and informed that no actual recordings had been made and that all participants would receive the 10 CHF bonus regardless of performance. They subsequently signed a written debriefing form confirming this information at the end of the experiment. Participants received the instructions for the task before sleep and again, after sleep, before conducting the task. Finally, participants rated their subjective stress level at three time points (before the task began, after the speech, and following the arithmetic task) using 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)?”).

In the neutral control condition (Study II), participants received the instructions before the nap that no task was to be performed upon awakening, and they would only be required to complete questionnaires. The procedure for the relaxation task is described in the work of Beck et al. (2023).

Questionnaires

The same questionnaires were used as in our previous study (Beck et al., 2023). Questionnaires completed after sleep included the Presleep Arousal Scale (PSAS; Nicassio et al., 1985) and a subjective sleep quality questionnaire (SF-A/R; Görtelmeyer, 2011). Before and after sleep in both sessions, 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 asked again at the beginning, after 5 minutes and at the end of the stressful task.

Immediately upon awakening, participants completed the PSAS to evaluate both cognitive and somatic components of pre-sleep arousal. The scale comprises 16 items rated on a 5-point Likert scale ranging from 1 (= not at all) to 5 (= extremely), reflecting the intensity of symptoms experiences before sleep onset. Eight items assess cognitive arousal (e.g., worrying about sleep, rumination, and anxious or depressive thoughts), while the remaining eight capture somatic arousal (e.g., sensations of racing heart or muscle tension). Separate subscale scores are computed for cognitive and somatic arousal, each ranging from 8 to 40, with higher values indicating greater arousal intensity. A cognitive arousal score exceeding 16 is considered indicative of elevated pre-sleep activation (Kalmbach et al., 2020).

Subjective sleep quality was assessed in the morning using the sleep quality subscale of the SF-A/R (Göertelmeyer, 2011). This measure includes four indices addressing difficulties with sleep initiation and maintenance, premature awakening with inability to resume sleep, and general characteristics of sleep quality. Each item is rated from 1 (absence of good sleep characteristics) to 5 (strong presence of good sleep characteristics). Additionally, subjective sleep onset latency (SOL) was rated as an indicator of perceived time to fall asleep.

EEG recording

Electroencephalographic (EEG) signals were recorded using 12 gold cup electrodes placed according to the international 10–20 system (C3, C4, Cz, F3, F4, Fpz, M1, M2, P3, P4, O1, and O2). Recordings were acquired with a BrainAmp amplifier (Brain Products, Gilching, Germany), at a sampling rate of 500 Hz. The Cz electrode served as the physical reference, and Fpz was used as the ground. Additional electrodes were applied to record electrooculographic (EOG) activity (two electrodes), electromyographic (EMG) activity from the chin (two bipolar electrodes), and electrocardiographic (ECG) activity (two electrodes). Electrode impedances were maintained below 10 k Ω . During the experimental tasks, two additional electrodes were affixed to the participant's left palm to measure electrodermal activity (EDA).

In accordance with the AASM recommendations (Iber et al., 2007), EEG electrodes were re-referenced offline to the contralateral mastoids for analysis and sleep staging. Preprocessing was conducted with BrainVision Analyzer 2.2 (Brain Products, Gilching, Germany), using standard AASM filtering parameters (e.g., EEG 0.3–35 Hz). Sleep stages were visually scored offline by an independent rater following standard AASM criteria (Iber et al., 2007). To complement manual scoring, an automated online algorithm (U-Sleep; <https://sleep.ai.ku.dk/>; accessed on the 6 October 2025; Perslev et al., 2021) was also employed. In the event of discrepancy between manual and automated classifications, a third expert scorer provided the final decision.

Preprocessing and artefact rejection

EEG preprocessing was conducted using BrainVision Analyzer 2.2 (Brain Products, Gilching, Germany). The continuous data was filtered with a 0.1 Hz high-pass and 40 Hz low-pass filter, along with a 50 Hz notch filter to remove line noise. Signals were re-referenced to the average of the mastoid electrodes. Based on sleep stage scoring, NREM sleep periods were

segmented into 30 s epochs and subsequently divided into segments of 2048 data points (4 sec, 102 points overlap). Artifact rejection was performed automatically according to the following criteria: (1) EMG activity difference below 150 μV across both EMG channels, (2) voltage steps not exceeding 50 $\mu\text{V}/\text{ms}$ in any EEG channel, (3) maximum EEG amplitude difference below 500 μV , and (4) a minimum EEG signal amplitude greater than 0.5 μV across all channels. These automatic rejection parameters have been validated in previous studies from our group (e.g., Baselgia et al., 2023; Beck et al., 2023). The number of excluded segments was subsequently verified by manual inspection.

Power analysis and slow-wave and spindle detection

For the analyses of oscillatory activity during sleep (power analysis and spindle and slow-wave detection), artifact rejected data was exported as continuous data and further analysed with the SleepTrip toolbox (<https://github.com/Frederik-D-Weber/sleeptrip>, accessed on the 6 October 2025) for Matlab R2024b (Mathworks, Natick) which is based on FieldTrip functions (Oostenveld et al., 2011). We used the default settings of SleepTrip (10% segment overlap, 20% Hanning window) to calculate the average power values (μV^2) during NREM sleep for the slow wave activity (SWA; 0.5–4.5 Hz) and beta activity (15–30 Hz) for each channel (F3, F4, C3, C4, P3, P4, O1, and O2). We then computed the ratio between SWA and beta activity as this measure is associated with objective sleep quality (Beck et al., 2023; Maes et al., 2014). Outliers were identified based on SWA values (criterion: 3 SD $\pm$ mean) and replaced with values from the contralateral electrode. One subject in each group was excluded from the power analysis due to SWA values exceeding the outlier criterion in all electrodes in one session. Additional exploratory analyses on 5 min segments of sleep were conducted on the sleep scoring data without the application of an artifact rejection procedure.

Following the procedure described by Beck et al. (2023), slow wave characteristics during NREM sleep were quantified for each participant and EEG channel. The number of slow waves and their density per 30 s epoch of NREM sleep were determined, along with their mean amplitude and duration. Additionally, the descending (down-) slope was computed as the ratio between the negative half-wave peak and the time interval from the first zero-crossing to the trough (expressed in $\mu\text{V}/\text{s}$), whereas the ascending (up-) slope was defined as the ratio between the absolute value of the negative half-wave peak and the duration from the trough to the subsequent zero-crossing (also in $\mu\text{V}/\text{s}$). Similarly to our previous study (Beck et al., 2023),

average slow spindle peaks for the newly acquired data set (Study II) ranged from 9.1 to 13.6 Hz with an average frequency of 11.48 ± 1.18 Hz ($M \pm SD$), and fast spindle peaks ranged from 12.4 to 15.3 Hz with an average frequency of 14.07 ± 0.56 Hz ($M \pm SD$).

Electrocardiography

The electrocardiogram (ECG) results were analysed using Kubios HRV Premium 3.4.3 (Kubios Oy, Kuopio, Finland). We analysed the ECG signal from the complete nap and from 15-min segments. The ECG data was exported in EDF+ format using BrainVision Analyzer 2.2.1.8266 (BrainProducts GmbH, Gilching, Germany). Kubios HRV Premium offers 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). The data was then analysed in the time and frequency domain and the mean heart rate (mean HR measured in beats per minute [bpm]) was used as an index for physiological arousal (Baselgia et al., 2023; Beck et al., 2023; Kogler et al., 2015).

Statistical analyses

Statistical analyses were performed using RStudio version 2025.09.1 (R Core Team). Data is presented as the means $\pm$ standard errors. To compare the effects of the anticipation of a stressful task, a relaxation task or no task on sleep, we performed a mixed-design analysis of variance (ANOVA) containing the within-subject factor ‘condition’ (stress vs. relaxation/control) and the between-subject factor ‘group’ (Study I vs. Study II). Post hoc tests for significant interactions and main effects consisted of uncorrected paired Students’s *t*-tests. In the event 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. Where the assumption of sphericity was violated, Greenhouse-Geisser corrected *p*-values are reported. The level of significance was set to $p < 0.05$.

Preregistration

The procedure for Study I was pre-registered and can be viewed via the following link: <https://osf.io/rf6tc> (accessed on the 6 October 2025).

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/clockssleep7040068/s1>.

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5.6. References

- Åkerstedt, T. (2006). Psychosocial stress and impaired sleep. *Scandinavian Journal of Work, Environment & Health*, 32(6), 493–501.
- Allen, A. P., Kennedy, P. J., Dockray, S., Cryan, J. F., Dinan, T. G., & Clarke, G. (2017). The Trier Social Stress Test: Principles and practice. *Neurobiology of Stress*, 6, 113–126. <https://doi.org/10.1016/j.ynstr.2016.11.001>
- Baker, F. C., & Lee, K. A. (2022). Menstrual Cycle Effects on Sleep. *Sleep Medicine Clinics*, 17(2), 283–294. <https://doi.org/10.1016/j.jsmc.2022.02.004>
- Baselgia, S., Combertaldi, S. L., Fahr, A., Wirz, D. S., Ort, A., & Rasch, B. (2023). Pre-sleep arousal induced by suspenseful series and cliffhangers have only minor effects on sleep: A sleep laboratory study. *Sleep Medicine*, 102, 186–198. <https://doi.org/10.1016/j.sleep.2023.01.005>
- Beck, J., Loretz, E., & Rasch, B. (2021). Exposure to relaxing words during sleep promotes slow-wave sleep and subjective sleep quality. *Sleep*, 44(11), zsab148. <https://doi.org/10.1093/sleep/zsab148>
- Beck, J., Loretz, E., & Rasch, B. (2023). Stress dynamically reduces sleep depth: Temporal proximity to the stressor is crucial. *Cerebral Cortex*, bhac055. <https://doi.org/10.1093/cercor/bhac055>
- Blanaru, M., Bloch, B., Vadas, L., Arnon, Z., Ziv, N., Kremer, I., & Haimov, I. (2012). The effects of music relaxation and muscle relaxation techniques on sleep quality and emotional measures among individuals with posttraumatic stress disorder. *Mental Illness*, 4(2), 59–65. <https://doi.org/10.4081/mi.2012.e13>
- Brodt, S., Inostroza, M., Niethard, N., & Born, J. (2023). Sleep—A brain-state serving systems memory consolidation. *Neuron*, 111(7), 1050–1075. <https://doi.org/10.1016/j.neuron.2023.03.005>
- Campbell, J., & Ehlert, U. (2012). Acute psychosocial stress: Does the emotional stress response correspond with physiological responses? *Psychoneuroendocrinology*, 37(8), 1111–1134. <https://doi.org/10.1016/j.psyneuen.2011.12.010>
- Casey, A. H. (2022). Contrast Effects. In *Encyclopedia of Animal Cognition and Behavior* (pp. 1673–1675). Springer, Cham. https://doi.org/10.1007/978-3-319-55065-7_1914
- Cordi, M. J., Rossier, L., & Rasch, B. (2020). Hypnotic Suggestions Given Before Nighttime Sleep Extend Slow-Wave Sleep as Compared to a Control Text in Highly Hypnotizable Subjects. *International Journal of Clinical and Experimental Hypnosis*, 68(1), 105–129. <https://doi.org/10.1080/00207144.2020.1687260>
- De Niet, G., Tiemens, B., Lendemeijer, B., & Hutschemaekers, G. (2009). Music-assisted relaxation to improve sleep quality: Meta-analysis. *Journal of Advanced Nursing*, 65(7), 1356–1364. <https://doi.org/10.1111/j.1365-2648.2009.04982.x>
- Driver, H. S., Werth, E., Dijk, D.-J., & Borbély, A. A. (2008). The Menstrual Cycle Effects on Sleep. *Sleep Medicine Clinics*, 3(1), 1–11. <https://doi.org/10.1016/j.jsmc.2007.10.003>
- Elder, G. J., Barclay, N. L., Wetherell, M. A., & Ellis, J. G. (2018). Anticipated next-day demand affects the magnitude of the cortisol awakening response, but not subjective or objective sleep. *Journal of Sleep Research*, 27(1), 47–55. <https://doi.org/10.1111/jsr.12569>
- Goldberg, Z., Thomas, K. G. F., & Lipinska, G. (2020). Bedtime Stress Increases Sleep Latency and Impairs Next-Day Prospective Memory Performance. *Frontiers in Neuroscience*, 14, 756. <https://doi.org/10.3389/fnins.2020.00756>
- Görtelmeyer, R. (2011). *SF-A/R und SF-B/R - Schlaffragebogen A und B*. Hogrefe.
- Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). *The AASM manual for the scoring of sleep and associated events rules, terminology and technical specifications* (American Academy of Sleep Medicine).
- Kalmbach, D. A., Buysse, D. J., Cheng, P., Roth, T., Yang, A., & Drake, C. L. (2020). Nocturnal cognitive arousal is associated with objective sleep disturbance and indicators of physiologic hyperarousal in good sleepers and individuals with insomnia disorder. *Sleep Medicine*, 71, 151–160. <https://doi.org/10.1016/j.sleep.2019.11.1184>
- Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The 'Trier Social Stress Test'—A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, 28(1–2), 76–81. <https://doi.org/10.1159/000119004>

- Kogler, L., Mueller, V. I., Chang, A., Eickhoff, S. B., Fox, P. T., Gur, R. C., & Derntl, B. (2015). Psychosocial versus physiological stress – meta-analyses on deactivations and activations of the neural correlates of stress reactions. *NeuroImage*, 119, 235–251. <https://doi.org/10.1016/j.neuroimage.2015.06.059>
- Koroma, M., Beck, J., Schmidt, C., Rasch, B., & Demertzi, A. (2024). Probing the embodiment of sleep functions: Insights from cardiac responses to word-induced relaxation during sleep. *Journal of Sleep Research*, 33(5), e14160. <https://doi.org/10.1111/jsr.14160>
- Liszio, S., Graf, L., & Masuch, M. (2018). The Relaxing Effect of Virtual Nature: Immersive Technology Provides Relief in Acute Stress Situations. *Annual Review of CyberTherapy and Telemedicine*, 16, 87–93.
- Liu, K., Chen, Y., Wu, D., Lin, R., Wang, Z., & Pan, L. (2020). Effects of progressive muscle relaxation on anxiety and sleep quality in patients with COVID-19. *Complementary Therapies in Clinical Practice*, 39, 101132. <https://doi.org/10.1016/j.ctcp.2020.101132>
- Maes, J., Verbraecken, J., Willemsen, M., De Volder, I., van Gastel, A., Michiels, N., Verbeek, I., Vandekerckhove, M., Wuyts, J., Haex, B., Willemsen, T., Exadaktylos, V., Bulckaert, A., & Cluydts, R. (2014). Sleep misperception, EEG characteristics and autonomic nervous system activity in primary insomnia: A retrospective study on polysomnographic data. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, 91(3), 163–171. <https://doi.org/10.1016/j.ijpsycho.2013.10.012>
- Mölle, M., Marshall, L., Gais, S., & Born, J. (2002). Grouping of Spindle Activity during Slow Oscillations in Human Non-Rapid Eye Movement Sleep. *The Journal of Neuroscience*, 22(24), 10941–10947. <https://doi.org/10.1523/JNEUROSCI.22-24-10941.2002>
- Nicassio, P. M., Mendlowitz, D. R., Fussell, J. J., & Petras, L. (1985). The phenomenology of the pre-sleep state: The development of the pre-sleep arousal scale. *Behaviour Research and Therapy*, 23(3), 263–271. [https://doi.org/10.1016/0005-7967\(85\)90004-X](https://doi.org/10.1016/0005-7967(85)90004-X)
- Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data. *Computational Intelligence and Neuroscience*, 2011, 1–9. <https://doi.org/10.1155/2011/156869>
- Perslev, M., Darkner, S., Kempfner, L., Nikolic, M., Jennum, P. J., & Igel, C. (2021). U-Sleep: Resilient high-frequency sleep staging. *Npj Digital Medicine*, 4(1), 72. <https://doi.org/10.1038/s41746-021-00440-5>
- Rasch, B., & Born, J. (2013). About Sleep's Role in Memory. *Physiological Reviews*, 93(2), 681–766. <https://doi.org/10.1152/physrev.00032.2012>
- Shechter, A., & Boivin, D. B. (2010). Sleep, Hormones, and Circadian Rhythms throughout the Menstrual Cycle in Healthy Women and Women with Premenstrual Dysphoric Disorder. *International Journal of Endocrinology*, 2010(1), 259345. <https://doi.org/10.1155/2010/259345>
- Sprajcer, M., Jay, S. M., Vincent, G. E., Vakulin, A., Lack, L., & Ferguson, S. A. (2018). The effects of anticipating a high-stress task on sleep and performance during simulated on-call work. *Journal of Sleep Research*, 27(6), e12691. <https://doi.org/10.1111/jsr.12691>
- Stewart-Williams, S., & Podd, J. (2004). The Placebo Effect: Dissolving the Expectancy Versus Conditioning Debate. *Psychological Bulletin*, 130(2), 324–340. <https://doi.org/10.1037/0033-2909.130.2.324>
- Tang, N. K. Y., & Harvey, A. G. (2004). Effects of Cognitive Arousal and Physiological Arousal on Sleep Perception. *Sleep*, 27(1), 69–78. <https://doi.org/10.1093/sleep/27.1.69>
- Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, 113(1), 210–220. <https://doi.org/10.1016/j.cmpb.2013.07.024>
- Van Dalsen, J. H., & Markus, C. R. (2018). The influence of sleep on human hypothalamic–pituitary–adrenal (HPA) axis reactivity: A systematic review. *Sleep Medicine Reviews*, 39, 187–194. <https://doi.org/10.1016/j.smrv.2017.10.002>
- Wuyts, J., De Valck, E., Vandekerckhove, M., Pattyn, N., Bulckaert, A., Berckmans, D., Haex, B., Verbraecken, J., & Cluydts, R. (2012). The influence of pre-sleep cognitive arousal on sleep onset processes. *International Journal of Psychophysiology*, 83(1), 8–15. <https://doi.org/10.1016/j.ijpsycho.2011.09.016>

- Zhou, L., Wei, H., Zhang, H., Li, X., Bo, C., Wan, L., Lu, X., & Hu, L. (2019). The Influence of Expectancy Level and Personal Characteristics on Placebo Effects: Psychological Underpinnings. *Frontiers in Psychiatry*, *10*. <https://doi.org/10.3389/fpsy.2019.00020>
- Zimmer, P., Buttlar, B., Halbeisen, G., Walther, E., & Domes, G. (2019). Virtually stressed? A refined virtual reality adaptation of the Trier Social Stress Test (TSST) induces robust endocrine responses. *Psychoneuroendocrinology*, *101*, 186–192. <https://doi.org/10.1016/j.psyneuen.2018.11.010>

5.7. Supplementary material

Anticipation of stress and relaxation dynamically impacts sleep

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Table S1: Post-hoc pairwise comparisons between conditions (stress vs. relaxation/control) within studies for subjective and objective sleep parameters.

	Study I						Study II					
	Anticipated Stress vs. Relaxation						Anticipated Stress vs. Neutral Control					
	Stress	Control	<i>t</i>	<i>p</i>	<i>d</i>	Stress	Control	<i>t</i>	<i>p</i>	<i>d</i>		
Subjective Sleep Parameters												
Cognitive PSA	17.82 ± 1.03	16.18 ± 0.91	1.95	0.060 ^a	0.34	13.32 ± 0.72	13.52 ± 0.83	-0.25	0.806	0.04		
Somatic PSA	12.33 ± 0.70	12.27 ± 0.80	0.13	0.898	0.02	16.74 ± 0.90	16.03 ± 0.94	0.77	0.447	0.14		
Sleep Quality	3.56 ± 0.14	3.57 ± 0.13	-0.05	0.957	0.01	3.71 ± 0.12	3.65 ± 0.11	0.43	0.670	0.08		
SOL	23.18 ± 1.93	20.45 ± 1.97	1.33	0.194	0.23	25.16 ± 1.97	22.58 ± 1.70	1.08	0.290	0.19		
Objective Sleep Parameters												
SOL [min]	16.76 ± 2.57	12.94 ± 1.74	2.06	0.047	0.36	15.76 ± 1.67	19.15 ± 1.88	-1.87	0.072 ^a	0.34		
WASO [%]	9.93 ± 2.63	5.74 ± 1.93	1.37	0.179	0.24	8.10 ± 1.54	6.79 ± 1.86	0.55	0.586	0.10		
N1 [%]	20.05 ± 2.75	17.07 ± 2.22	1.53	0.137	0.27	9.63 ± 1.13	11.30 ± 1.49	-1.14	0.262	0.21		
N2 [%]	37.82 ± 2.61	39.70 ± 2.57	-0.73	0.470	0.13	44.92 ± 3.24	50.96 ± 3.55	-1.79	0.083 ^a	0.32		
N3 [%]	20.55 ± 3.14	26.23 ± 3.20	-1.76	0.088 ^a	0.31	18.40 ± 3.37	12.21 ± 2.28	1.62	0.116	0.29		
REM [%]	11.64 ± 1.71	11.27 ± 1.77	0.18	0.859	0.03	12.55 ± 2.17	12.37 ± 2.54	0.06	0.954	0.01		
TST [min]	63.67 ± 3.48	68.30 ± 3.16	-1.47	0.150	0.26	64.81 ± 3.00	61.68 ± 2.96	0.86	0.396	0.15		
WASO [min]	7.18 ± 1.89	3.36 ± 0.85	1.94	0.061 ^a	0.34	5.84 ± 1.05	4.69 ± 1.20	0.73	0.474	0.13		
N1 [min]	13.14 ± 1.64	11.26 ± 1.35	1.27	0.214	0.22	7.35 ± 0.80	7.55 ± 0.82	-0.23	0.819	0.04		
N2 [min]	26.50 ± 2.21	28.50 ± 2.07	-0.93	0.357	0.16	33.95 ± 2.37	35.21 ± 1.52	-0.46	0.651	0.08		
N3 [min]	14.97 ± 2.52	19.80 ± 2.56	-2.11	0.043	0.37	13.79 ± 2.23	9.40 ± 1.71	1.54	0.135	0.28		
REM [min]	9.06 ± 1.38	8.74 ± 1.42	0.19	0.850	0.03	9.71 ± 1.70	9.45 ± 1.92	0.11	0.916	0.02		

Notes: Subjective parameters are based on subjective ratings in the PSAs, assessing pre-sleep arousal (PSA) and SF-A/R questionnaire, measuring subjective sleep quality and sleep onset latency (SOL). Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), SOL, SWS latency, REM sleep latency are measured in minutes and percentages indicate partial percentage of total sleep time (TST). Values are mean and standard error of the mean. Significant results are highlighted in bold. ^a indicates $p < 0.09$. *d* represents the effect sizes where a value around 0.2 reflects a small effect, a value around 0.5 reflects a medium effect, and a value around 0.8 reflects a large effect.

6. Study IV

Can hypnotic suggestions and circadian manipulation increase REM sleep and REM-related emotional processing? A proof-of-concept study

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6.1. Abstract

REM sleep has been repeatedly associated with enhanced emotional processing, although the empirical evidence is mixed. A methodological problem for examining the function of REM sleep is that experimental manipulations of REM sleep amount are difficult to perform in humans. Identifying novel, non-pharmacological interventions to reliably manipulate REM sleep is therefore critical for understanding its function in emotional processing. In this study, we tested two approaches to manipulate REM sleep: a) specific hypnotic suggestions to increase the amount of REM sleep and b) a circadian manipulation (i.e., morning vs. midday naps). Fifty healthy young participants spent one adaptation nap and two experimental naps in the sleep laboratory while sleep was recorded with polysomnography. In one nap, they listened to standardised hypnotic suggestions to increase REM sleep, while in the other nap a neutral control text was presented, in a randomised order. One group napped in the morning after mild sleep deprivation ($n = 26$), while the other group napped during midday ($n = 24$). Before and after the nap, participants were exposed to recordings of their own out-of-tune singing to elicit embarrassment. The change in embarrassment from pre- to post-nap was used to assess emotional processing. Contrary to our expectations, pre-sleep hypnotic suggestions did not significantly increase REM sleep. However, in highly hypnotisable subjects, we observed a descriptive increase in the duration of REM sleep and a significant increase in REM episodes accompanied by a significant decrease in slow-wave sleep duration after REM-increasing hypnotic suggestions. Interestingly, this change in sleep architecture was associated with a stronger reduction in embarrassment ratings across the nap. As expected, morning naps contained significantly more REM sleep compared with midday naps, but this difference did not result in a greater reduction in embarrassment ratings across morning naps. Our results suggest that hypnotic suggestions might be more effective in influencing SWS rather than REM sleep, while the latter can more effectively be manipulated by circadian manipulations. However, the circadian manipulation of REM sleep did not prove any functional role for REM sleep amount in emotional processing, while hypnotic suggestions intended to alter REM sleep were able to increase emotional processing during the nap. Further research is needed to further understand the role of REM sleep in emotional processing.

Key words: hypnotic suggestions, REM sleep, emotions

6.2. Introduction

Sleep is essential for human physical and mental health and plays an important role for general well-being (e.g., Irwin, 2015). Slow wave sleep (SWS) is known for highly benefitting the immune system, cognitive functioning and brain plasticity (e.g., Lange et al., 2010; Rasch & Born, 2013), whereas the functional role of rapid eye movement (REM) sleep remains a debated topic (Peever & Fuller, 2017). Most existing evidence shows an involvement of REM sleep in emotion regulation (Goldstein & Walker, 2014; Vandekerckhove & Cluydts, 2010; Vandekerckhove & Wang, 2018), the consolidation of emotional memories (Diekelmann & Born, 2010; Poe et al., 2010; Wagner et al., 2001) and creativity (Cai et al., 2009).

REM sleep is typically associated with the consolidation of emotional memories and emotional processing in general (Fairholme & Manber, 2015; Goldstein & Walker, 2014; Palmer & Alfano, 2017; Vandekerckhove & Wang, 2018). Emotional memories, compared to neutral ones are more strongly consolidated during REM-rich sleep, and this enhancement correlates with REM duration in both naps and nighttime sleep (Carr & Nielsen, 2015; Lara-Carrasco et al., 2009; Nishida et al., 2009; Wagner et al., 2001; Wiesner et al., 2015). The “sleep to forget, sleep to remember” hypothesis posits that REM sleep facilitates the consolidation of memory content, while reducing the emotional charge associated with these memories (van der Helm & Walker, 2009). This hypothesis thus predicts that, while the content of a memory is maintained or improved through sleep, the reduction of the emotional experience linked to that memory is proportional to the amount of REM sleep following the experience. Supporting evidence shows that healthy sleep promotes overnight habituation to distressing experiences, whereas insomnia patients, who experience disrupted sleep, show impaired emotional adaptation (Wassing, Benjamins, et al., 2019; Wassing, Lakbila-Kamal, et al., 2019). Experimental nap studies further suggest that these effects are REM-specific: for instance Gujar et al. (2011) found that a 90-minute nap reduced reactivity to negative emotions only in participants who entered REM sleep.

To experimentally induce embarrassment, a karaoke paradigm proposes to expose participants to recordings of their own out-of-tune singing. Using this approach, recent studies suggest that REM sleep modulates both physiological and subjective responses to embarrassment-related stimuli. For example, Wassing et al. (2019) showed that longer periods of unperturbed REM sleep predict stronger overnight decreases in amygdala responses to the embarrassment-related stimuli, whereas this effect was attenuated when REM sleep was fragmented (Wassing, Lakbila-Kamal, et al., 2019). In contrast, REM sleep has been associated

with the preservation of physiological reactivity (i.e., skin conductance) to the karaoke task (Halonen et al., 2024), particularly when REM sleep was fragmented (Halonen et al., 2021), consistent with studies showing that REM sleep preserves the affective component of memories (Baran et al., 2012; Lara-Carrasco et al., 2009; Pace-Schott et al., 2011; Werner et al., 2015, 2021). While further research is needed to better understand the precise mechanisms underlying these processes, these findings underscore the role of REM sleep in regulating affective experiences.

REM sleep is tightly regulated by homeostatic and circadian processes and is generally difficult to amplify experimentally, even with pharmacological approaches. For example, agents that enhance cholinergic activity, which is the neurotransmitter system most strongly associated with REM generation, tend to produce only modest or inconsistent increases in REM sleep (Hornung et al., 2006, 2007), and other hypnotic drugs often suppress or fragment it (McEntire et al., 2014; Pagel & Parnes, 2007). However, an efficient way to increase REM sleep is to reduce it first: physiological REM sleep deprivation leads to a robust REM rebound on the subsequent night (Feriante & Singh, 2025), demonstrating that manipulations acting directly on REM pressure can reliably modulate the amount of REM sleep. In this context, a morning nap following mild sleep deprivation is expected to bias sleep architecture toward more REM sleep, as prior sleep restriction increases REM pressure and the early-morning circadian phase is characterised by high REM propensity (Mantua & Spencer, 2017). However, to better understand and examine the functions of REM sleep, there is a need to develop novel non-pharmacological interventions capable of reliably manipulating REM sleep. Pre-sleep hypnotic suggestions might offer a potential solution to this issue.

Recent experimental work from our group demonstrated that hypnotic suggestions can selectively increase SWS duration and slow-wave activity (SWA) during both naps and nighttime sleep, with no effects on other sleep stages (Cordi et al., 2014, 2015, 2020). The hypnosis was delivered via an audio recording. After a standardized hypnotic induction procedure, participants were invited to imagine following a fish diving deeper and deeper in the ocean. This imagery was accompanied by suggestions of safety, letting go, depth, heaviness etc. In those studies, medium-to-high hypnotisable subjects showed an increase in the duration of SWS accompanied by an increase in slow-wave activity (SWA). In another study using the same procedure, the hypnosis-induced increase in deep sleep was also accompanied by a highly significant increase in the release of growth hormone during a midday nap (Besedovsky et al., 2022). These results all speak for an increase in sleep depth induced by the hypnotic suggestions

at bedtime. However, the impact of hypnosis on the deepening of sleep appears to be limited to participants who are moderately to highly hypnotisable. This is evidenced by the fact that low hypnotisable participants showed the opposite pattern with a decrease in the duration of SWS after hypnosis compared with the control condition, both during midday naps and nighttime sleep (Cordi et al., 2014, 2015, 2020). These findings suggest that hypnotisability is a key factor influencing responsiveness to hypnotic interventions. While these findings highlight the potential of hypnosis to modulate sleep architecture, no study has yet tested whether hypnotic suggestions can specifically increase REM sleep.

Thus, here we aimed at examining whether hypnotic suggestions given before sleep are effective in altering the amount of REM sleep during a nap. However, several aspects need to be considered: 1) REM sleep occurs after NREM sleep, thus the time between suggestions given before sleep and the to-be-affected sleep stage is longer compared to our SWS studies; 2) REM sleep is a paradoxical sleep stage, less related to general features of relaxation (in contrast to NREM and SWS) and more associated with an active mental state, together with specific characteristics such as a) eye movements, b) muscle atonia, and c) vivid dreaming. Therefore, we decided to target these three aspects of REM sleep in our hypnotic suggestions. We also acknowledge the typical time course of REM occurrence, inviting participants to first swim in the ocean (symbolising NREM sleep) and then arriving (earlier and for a longer duration than usual) in a “dream cave”, in which they are asked to look around, while being immobile, and seeing vivid images.

In addition to trying to alter the amount of REM sleep by hypnotic suggestions, we included a second REM sleep manipulation in our study: one group slept in our sleep laboratory in the morning after mild sleep deprivation, while another took their nap during midday. In both conditions, they were given a sleep opportunity of 105 minutes. As REM sleep pressure is higher in the morning after mild sleep deprivation compared to midday (Endo et al., 1981; Mantua & Spencer, 2017; Webb et al., 1966), we expected to have more REM sleep in morning naps compared to midday naps. Thus, we used both hypnotic suggestions and timing of naps to manipulate the amount of REM sleep during naps, in order to test the function of REM sleep in emotional regulation processes.

The present study thus investigates whether hypnotic suggestions and circadian manipulation can increase REM sleep duration and reduce REM latency. Participants received REM-targeted hypnotic suggestions before either a midday nap or a morning nap following mild sleep deprivation, to induce natural variation in REM propensity. Sleep was recorded with

polysomnographic data, and emotional processing was assessed using a karaoke-based embarrassment paradigm (Reinhold et al., 2022; Wassing, Benjamins, et al., 2019). We hypothesised that (1) hypnotic suggestions will increase REM sleep duration and decrease REM latency compared with a control text, (2) morning naps will include more REM sleep than midday naps; and (3) higher REM sleep will predict improved emotional regulation, indexed by lower subjective ratings after sleep. This work aims to test the feasibility of hypnosis as a tool for selectively modulating REM sleep and provide novel insights into REM sleep's function in emotion processing.

6.3. Methods

Participants

Fifty-six healthy French-speaking individuals completed all sessions of the experiment. One subject was excluded due to technical problems, and five subjects were excluded due to insufficient sleep in at least one of the two experimental naps (sleep time lower than 3 SD below the mean). The final sample consisted of 50 young adults (39 women; mean age = 21.80 ± 2.78 [M $\pm$ SD]; age range: 18 – 33 years).

Participants were recruited through advertisements placed at the University of Fribourg and on social media. For their participation, they received experimental credits required in their Bachelor program or 80 CHF. 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: 2023-881), 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/ztxqk/> (accessed on the 1st of April 2025).

Procedure

Each participant spent one adaptation nap in the sleep laboratory of the University of Fribourg, which was followed by two experimental naps. The three nap sessions took place on the same day of the week, spaced exactly 7 days apart. One week before each of the experimental sessions, subjects filled out a sleep diary. All subjects were explicitly informed about the purpose of the study to extend their time in REM sleep with hypnotic suggestions, and about the role of REM sleep in emotional processing. During the experimental sessions, participants listened either to the tape including hypnotic suggestions or the control tape played over bedside speakers. The order of the condition was counterbalanced across participants according to a within-subject design. In an additional between-subject factor, one group of participants took a midday nap at approximately 12 am (midday group; $n = 24$), while another group of participants took a morning nap at approximately 8 am after mild sleep deprivation (morning group; $n = 26$). Participants from the morning group were asked to restrict their time in bed to a maximum of 6 hours on the preceding night.

Both experimental sessions started at the same time, according to the group: 6 am for the morning group and 10 am for the midday group. Each session started with the attachment of electrodes for recordings of electroencephalography (EEG), electromyography (EMG), electrooculography (EOG), and electrocardiography (ECG). Before sleep, a karaoke paradigm was used to induce an embarrassing episode (see *Karaoke task* section for details about the task). Before going to bed, participants performed a 5-min exercise in front of the computer, with the objective to familiarise themselves with the main characteristics of REM sleep (rapid eye movements, atonia, dreams). In this exercise, they were instructed to perform the following tasks: 1) move their eyes from left to right during 30 sec, 2) remain still during 1 min, 3) close their eyes and allow their mind to wander during 1 min, and 4) perform all three tasks simultaneously during 1 min. This exercise was performed using EPrime 2.0.10 (Psychology Software Tools Inc., Pittsburgh) and was designed to enhance the effect of the hypnosis. Afterwards, when participants were lying in bed, lights were turned off and the tape recording was started according to the condition (hypnosis or control). The duration of the tape recordings was approximately 15 minutes. Participants were asked to follow the instructions given in the audio but were allowed to fall asleep during the recording. In all conditions, subjects were awakened after 105 minutes via the intercom following a standardised procedure asking for their mental activity during sleep. This data on their dreams is not analysed in the current manuscript. Afterwards, subjective sleep quality was assessed via questionnaires, and the

karaoke paradigm was again used to reactivate the embarrassing episode (see Figure 1A for a summary of the experimental procedure). Before and after the tasks, participants completed standardised questionnaires (see *Questionnaires* section).

Hypnotic and control texts

The hypnosis text was written in German by B. Rasch and translated in French by S. Baselgia. The French translation was checked and validated by Christophe Marquis, a professional hypnotherapist. The text was spoken and recorded in French by C. Marquis. The text started with a 5-min progressive induction technique, including 10 steps which each indicated a further step into relaxation, leading the listener into the state of hypnotic trance. The induction was followed by hypnotic suggestions to enter deep sleep and REM sleep. Similarly to our previous studies (Cordi et al., 2014, 2015, 2020), the metaphor of immersing oneself deeper and deeper into the sea was again used to symbolise deep sleep. Then, the hypnotic suggestions were aiming at inducing REM sleep at an earlier stage and to make it last longer. More specifically, the subjects were reminded about the “dreamland” that follows deep sleep. The “dreamland” was symbolised by a cave in the sea, to which the listeners were invited to swim to and remain for as long as possible. Once in this warm and beautiful cave, the listeners were repeatedly invited to look around (rapid eye movements), while their body could remain immobile (atonia). The hypnotic suggestions hinted at intense colours, inner images, beautiful memories present in the cave (dreams) that the listeners were invited to explore. Several suggestions were continuously included in the text such as safety, letting go, being allowed to sleep and others. There were no suggestions to bring the listener out of the hypnotic trance at the end of the text; instead, the listeners were invited to fall asleep at any time afterwards. In total, the tape was 17 minutes long in which 1’752 words were spoken with a soft, slow, hypnotic and calming voice, frequently containing relaxing words such as “deep sleep”, “easily”, “relax”, “let go”.

We used the same control text as our previous studies (Cordi et al., 2014, 2015, 2020), which was recorded again by C. Marquis to match the hypnotic text. The control text consisted of a documentation about natural mineral deposits taken from Wikipedia. The control text was matched to the hypnotic text with respect to length in minutes and volume. In this text, 2’134 words were spoken with an everyday intonation and speed. The text was not designed to contain relaxing or arousing words in particular but to be as neutral and objective as possible.

Assessment of hypnotisability

Similarly to our previous studies (Cordi et al., 2014, 2015, 2020), hypnotisability was assessed for all subjects before their participation using the Harvard Group Scale of Hypnotic Susceptibility Test, Form A (HGSHS:A; Shor & Orne, 1963; French translation, see Cordi et al., 2020). In this standardised test, a hypnotic text was played from a tape, leading subjects into a state of trance in which motoric, perceptual, cognitive and posthypnotic suggestions were given. The German version of this text was translated into French and recorded by Laurent Rossier. Afterwards, a questionnaire on the subjective experience during listening was filled out. Participants were then divided into three groups of high (HGSHS score ≥ 9 ; $n = 11$), medium (HGSHS score between 6 and 8; $n = 25$) and low hypnotisable (HGSHS score ≤ 5 ; $n = 14$). The group distribution was rather balanced with 6 high, 11 medium and 9 low in the morning naps and 5 high, 14 medium and 5 low in the midday naps. The highly hypnotisable group (9 females, 2 males) achieved a score of 9.82 ± 0.26 (SEM) on average; the medium group (18 females, 7 males) achieved a score of 6.88 ± 0.17 on average, and the low hypnotisable group (12 females, 2 males) scored 4.00 ± 0.36 on average (see Figure 1B). Those means differed significantly ($F_{1,47} = 102.13$, $p < 0.001$, $\eta^2 = 0.81$). The three groups neither differed in age ($p = 0.110$) nor sex ($p = 0.206$).

Karaoke task

REM sleep has been highlighted as playing a key role in the processing of emotions, promoting the reactivation of emotional memory traces (Baran et al., 2012; Pace-Schott et al., 2011). To further explore these processes, we used a karaoke paradigm, which was designed to create an emotional autobiographical memory trace (see Figure 1A for the experimental procedure). This paradigm has already been used in previous studies yielding promising results (e.g., Reinhold et al., 2022; Wassing, Lakbila-Kamal, et al., 2019). We used a similar procedure as Reinhold et al. (2022), for which we selected six widely known and rather challenging songs: “Dancing Queen” by ABBA, “Someone Like You” by Adele, “Le Cycle de la Vie” from the film *The Lion King*, “Libérée, Délivrée” from the film *Frozen*, “Relax (Take It Easy)” by Mika, and “Wrecking Ball” by Miley Cyrus. In each of the nap sessions (the adaptation and both experimental sessions), participants were asked to sing along to two songs while their voice was recorded. The lyrics were given on a sheet, and the participants were instructed to sing loud and at the best of their ability. The participants were left alone in the room during the singing. To promote out-of-tune singing, the original songs were played through headphones at a high

volume, to hinder pitch correction. The order of songs was randomised and counterbalanced across all participants and all sessions.

After the recording of both songs, participants stayed in a different room where they completed sudoku as a distraction task for a duration of 30 minutes. This distraction task in a different environment aimed at separating the singing experience from the subsequent exposure experience. In the meantime, experimenters selected 40-sec-long fragments of each recording that contained the most out-of-tune singing. The selected fragments thus contained different parts of the songs across participants.

After the 30 minutes, participants were brought back to the first room to experimentally induce the embarrassing episode (first exposure). The exposure was performed using EPrime 2.0.10 (Psychology Software Tools Inc., Pittsburgh) and contained three blocks. Each block started with a 1-min resting period with eyes closed. This was followed by a 40-sec exposure to one song fragment played through speakers. The three different fragments were either the embarrassment-inducing recording (own out-of-tune singing), the original version of that recording (orig), or a new song (control). Similarly to Reinhold et al. (2022), fragments of the original and new songs were added as potential neutral stimuli (i.e., songs that do not induce embarrassment), also clarifying whether the original songs could also induce emotional reactivity by reminding the participants of their own recordings. For the embarrassment-inducing fragment (own), one of the two previously sung songs was randomly selected. The new control song was “Respect” by Aretha Franklin, played for 40 seconds. After each exposure, participants rated their embarrassment and valence on two visual analogue scales (VAS), ranging from 1 = ‘not embarrassed at all’/‘extremely negative’ to 9 = ‘extremely embarrassed’/‘extremely positive’. The two scales were presented one at a time in randomised order, and without time limit to give a response. Afterwards, participants performed a simple distraction task (1-back task) in between exposures to avoid carry-over effects from one block to the next. All participants were exposed to all three song fragments once in a randomised order. Throughout the task, an experimenter was sitting left behind the participant, who was instructed to not interact with them. This addition of this observer aimed at increasing the feeling of embarrassment during the exposure to their own singing. After the three blocks, participants could go to bed.

After the nap, participants were again exposed to song fragments, following the same procedure but including more fragments (second exposure). This second exposure contained

seven test blocks: the three fragments from the first exposure (own, orig, control), as well as new fragments of their own recording from before sleep (own2) and its original (orig2), and new fragments of their own recording from the adaptation session (own3) and its original (orig3). The original versions of the recordings were added as additional newly exposed control stimuli. The order of the different song fragments was again randomised.

Questionnaires

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, participants were asked to complete several standardised questionnaires on their sleeping habits, personality traits, mood and general well-being (e.g., Multidimensional Mood State Questionnaire short form A; Steyer, 1997; Presleep Arousal Scale; Nicassio et al., 1985).

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, Fz, 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 Fz as a ground electrode. Two electrodes were used to collect electrooculographic (EOG) data, two bipolar chin electrodes were used to collect electromyographic (EMG) data, two electrodes for electrocardiographic (ECG) data, and two electrodes to collect electrodermal activity (EDA) in the palm of the left-hand. Additional EMG electrodes were attached on the corrugator (two bipolar electrodes) and the zygomatic (two bipolar electrodes) muscles to measure muscle activity related to facial expressions during the karaoke paradigm. Impedances were kept below 10 k Ω .

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 the event of discrepancy between manual and automated classifications, the independent scorer reassessed the epoch and made the final decision.

We exploratorily examined several metrics to characterise REM sleep fragmentation. Each sequence of one or more consecutive REM epochs was identified as one REM episode. Thus, REM sleep interruptions by other sleep stages resulted in a higher number of REM episodes, indicating greater REM fragmentation. The mean REM episodes duration was calculated as the average duration of REM episodes (in minutes). We also quantified the number of arousals occurring during REM epochs. Finally, a REM fragmentation index was computed by dividing the total number of REM interruptions (i.e., transitions to another stage or arousals whether or not accompanied by a stage transition) by the total time spent in REM (in hours).

Preprocessing, artefact rejection and power analyses

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-second epochs of NREM and REM sleep based on sleep scoring results and further segmented into equally sized segments of 2048 data points (4 sec, 102 points overlap). Segments with artefacts were automatically rejected, based on the following criteria: (1) a maximum difference in EMG activity $<150 \mu\text{V}$ in both EMG channels, (2) a maximum voltage step in all EEG channels $<50 \mu\text{V/ms}$, (3) a maximum difference in EEG activity $<500 \mu\text{V}$ in all EEG channels, and (4) a minimum activity in EEG $>0.5 \mu\text{V}$ 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.

The artefact-free data was exported as continuous data and further analysed with the SleepTrip toolbox (<https://github.com/Frederik-D-Weber/sleeptrip>, accessed on the 5 January 2026) for Matlab R2024b (Mathworks, Natick, MA, USA) which is based on FieldTrip

functions (Oostenveld et al., 2011). We used the default settings of SleepTrip (10% segment overlap, 20% Hanning window) to calculate the average power value (μV^2) during NREM sleep for the slow wave activity (SWA; 0.5–4.5 Hz) in the frontal electrodes (F3, F4), and during REM for the theta activity (4–8 Hz) in the central (C3, C4) and parietal electrodes (P3, P4). Additionally, we calculated the average power value (μV^2) for the theta activity in the central (C3, C4) and parietal electrodes (P3, P4) during the listening of the audio while lying in bed. Outliers were identified based on the criteria of a value above or below 3 SD of the mean and replaced with values from the contralateral electrode. One participant was excluded from these analyses due to values larger than 3 SD of the mean in all electrodes in one session.

Statistical analyses

Statistical analyses were performed using RStudio version 2025.09.2 (R Core Team). Data is presented as means $\pm$ standard error. Data was analysed using repeated-measures analysis of variance (ANOVA) including the within-subject factors condition (hypnosis, control) and hypnotisability (high, medium, low), and the between-subject factors group (morning naps, midday naps). Post-hoc tests for significant interactions and main effects consisted of uncorrected paired Students's *t*-tests. In the event 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. Where the assumption of sphericity was violated, Greenhouse-Geisser corrected *p*-values are reported. To account for participants who did not display any REM sleep in one session, we used Linear Mixed Models (LMM) for REM metrics (i.e., fragmentation, power analyses) and for the karaoke task, with the same factors as the ANOVA, and the random intercepts for participants. 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. ANOVA tests were performed to test each LMM for significance, and post-hoc tests for significant interactions and main effects consisted of uncorrected pairwise contrasts of estimated marginal means (EMM) derived from the fitted models. Associations were explored using Pearson product-moment correlations. Exploratory analyses were not corrected for multiple comparisons. The level of significance was set to $p < 0.05$.

6.4. Results

Effects of morning vs midday naps on REM sleep parameters

As expected, participants in the morning naps spent significantly more time in REM sleep (23.27 ± 1.76 min; 24.64 ± 1.87 %) compared with participants in the midday naps (11.82 ± 1.34 min; $F_{1,44} = 15.23$, $p < 0.001$, $\eta^2 = 0.20$; 13.35 ± 1.45 %; $F_{1,44} = 13.08$, $p < 0.001$, $\eta^2 = 0.17$; see Table 1 and Figure 1C). REM sleep latency also tended to be shorter in morning naps (51.06 ± 2.65 min) compared to midday naps (63.01 ± 2.64 ; $F_{1,44} = 3.97$, $p = 0.052$, $\eta^2 = 0.05$; see Table 1). Similarly, the latency to SWS also tended to differ between groups, with longer latency in morning naps (57.45 ± 4.52 min) than in midday naps (41.44 ± 4.68 min; $F_{1,44} = 3.84$, $p = 0.056$, $\eta^2 = 0.06$; see Table 1). These findings indicate that the group manipulation (morning vs midday naps) worked as expected, as REM sleep pressure should be higher in the early morning. Since these effects reflect the expected circadian modulation of sleep architecture and as the general pattern of sleep parameters was comparable in both groups (morning naps, midday naps), the main Figures and Tables present data collapsed across groups for the within-subject comparison of the hypnotic suggestions for clarity, while the group-specific results are provided in the Supplementary Figure S1 and Supplementary Tables S2 and S3.

Subjectively, participants in the morning naps reported an overall higher subjective sleep quality (3.60 ± 0.10) than participants in the midday naps (3.33 ± 0.11 ; $F_{1,44} = 5.74$, $p = 0.021$, $\eta^2 = 0.08$; see Table 1).

Table 1: Subjective and objective sleep parameters separated for morning and midday naps.

	Morning naps	Midday naps	Main effect of group	
			<i>p</i>	η^2
Subjective Sleep Parameters				
Sleep Quality	3.60 ± 0.10	3.33 ± 0.11	0.021	0.08
SOL	18.37 ± 1.46	21.98 ± 1.94	0.129	0.04
Objective Sleep Parameters				
TST [min]	90.56 ± 2.08	86.17 ± 2.28	0.224	0.02
WASO [%]	6.82 ± 1.35	8.10 ± 1.21	0.553	<0.01
N1 [%]	8.48 ± 0.59	10.25 ± 0.81	0.190	0.03
N2 [%]	47.10 ± 1.76	50.06 ± 1.68	0.257	0.02
SWS [%]	12.97 ± 1.93	18.25 ± 2.26	0.254	0.03
REM [%]	24.64 ± 1.87	13.35 ± 1.45	<0.001	0.17
WASO [min]	5.94 ± 1.14	6.99 ± 1.11	0.618	<0.01
N1 [min]	7.45 ± 0.48	8.44 ± 0.59	0.329	0.02
N2 [min]	42.03 ± 1.62	42.66 ± 1.70	0.762	<0.01
SWS [min]	11.87 ± 1.83	16.26 ± 2.11	0.348	0.02
REM [min]	23.27 ± 1.76	11.82 ± 1.34	<0.001	0.20
SWS lat [min]	57.45 ± 4.52	41.44 ± 4.68	0.056 ^a	0.06
REM lat [min]	51.06 ± 2.65	63.01 ± 2.64	0.052 ^a	0.05
SOL [min]	11.87 ± 1.40	12.81 ± 1.34	0.341	0.01

Notes: Subjective parameters are based on subjective ratings in the SF-A/R questionnaires. Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), sleep onset latency (SOL), SWS latency, REM sleep latency are measured in minutes, and percentages indicate partial percentage of total sleep time (TST). Values are means and standard errors of the mean. The main effect of group is drawn from the full model including the within-subject factor condition (hypnosis, control) and the between-subject factor hypnotisability (high, medium, low). Significant results are highlighted in bold. ^a indicates $p < 0.06$. 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 reflects a large effect.

Effects of hypnotic suggestions on REM sleep parameters

We first tested our a priori hypothesis regarding the effects of hypnotic suggestions on REM sleep duration and latency, separately for morning and midday naps and for high, medium and low hypnotisable participants. No significant difference in REM sleep parameters was observed between hypnosis and control conditions (all p -values > 0.260), and no other main effects or interactions emerged for REM sleep variables (all p -values > 0.228 ; see Table 2). However, there was a significant main effect of condition for the time spent in slow-wave sleep (SWS; $F_{1,44} = 7.53$, $p = 0.009$, $\eta^2 = 0.02$), with participants spending less time in SWS in the hypnosis condition (12.48 ± 1.81 min) than in the control condition (15.47 ± 2.13 min; see Figure 1D). This effect interacted with the hypnotisability ($F_{2,44} = 3.39$, $p = 0.043$, $\eta^2 = 0.02$), where the difference between the conditions was significant only in high hypnotisable participants ($t_{10} = -2.56$, $p = 0.029$, $d = 0.771$) and not in medium and low hypnotisable groups (both p -values > 0.394).

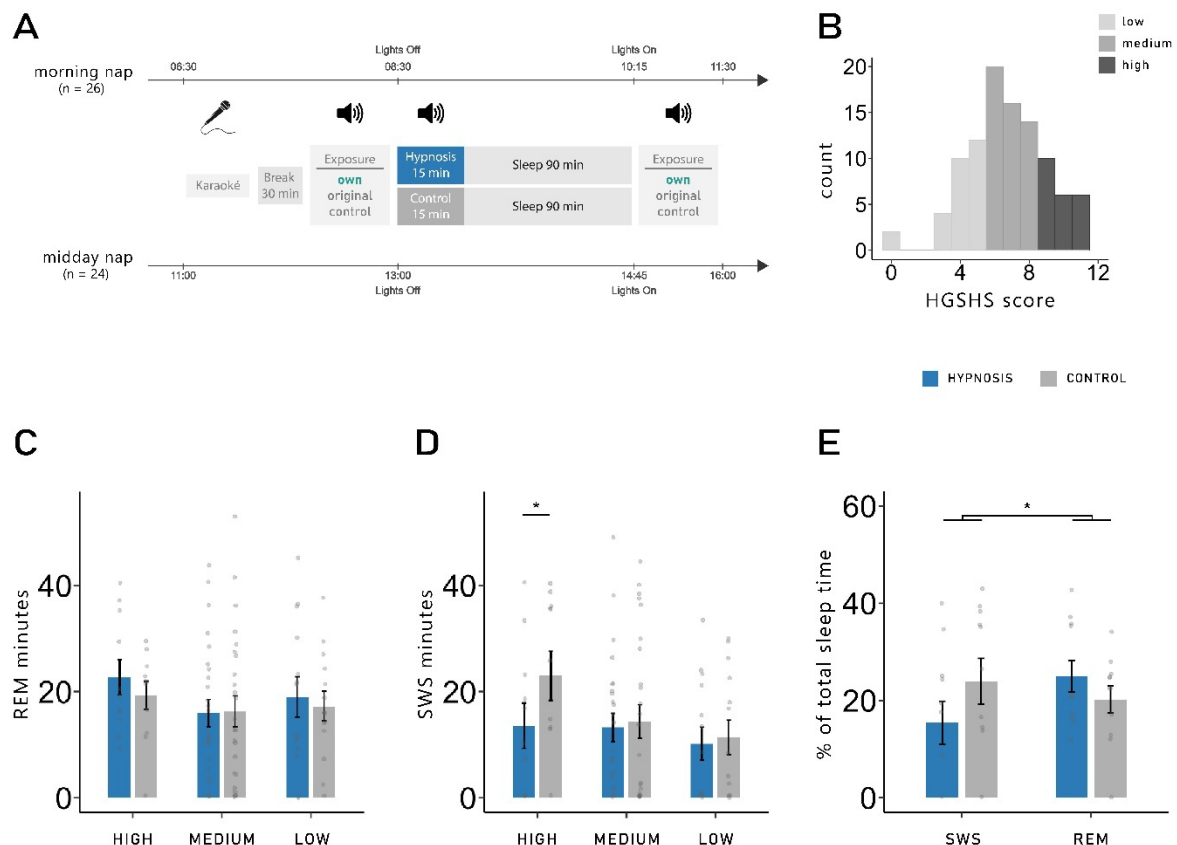


Figure 1: A) Experimental procedure: healthy young participants listened either to a tape with hypnotic suggestions or a control tape while lying in bed. One group of participants took a morning nap after mild sleep deprivation, while another group of participants took a midday nap. The hypnosis tape included a metaphor of immersing oneself deeper and deeper into the sea to symbolise deep sleep, followed by specific suggestions to induce REM sleep at an earlier stage and to make it last longer. Before sleep, they were required to sing a song. Then, before and after sleep, participants were exposed to the recordings of their own out-of-tune singing (own; in green) as well as to the original version of the song (original) and a control song (control; Respect by Aretha Franklin). **B) Distribution of participants by group, depending on their score on the HGSHS questionnaire:** 11 subjects were categorised as high hypnotisable (high; dark grey), 25 subjects as medium (medium; grey), and 14 as low hypnotisable (low; light grey). **C) Minutes spent in REM sleep:** no significant difference was observed between both conditions (hypnosis, control) in the three groups (high, medium, low hypnotisable; all p -values > 0.228). **D) Minutes spent in SWS:** participants spent significantly less time in slow-wave sleep (SWS) in the hypnosis condition than in the control condition ($F_{1,44} = 7.53$, $p = 0.009$). Post-hoc pairwise comparisons revealed that this effect was significant only in high hypnotisable participants ($t_{10} = -2.56$, $p = 0.029$). **E) Comparison between time spent in SWS and REM sleep in high hypnotisable subjects:** in the hypnosis condition, high hypnotisable subjects showed more REM sleep than SWS sleep, while the opposite was found in the control condition ($F_{1,9} = 5.46$, $p = 0.044$). Means $\pm$ standard errors of the mean are displayed. *: $p \leq 0.05$.

Although our primary aim was to modulate REM sleep by hypnotic suggestions, a significant effect was observed in SWS sleep, especially in the high hypnotisable participants. To examine whether these effects reflected a broader alteration in sleep stage distribution rather than stage-specific influence, we conducted an additional ANOVA with the percentages of

SWS and REM sleep, including sleep stage (SWS vs REM) as a within-subject factor. This approach allowed us to assess whether the effects of hypnosis differentially affected the SWS vs REM sleep distribution in the high hypnotisable group. A significant interaction was found between the factors condition (hypnosis vs control) and sleep stage (SWS vs REM; $F_{1,9} = 5.46$, $p = 0.044$, $\eta^2 = 0.09$), where in the hypnosis condition, high hypnotisable subjects showed more REM sleep (24.98 ± 3.24 %) than SWS sleep (15.44 ± 4.43), and the opposite in the control condition (REM sleep: 20.22 ± 2.82 ; SWS: 23.95 ± 4.73). However, these differences were not significant in the post-hoc pairwise comparisons (both p -values > 0.210 ; see Figure 1E). We further examined whether the difference in SWS and REM sleep from the hypnosis to the control condition (hypnosis – control) were related to the suggestibility score. No significant correlations emerged (both $p > 0.616$).

We exploratorily investigated other REM sleep metrics to examine different aspects of REM fragmentation: the number of REM episodes, the mean duration by REM episodes, the number of arousals during REM episodes and REM fragmentation (see *EEG recording & sleep scoring*). To account for participants who did not have REM sleep in both sessions, we used a linear mixed model including the fixed effects of group (morning, midday), condition (hypnosis, control) and hypnotisability (high, medium, low), and random intercepts for participants. In the hypnosis condition, participants tended to show more REM episodes (1.73 ± 0.17) than in the control condition (1.34 ± 0.17 ; $F_{1,44} = 3.84$, $p = 0.056$). The 3-way interaction was also significant ($F_{2,44} = 3.27$, $p = 0.047$). Post-hoc pairwise comparisons revealed that highly hypnotisable subjects in the morning naps had significantly more REM episodes in the hypnosis condition (3.17 ± 0.45) than in the control condition (ED: -1.67 ± 0.53 ; $t_{44} = -3.14$, $p = 0.003$). This difference was a statistical trend in the medium subjects in the midday naps ($p = 0.071$) and not significant in the other groups (all p -values > 0.311 ; see Figure 2A). Regarding the index of REM fragmentation, the interaction between group and hypnotisability was significant ($F_{2,41.83} = 7.78$, $p = 0.001$). Post-hoc pairwise comparisons revealed that, in the midday naps, the medium hypnotisable subjects had a greater REM fragmentation (17.66 ± 1.77) than both the low hypnotisable (ED: 9.96 ; $t_{41.7} = 3.01$, $p = 0.013$) and high hypnotisable subjects (ED: 12.34 ; $t_{41.7} = 3.73$, $p = 0.002$; see Figure 2B). In addition, REM episodes were on average longer (17.47 ± 1.50) and contained more arousals (3.08 ± 0.50) in morning naps than in midday naps (mean duration: 10.88 ± 1.74 ; $F_{1,39.80} = 8.28$, $p = 0.006$; arousals: 1.31 ± 0.56 ; $F_{1,44} = 5.60$, $p = 0.022$). No other differences emerged (all p -values > 0.063).

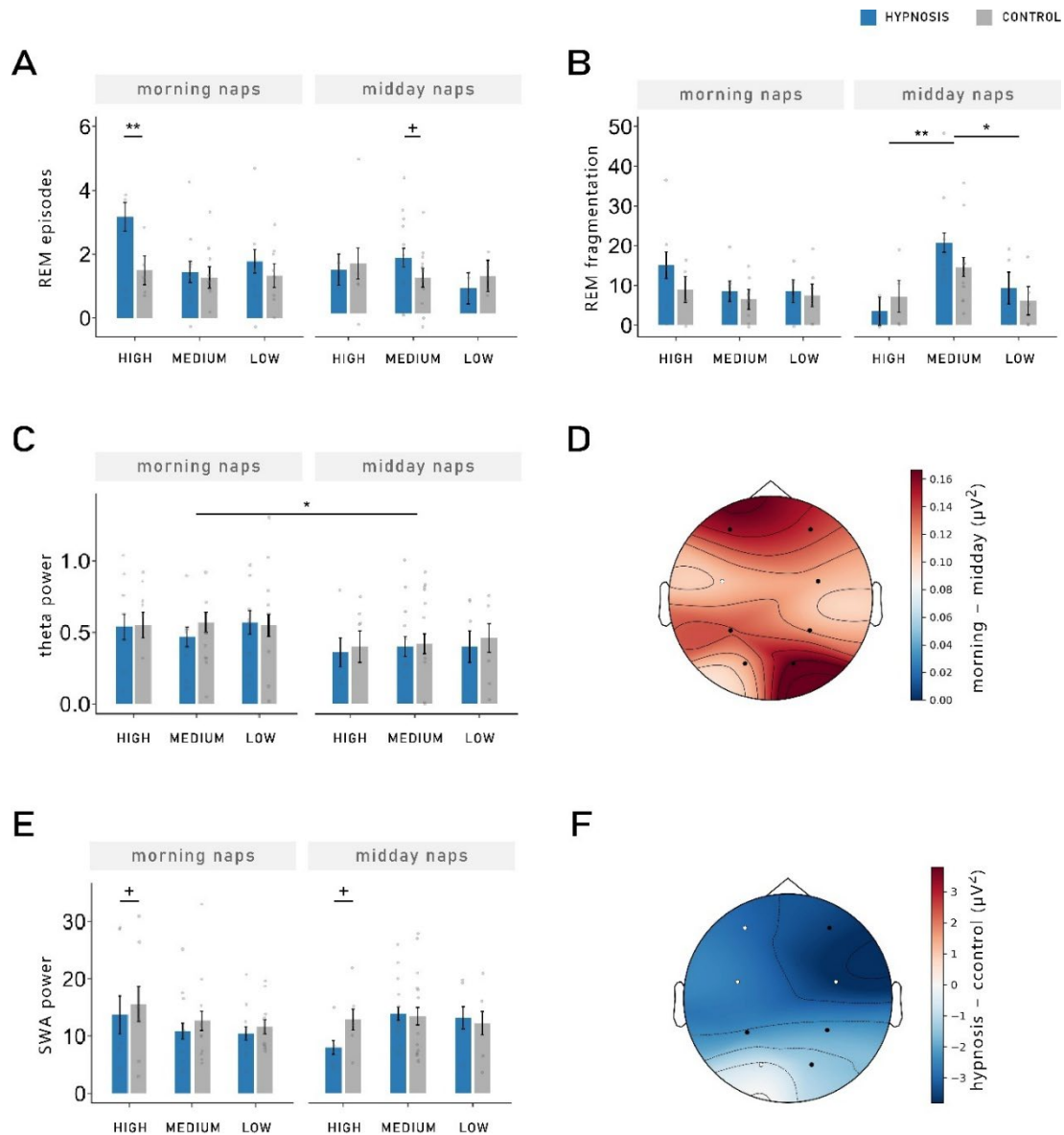


Figure 2: A) Number of REM episodes: in the hypnosis condition, participants tended to show more REM episodes than in the control condition. Post-hoc pairwise comparisons revealed that highly hypnotisable subjects in the morning naps had significantly more REM episodes in the hypnosis condition than in the control condition ($t_{44} = -3.14, p = .003$). This difference was a statistical trend in medium subjects in the midday naps ($p = 0.071$) and not significant in the other groups (all p -values > 0.311). **B) REM sleep fragmentation index:** in the midday naps, the medium hypnotisable subjects had a greater REM fragmentation than both the low and high hypnotisable subjects (both p -values < 0.013). **C) Theta power during REM sleep, in the parietal region:** theta power in the parietal region was higher in morning naps than in midday naps ($F_{1,41.54} = 4.65, p = 0.037$). **D) Topographical distribution of the theta power differences (4-8 Hz; μV^2) between morning and midday naps (morning – midday) in the parietal region during REM sleep.** Filled black dots represent electrodes who showed a significant difference between the groups. **E) Slow wave activity (SWA) power during NREM sleep, in the frontal region:** no difference was observed overall (all p -values > 0.095). When the analysis was limited to high hypnotisable subjects, a statistical trend was observed for the main effect of condition where, SWA power was significantly lower in the hypnosis condition than in the control condition ($F_{1,9} = 4.61, p = 0.060$). **D) Topographical distribution of the SWA power differences (0.5-4.5 Hz; μV^2) between the hypnosis and control conditions (hypnosis – control) in the frontal region during NREM sleep, in high hypnotisable subjects.** Filled black dots represent electrodes who showed a significant difference between the conditions. Means $\pm$ standard errors of the means are displayed. **: $p < 0.01$; *: $p < 0.05$; +: $p < 0.075$.

We further explored whether other sleep parameters were influenced by the conditions and hypnotisability. No effects were observed in objective sleep parameters (all p -values > 0.079 ; see Table 2). No differences were observed in subjective sleep quality and sleep onset latency (all p -values > 0.076 ; see Table 2). For interactions involving the factor group, the results are reported in supplementary material (see Supplementary Results and Supplementary Figure S4).

Table 2. Subjective and objective sleep parameters in the hypnosis and control conditions, separated for hypnotisability.

	High hypnotisable		Medium hypnotisable		Low hypnotisable		Main effect of condition		Main effect of hypnotisability		Interaction	
	Hypnosis	Control	Hypnosis	Control	Hypnosis	Control	<i>p</i>	η^2	<i>p</i>	η^2	<i>p</i>	η^2
Subjective Sleep Parameters												
Sleep Quality	3.60 ± 0.27	3.67 ± 0.23	3.40 ± 0.14	3.47 ± 0.16	3.41 ± 0.17	3.39 ± 0.16	0.650	<0.01	0.584	0.02	0.965	<0.01
SOL	15.45 ± 3.12	21.36 ± 3.76	17.60 ± 1.94	20.00 ± 2.45	23.57 ± 3.97	23.93 ± 3.60	0.076 ^a	0.02	0.118	0.07	0.726	<0.01
Objective Sleep Parameters												
TST [min]	89.91 ± 4.50	95.14 ± 2.08	86.56 ± 3.52	87.62 ± 3.57	86.61 ± 4.38	88.75 ± 3.17	0.174	0.01	0.522	0.02	0.651	<0.01
WASO [%]	5.00 ± 2.04	7.10 ± 4.08	9.79 ± 2.29	6.31 ± 1.11	7.67 ± 1.63	7.16 ± 2.68	0.755	<0.01	0.691	0.01	0.393	0.02
N1 [%]	7.50 ± 1.31	5.83 ± 0.92	10.58 ± 1.14	9.90 ± 1.12	9.92 ± 1.19	9.63 ± 0.98	0.284	<0.01	0.079 ^a	0.08	0.723	0.01
N2 [%]	47.09 ± 2.26	42.94 ± 3.67	47.27 ± 2.64	50.93 ± 2.74	48.84 ± 2.40	51.61 ± 3.62	0.755	<0.01	0.436	0.02	0.412	0.02
SWS [%]	15.44 ± 4.43	23.95 ± 4.73	14.79 ± 2.76	15.59 ± 3.37	12.97 ± 3.96	12.58 ± 3.51	0.080 ^a	<0.01	0.439	0.03	0.077 ^a	0.02
REM [%]	24.98 ± 3.24	20.22 ± 2.82	17.56 ± 2.79	17.27 ± 2.97	20.59 ± 4.01	19.00 ± 3.04	0.260	<0.01	0.572	0.02	0.684	<0.01
WASO [min]	4.68 ± 1.92	6.91 ± 4.13	8.16 ± 1.74	5.32 ± 0.94	6.71 ± 1.48	6.14 ± 2.43	0.899	<0.01	0.858	<0.01	0.397	0.02
N1 [min]	6.68 ± 1.16	5.41 ± 0.79	8.62 ± 0.78	8.18 ± 0.79	8.68 ± 1.10	8.43 ± 0.87	0.369	<0.01	0.111	0.07	0.640	<0.01
N2 [min]	42.23 ± 2.92	40.50 ± 3.22	40.52 ± 2.71	43.40 ± 2.28	42.04 ± 2.89	45.46 ± 3.35	0.416	<0.01	0.867	<0.01	0.642	<0.01
SWS [min]	13.59 ± 4.28	23.00 ± 4.64	13.28 ± 2.63	14.42 ± 3.16	10.18 ± 3.14	11.43 ± 3.22	0.009	0.02	0.353	0.04	0.043	0.02
REM [min]	22.73 ± 3.36	19.32 ± 2.62	15.98 ± 2.61	16.30 ± 2.90	19.00 ± 3.77	17.29 ± 2.76	0.401	<0.01	0.567	0.02	0.716	<0.01
SWS lat [min]	52.32 ± 11.72	41.00 ± 9.54	46.72 ± 6.64	51.42 ± 7.02	50.86 ± 8.79	56.04 ± 8.40	0.936	<0.01	0.849	<0.01	0.343	0.01
REM lat [min]	49.18 ± 3.53	59.68 ± 4.41	57.78 ± 4.84	56.78 ± 4.87	57.86 ± 3.74	57.79 ± 3.96	0.306	<0.01	0.771	<0.01	0.371	0.02
SOL [min]	10.64 ± 2.71	8.09 ± 1.93	11.58 ± 1.22	12.62 ± 2.35	16.75 ± 3.83	13.32 ± 1.87	0.305	<0.01	0.143	0.06	0.376	0.01

Notes: Subjective parameters are based on subjective ratings in the SF-A/R questionnaires. Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), sleep onset latency (SOL), SWS latency, REM sleep latency are measured in minutes, and percentages indicate partial percentage of total sleep time (TST). Values are means and standard errors of the mean. Main effects and interactions are drawn from the full model including the between-subject factor group (morning vs midday naps). Significant results are highlighted in bold. ^a indicates $p \leq .08$. η^2 represents the effect sizes where a value below or equal to .02 reflects a small effect, a value between .02 and .14 reflects a medium effect, and a value above .14 reflects a large effect.

Theta power during listening of hypnosis and during REM sleep

In our previous studies, we showed that during the listening of hypnotic suggestions to increase SWS, theta power was significantly increased compared with listening to a control text (Cordi et al., 2014, 2020). This effect was most prominent for highly hypnotisable subjects and in parietal and central brain regions. Therefore, we tested whether the hypnotic suggestions used in the current study also induced changes in theta activity in central and parietal regions during listening. One participant was excluded from this analysis due to values larger than 3 SD of the mean in all electrodes. A significant interaction between group (morning, midday) and condition (hypnosis, control) was observed in the central region ($F_{1,43} = 6.10, p = 0.018, \eta^2 = 0.02$): in morning naps, there was a tendency for a lower theta activity during the listening of the hypnosis (0.83 ± 0.10) compared with the control text (1.00 ± 0.15 ; $t_{24} = -1.90, p = 0.069, d = 0.380$). No differences were observed in midday naps ($p = 0.191$). No other effects were observed in central regions or parietal regions (all p -values > 0.131). Restricting the analysis to high hypnotisable subjects revealed no significant differences in the central region (all p -values > 0.191). However, the interaction between group and condition was significant in the parietal region ($F_{1,9} = 5.51, p = 0.044, \eta^2 = 0.03$): in morning naps, theta power was lower in the hypnosis condition (0.75 ± 0.19) than in the control condition (0.94 ± 0.21), while the opposite emerged in midday naps (hypnosis: 0.62 ± 0.12 ; control: 0.54 ± 0.10). However, the post-hoc pairwise comparisons were not significant (both p -values > 0.103).

We performed the same analysis for theta activity during REM sleep. To account for participants who did not have REM sleep in both sessions, we used a linear mixed model including the fixed effects of group (morning, midday), condition (hypnosis, control) and hypnotisability (high, medium, low), and random intercepts for participants. Two participants were excluded from this analysis for not displaying any REM sleep in either session; in addition, one participant was excluded due to values larger than 3 SD of the mean. In the parietal region, theta power was higher in morning naps (0.54 ± 0.04) than in midday naps (0.41 ± 0.05 ; $F_{1,41.54} = 4.65, p = 0.037$; see Figure 2C-D). No other main effect or interactions were observed in both regions (all p -values > 0.120), nor when the analysis was limited to high hypnotisable subjects (all p -values > 0.170).

Exploratory analysis on power activity during NREM sleep

For completeness, we also report the exploratory analysis of hypnotic suggestions on slow wave activity (SWA) during N2 sleep and SWS in the frontal region. No differences were

observed (all p -values $> .095$; see Figure 2E-F). When the analysis was limited to high hypnotisable subjects, a statistical trend was observed for the main effect of condition where SWA power was significantly lower in the hypnosis condition (11.11 ± 2.76) than in the control condition (14.35 ± 2.67 ; $F_{1,9} = 4.61$, $p = 0.060$, $\eta^2 = 0.04$).

REM sleep and emotional processing

First, as manipulation check, we tested whether the listening of their own out-of-tune singing before sleep did elicit more self-reported embarrassment compared with control songs. We used a linear mixed model including the fixed effect of song (own, control, original) and group (morning, midday) and random intercepts for participants. The main effect of song was highly significant ($F_{2,226.25} = 110.61$, $p < 0.001$). Post-hoc comparisons revealed that their own singing led to higher embarrassment (estimated marginal mean (EMM): 5.48 ± 0.27) compared with both the control song (estimated difference (ED): 3.15 ± 0.23 ; $t_{226} = 13.68$, $p < 0.001$) and the original song (ED: 2.74 ± 0.23 ; $t_{227} = 11.85$, $p < 0.001$). No difference was found between the control song and the original ($p = 0.233$; see Figure 3A). No main effect of group nor interaction emerged (both p -values > 0.474). The model explained 63% of the variance (conditional $R^2 = 0.632$; marginal $R^2 = 0.296$).

As no differences in REM sleep emerged between the experimental conditions (hypnosis vs control), we focused this analysis on the group comparison (morning vs midday naps), where large differences were observed. Therefore, we compared subjective ratings of embarrassment on a 9-point Likert scale (“How embarrassed are you feeling right now?”, 1 = not at all, 9 = extremely) following the exposure of the embarrassing episode, before and after sleep (see *Karaoke task*). For these analyses, we used linear mixed models including the fixed effects of song (own, original, control), group (morning, midday) and time (pre, post), and random intercepts for participants.

Since it appeared that listening to their own out-of-tune singing before sleep did lead to more self-reported embarrassment compared with both control songs, we further tested whether the emotional regulation across sleep differed depending on the group (morning, midday). To this end, we used a linear mixed model on the difference between pre- and post-sleep ratings (post-sleep – pre-sleep), including the fixed effects of song (own, control, original) and group (morning, midday), and random intercepts for participants. No differences emerged (all p -values > 0.271 ; see Figure 3B).

The pre-to-post difference in embarrassment after listening to their own singing did not correlate with the time spent in REM sleep overall ($r = -0.11$, $p = 0.284$; see Figure 3C). However, when separating for groups, the pre-to-post difference in embarrassment correlated negatively with the time spent in REM sleep in the morning naps ($r = -0.36$, $p = 0.014$; see Figure 3D), while the positive correlation in the midday naps was not significant ($r = 0.26$, $p = 0.088$; Figure 3E). The two correlations were significantly different from each other ($z = -2.08$, $p = 0.037$). The difference in embarrassment did not correlate with theta power during REM sleep (all p -values > 0.053).

The same analyses were run for the self-reported valence (“How are you feeling right now?”, 1 = very negative, 9 = very positive) induced by the different songs. In the model comparing the valence before sleep between their own singing and both control songs, the main effect of song was also significant ($F_{2,227.3} = 5.43$, $p = 0.005$). The valence was rated as more negative following their own singing (5.91 ± 0.22) compared to both control songs (both estimated differences (ED): -0.49 ± 0.17 ; $t_{228} = -2.85$, $p = 0.014$), while there was no difference between both control songs ($p = 1.00$). The differences across sleep for each song did not differ depending on the group (all p -values > 0.198 ; see Supplementary Figure S5A).

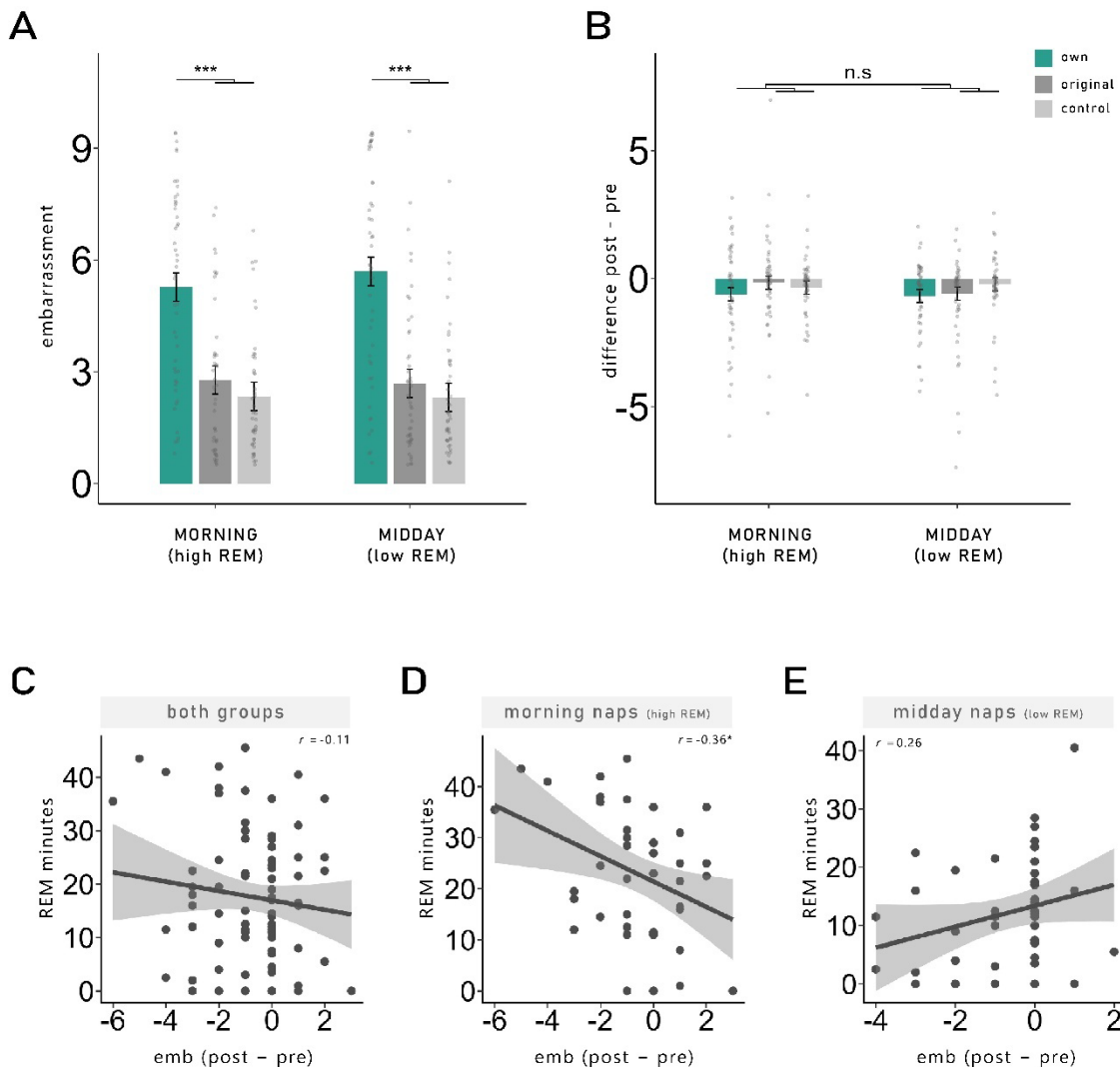


Figure 3: A) Ratings of embarrassment before sleep for each group: listening to their own out-of-tune singing led to higher embarrassment compared with both the original and the control songs (both p -values < 0.001). B) Pre- to post-sleep difference in ratings of embarrassment for each song, separated for groups: there was no difference in the reduction of embarrassment oversleep depending on the group (all p -values > 0.271). Estimated Marginal Means (EMM) $\pm$ their standard errors are shown. C) The difference from pre- to post-sleep embarrassment ratings (post – pre) did not correlate with the minutes spent in REM sleep in both groups. However, when separated for groups, the D) pre- to post-sleep difference in embarrassment correlated negatively with the minutes spent in REM sleep in the morning naps ($p = 0.014$), E) while the positive correlation in the midday naps was not significant ($p = 0.088$). ***: $p < 0.001$; *: $p < 0.05$.

Differences in embarrassment between hypnosis and control

For completeness, we still analysed whether the conditions had an effect on the reduction of embarrassment over sleep. Since we initially hypothesised that the hypnosis condition would lead to higher REM sleep, we expected a greater reduction in embarrassment in the hypnosis condition, compared with the control condition. To test this, we used a linear mixed model including the fixed effects of song (own, control, original) and condition (hypnosis, control), and random intercepts for participants. The interaction between song and

condition was significant ($F_{2,219.12} = 5.37, p = 0.005$). As expected, in the hypnosis condition, the reduction of embarrassment from pre- to post-sleep was bigger when listening to their own singing compared with both control songs (both p -values < 0.043); this was not observed in the control condition (all p -values > 0.434 ; see Figure 4A). No main effect emerged (both p -values > 0.262). The model explained 15% of the variance (conditional $R^2 = 0.154$; marginal $R^2 = 0.042$). When restricting the analysis to their own out-of-tune singing, the main effect of condition was significant, with a greater reduction in the hypnosis condition (-1.14 ± 0.25) than in the control condition (-0.29 ± 0.24 ; $F_{1,40.825} = 6.44, p = 0.015$). The interaction between condition and hypnotisability showed a statistical trend ($F_{2,40.857} = 3.14, p = 0.054$). Post-hoc pairwise comparisons revealed that the difference between conditions was significant only in high hypnotisable subject (EMM: -2.14 ± 0.68 ; $t_{42.5} = -3.16, p = 0.003$; see Figure 4B). The main effect of hypnotisability was not significant ($p = 0.147$).

Since the increase in REM sleep and the reduction of embarrassment following the hypnotic suggestions were observed only in the high hypnotisable group, we computed the correlations between the reduction of embarrassment and the amount of REM sleep (in minutes) separately for the three groups (high, medium, low). Although the high group visually showed the expected correlation (i.e., more REM sleep correlates with a greater reduction in embarrassment; see Figure 4C), the correlations were not significant for all groups (all p -values > 0.180 ; see Figure 4D-E).

Given the differences observed in SWS depending on the conditions, we checked whether the pre-to-post difference in embarrassment after listening to their own singing correlated with the time spent in SWS (in minutes). No correlations were found overall, nor when separating for hypnotisability (all p -values > 0.097). However, in the high hypnotisable group, the difference in embarrassment tended to correlate positively with SWA during NREM sleep ($r = 0.43, p = 0.067$; see Figure 4F), while it was not the case in the medium and low groups (both p -values > 0.680 ; see Figure 4G-H). However, the correlations were not significantly different from each other (both p -values > 0.232).

Regarding the valence ratings, a main effect of condition emerged in the pre- to post-sleep difference, with an increase from pre- to post-sleep in the hypnosis condition (0.18 ± 0.14) and a decrease in the control condition (-0.21 ± 0.14 ; $F_{1,232.47} = 5.17, p = 0.024$). No main effect of song or interaction emerged (both p -values > 0.222 ; see Supplementary Figure 5B). When restricting the analysis to their own out-of-tune singing, the main effect of condition was again significant ($F_{1,84} = 4.77, p = 0.032$), but no main effect of hypnotisability or interaction emerged (both $p > 0.215$; see Supplementary Figure 5C).

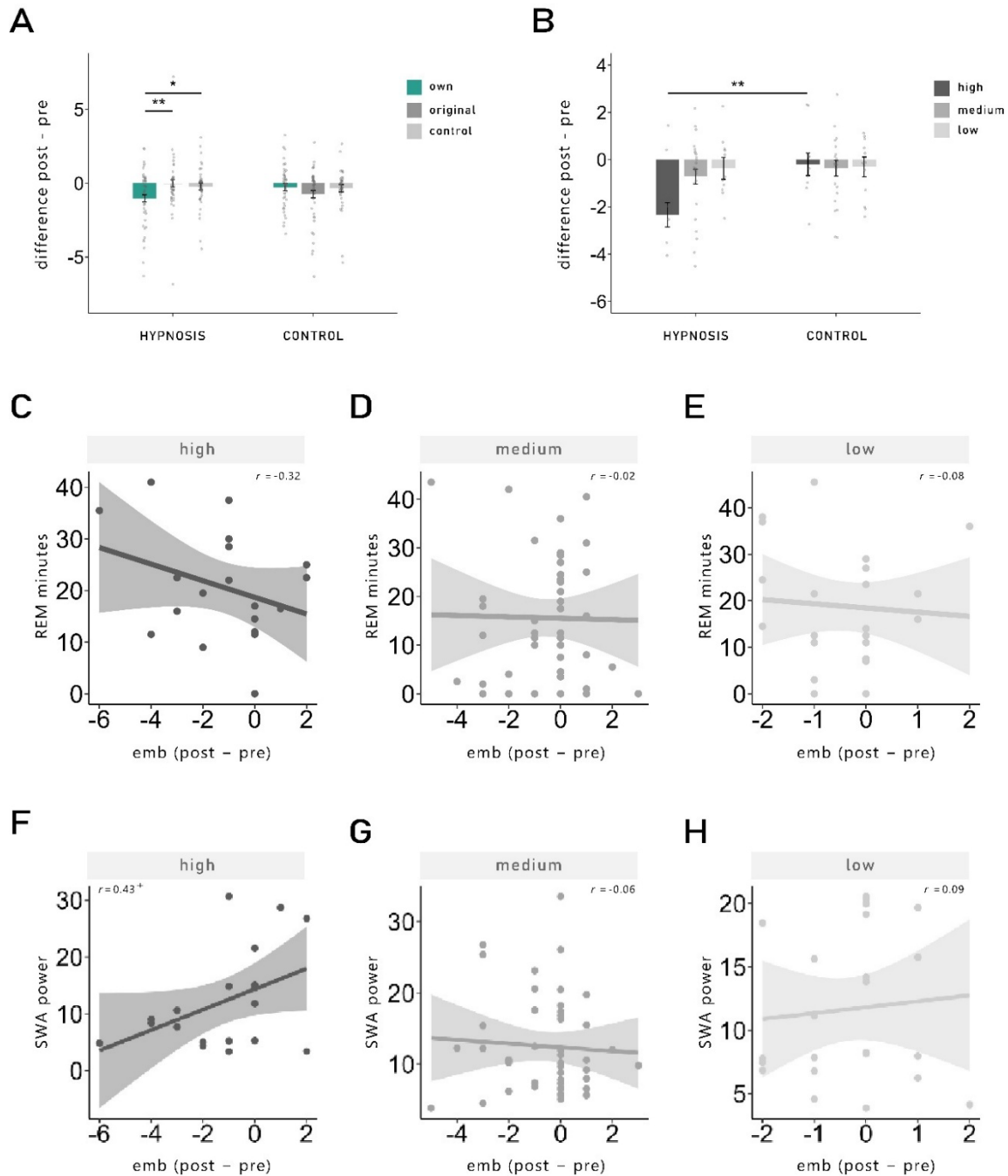


Figure 4: A) Pre- to post-sleep difference in ratings of embarrassment for each song, separated for conditions: in the hypnosis condition, the reduction of embarrassment from pre- to post-sleep was bigger when listening to their own singing (green) compared with both control songs (both p -values < 0.043). This was not observed in the control condition (all p -values > 0.434). **B) Pre- to post-sleep difference in ratings of embarrassment for their own singing, separated for hypnotisability:** in high hypnotisable subjects, listening to their own singing led to a greater reduction in embarrassment in the hypnosis condition compared with the control condition ($t_{42.5} = -3.16, p = 0.003$). Estimated Marginal Means (EMM) $\pm$ their standard errors are shown. **Correlation between the difference from pre- to post-sleep embarrassment ratings and time spent in REM sleep (in minutes) in C) high hypnotisable subjects, D) medium hypnotisable subjects, and E) low hypnotisable subjects:** although the high group visually showed the expected correlation (i.e., more REM sleep correlates with a greater reduction in embarrassment), the correlations were not significant (all p -values > 0.180). **Correlation between the difference from pre- to post-sleep embarrassment ratings and SWA power during NREM sleep in F) high hypnotisable subjects, G) medium hypnotisable subjects, and H) low hypnotisable subjects:** no correlation was observed in medium and low hypnotisable subjects, whereas a trend emerged in high hypnotisable subjects, with higher SWA power associated with a smaller reduction in embarrassment ($p = 0.067$). $^+ : p \geq .070$; $^* : p \geq .05$; $^{**} : p \geq .01$

6.5. Discussion

In this study, we aimed to modulate REM sleep using hypnotic suggestions specifically designed to increase its duration and reduce its latency. Contrary to our expectations, the hypnotic suggestions did not affect REM sleep; instead, we observed a reduction in slow-wave sleep (SWS), leading to alterations in overall sleep architecture. Importantly, this effect was restricted to highly hypnotisable individuals. Furthermore, our results did not provide strong evidence for a general role of REM sleep in emotional regulation. However, the results point toward potential differences in emotional regulation between early morning and midday REM sleep.

In our previous studies, we showed that pre-sleep hypnotic suggestions to sleep more deeply efficiently increased the amount of SWS (Cordi et al., 2014, 2015, 2020) and most importantly, hypnotic suggestions specifically affected slow-waves parameters, leaving sleep spindles unaffected (Beck, Cordi, et al., 2021). This specific effect on sleep depth as well as the missing SWS increase after unspecific hypnotic suggestions to relax (see Cordi et al., 2014) suggests that the sleep-promoting effect of hypnotic suggestions is not caused by a hypnosis-induced state of relaxation but is rather due to cognitive processes during sleep related to the semantic content of the hypnosis. Our current findings strongly support this notion: after listening to hypnotic suggestions given before sleep, high hypnotisable participants significantly reduced their amount of SWS instead of increasing it as in our previous studies. Thus, hypnosis does not increase SWS generally, but the effects strongly depend on the specific content of the hypnotic suggestions given before sleep. In contrast to SWS, we were not able to similarly modulate REM sleep by specific hypnotic suggestions given before sleep. However, in high hypnotisable participants, pre-sleep hypnotic suggestions targeting REM sleep did influence the ratio between SWS and REM sleep. We have previously suggested that the content of pre-sleep cognitive activity might be spontaneously reactivated during subsequent sleep (Baselgia et al., 2023; Beck et al., 2023; Cordi et al., 2020), and that this repeated reactivation of pre-sleep cognitive content during sleep could activate associated physiological networks and brain regions. The results in high hypnotisable subjects suggest that the pre-sleep hypnotic suggestions might have indeed been reactivated during sleep, altering ongoing physiological processes. These findings may be understood as reflecting an attempted, but physiologically constrained, modulation of sleep architecture. The hypnotic suggestions were intended to promote an earlier onset and greater amount of REM sleep. It is plausible that, in highly hypnotisable participants, these cognitions were indeed reactivated during sleep and

initiated a drive toward the physiological profile characteristic of REM sleep. However, unlike transitions among NREM stages, the shift from SWS to REM sleep entails a profound change in neurophysiology: REM sleep is characterised by unique patterns of brain activity that differ substantially from those of NREM sleep. This sharp discontinuity may explain why we were not able to reach a similar efficiency of hypnotic suggestions as in our previous studies (Cordi et al., 2014, 2015, 2020). Consequently, instead of producing a straightforward REM sleep enhancement, the suggestions yielded an altered ratio between SWS and REM sleep, potentially reflecting a conflict between top-down cognitive influence (i.e., “I should be in REM sleep”) and the endogenous homeostatic and ultradian pressures favouring SWS at that point of the sleep process. It should be noted that the hypnosis also included suggestions related to deep sleep, which may have reduced the specificity or efficacy of stage-specific suggestions. Future studies may want to isolate REM-specific effects by restricting suggestions to REM sleep only. Importantly, similarly to our previous studies (Cordi et al., 2014, 2015, 2020), these effects emerged only in high hypnotisable participants, further underscoring that a sufficient level of hypnotic responsiveness is likely required for REM-targeted suggestions to be encoded, reactivated, and capable of influencing sleep.

Regarding the role of REM sleep in emotional processing, we found no overall evidence for a direct association between REM sleep duration and emotional processing. However, nuanced patterns emerged when considering REM sleep in both groups: REM sleep in morning naps was more strongly associated with emotional regulation, whereas REM sleep in midday naps showed no such relationship. This temporal dissociation suggests that any functional link between REM sleep and emotional processing may depend on qualitative features of REM sleep rather than its duration alone. This interpretation is consistent with recent meta-analyses and reviews indicating that REM sleep duration alone is an unreliable predictor of emotional outcomes (Lipinska et al., 2019, 2022; Rawson & Jackson, 2024; Schäfer et al., 2020) whereas indices of REM sleep quality, such as fragmentation or phasic activity, provide stronger predictive value (Halonen et al., 2021; Mendoza-Alvarez et al., 2025; Miller & Gehrman, 2019). Late-night REM sleep unfolds under the full expression of REM-specific neurochemical and physiological conditions, including reduced noradrenergic tone, heightened cholinergic activity, increased limbic system engagement, and greater phasic eye-movement activity. Together, these features may create an optimal neurobiological environment for the reactivation, integration, and reorganisation of affective representations, thereby facilitating the attenuation of emotional charge. However, it is important to note that, due to the circadian

manipulation to alter REM sleep, the emotional task was performed at different circadian times in the morning and the midday nap groups, which might have confounded processes of emotional regulation. Moreover, this comparison was between subjects, which may have reduced sensitivity due to inter-individual variability.

Importantly, we observed a greater reduction of embarrassment in the hypnosis condition compared with the control condition, despite the absence of differences in REM sleep duration between conditions. This dissociation further suggests that emotional benefits may not depend exclusively on the amount of REM sleep obtained. Rather, it raises the possibility that suggestions to enhance REM sleep, without producing a measurable increase in REM duration, may be sufficient to modulate the functional engagement of REM sleep in emotional processing. For instance, such suggestions could bias cognitive or affective processes engaged during REM sleep, potentially by shaping expectancies regarding sleep-dependent emotional regulation. Support for this interpretation comes from the observation that associations between sleep parameters and emotional outcomes were present only in high hypnotisable subjects, who may be particularly likely to reactivate REM-related cognitions during sleep. However, this interpretation remains speculative and cannot be directly tested with the present data. Alternatively, the observed results may reflect demand characteristics. Since participants were explicitly informed about the aim of the hypnosis and the role of REM sleep in emotional processing, the reduction in embarrassment in the hypnosis condition may stem from participants adjusting their behaviour to align with perceived experimental expectations. Moreover, SWS was significantly reduced in the hypnosis condition resulting in a shift in overall sleep architecture towards REM sleep. Such changes in sleep architecture may have contributed to the reduction in embarrassment, as supported by the negative association with SWA during NREM sleep. Furthermore, by providing relaxation or distraction, the hypnosis induction before sleep may have enabled a downregulation of embarrassment already during wakefulness, before the onset of (REM) sleep (e.g., Efinger et al., 2019). Taken together, these findings further underscore the notion that emotional regulation is unlikely to be supported solely by REM sleep duration, but rather by specific neurophysiological and cognitive processes that may be preferentially expressed during REM sleep.

Our study has several limitations that should be considered when interpreting the findings. First, it has to be noted that the present manipulation was tested using a nap paradigm, and the extent to which these findings generalise to nocturnal sleep remains uncertain. Second, the use of a karaoke task before sleep may itself have influenced subsequent sleep, for example

by increasing emotional and/or cognitive arousal, independently of the hypnotic suggestions. Future studies should include a control condition without a pre-sleep emotional task, as well as a condition without any auditory input before sleep, to better isolate the specific contribution of hypnosis-related suggestions. Third, to be consistent with our previous work, hypnotisability was assessed using the self-reported score on the Harvard Group Scale of Hypnotic Susceptibility Test (HGSHS, Form A; Shor & Orne, 1963; French translation, see Cordi et al., 2020). Although this measure is validated and widely used, self-assessments may not fully capture individual differences in hypnotic responsiveness. In addition, a substantial proportion of participants scored at the cut-off score used to classify participants into low and high hypnotisable subjects. This is why three groups were created in the current study (high, medium, low), to increase sensitivity to more fine-grained interindividual differences but weakening the comparability with our previous studies in which only two groups were created (high, low). Fourth, although the present study aimed to investigate the role of REM sleep in emotional processing, the absence of a wake control group prevents from disentangling sleep-dependent effects from those attributable to time. As a result, we cannot distinguish between changes in emotional responses attributed specifically to REM sleep and those to nonspecific temporal or circadian factors. Finally, the karaoke paradigm itself may be subject to habituation effects. Repeated exposure to listening to one's own out-of-tune singing may have led to a progressive reduction in embarrassment across sessions, independent of sleep or hypnosis-related mechanisms (Halonen et al., 2021, 2024). Such habituation may have influenced the results and should be considered in their interpretation.

In conclusion, circadian manipulation effectively modulated the amount of REM sleep during naps, whereas REM-targeted hypnotic suggestions did not show reliable effects. Nevertheless, alterations in sleep architecture were observed in high hypnotisable individuals, suggesting that hypnosis can exert measurable effects in this population. These findings indicate that the efficacy of hypnosis may depend on individual responsiveness and the specific content of hypnosis suggestions, while circadian manipulation appears to provide a more robust and reliable approach for experimentally modulating REM sleep. However, this approach inherently introduces a circadian bias which may complicate the interpretation of cognitive and emotional outcomes. In the present emotional task, we found no evidence for a functional role of REM sleep quantity in emotional processing, while hypnotic suggestions aimed at modulating REM sleep were associated with beneficial effects. Together, these observations highlight both the efficiency of circadian manipulation for modulating REM sleep and the need

for further investigation on the role of this sleep stage and its specific features in emotional processing.

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Conflict of 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.

6.6. References

- Baran, B., Pace-Schott, E. F., Ericson, C., & Spencer, R. M. C. (2012). Processing of Emotional Reactivity and Emotional Memory over Sleep. *The Journal of Neuroscience*, 32(3), 1035–1042. <https://doi.org/10.1523/JNEUROSCI.2532-11.2012>
- Baselgia, S., Combetaldi, S. L., Fahr, A., Wirz, D. S., Ort, A., & Rasch, B. (2023). Pre-sleep arousal induced by suspenseful series and cliffhangers have only minor effects on sleep: A sleep laboratory study. *Sleep Medicine*, 102, 186–198. <https://doi.org/10.1016/j.sleep.2023.01.005>
- Beck, J., Cordi, M. J., & Rasch, B. (2021). Hypnotic Suggestions Increase Slow-Wave Parameters but Decrease Slow-Wave Spindle Coupling. *Nature and Science of Sleep*, 13, 1383–1393. <https://doi.org/10.2147/NSS.S316997>
- Beck, J., Loretz, E., & Rasch, B. (2023). Stress dynamically reduces sleep depth: Temporal proximity to the stressor is crucial. *Cerebral Cortex*, bhac055. <https://doi.org/10.1093/cercor/bhac055>
- Besedovsky, L., Cordi, M., Wißlicen, L., Martínez-Albert, E., Born, J., & Rasch, B. (2022). Hypnotic enhancement of slow-wave sleep increases sleep-associated hormone secretion and reduces sympathetic predominance in healthy humans. *Communications Biology*, 5(1). <https://doi.org/10.1038/s42003-022-03643-y>
- Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., & Mednick, S. C. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences*, 106(25), 10130–10134. <https://doi.org/10.1073/pnas.0900271106>
- Carr, M., & Nielsen, T. (2015). Morning REM Sleep Naps Facilitate Broad Access to Emotional Semantic Networks. *Sleep*, 38(3), 433–443. <https://doi.org/10.5665/sleep.4504>
- Cordi, M. J., Hirsiger, S., Mérillat, S., & Rasch, B. (2015). Improving sleep and cognition by hypnotic suggestion in the elderly. *Neuropsychologia*, 69, 176–182. <https://doi.org/10.1016/j.neuropsychologia.2015.02.001>
- Cordi, M. J., Rossier, L., & Rasch, B. (2020). Hypnotic Suggestions Given Before Nighttime Sleep Extend Slow-Wave Sleep as Compared to a Control Text in Highly Hypnotizable Subjects. *International Journal of Clinical and Experimental Hypnosis*, 68(1), 105–129. <https://doi.org/10.1080/00207144.2020.1687260>
- Cordi, M. J., Schlarb, A. A., & Rasch, B. (2014). Deepening sleep by hypnotic suggestion. *Sleep*, 37(6), 1143–1152. <https://doi.org/10.5665/sleep.3778>
- Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, 11(2), 114–126. <https://doi.org/10.1038/nrn2762>
- Efinger, L., Thuillard, S., & Dan-Glauser, E. S. (2019). Distraction and reappraisal efficiency on immediate negative emotional responses: Role of trait anxiety. *Anxiety, Stress, & Coping*, 32(4), 412–427. <https://doi.org/10.1080/10615806.2019.1597859>
- Endo, S., Kobayashi, T., Yamamoto, T., Fukuda, H., Sasaki, M., & Ohta, T. (1981). Persistence of the Circadian Rhythm of REM Sleep: A Variety of Experimental Manipulations of the Sleep-Wake Cycle. *Sleep*, 4(3), 319–328. <https://doi.org/10.1093/sleep/4.3.319>
- Fairholme, C. P., & Manber, R. (2015). Sleep, Emotions, and Emotion Regulation. In *Sleep and Affect* (pp. 45–61). Elsevier. <https://doi.org/10.1016/B978-0-12-417188-6.00003-7>
- Feriante, J., & Singh, S. (2025). REM Rebound Effect. In *StatPearls*. StatPearls Publishing. <http://www.ncbi.nlm.nih.gov/books/NBK560713/>
- Goldstein, A. N., & Walker, M. P. (2014). The Role of Sleep in Emotional Brain Function. *Annual Review of Clinical Psychology*, 10(1), 679–708. <https://doi.org/10.1146/annurev-clinpsy-032813-153716>
- Görtelmeyer, R. (2011). *SF-A/R und SF-B/R - Schlaffragebogen A und B*. Hogrefe.
- Gujar, N., McDonald, S. A., Nishida, M., & Walker, M. P. (2011). A Role for REM Sleep in Recalibrating the Sensitivity of the Human Brain to Specific Emotions. *Cerebral Cortex (New York, NY)*, 21(1), 115–123. <https://doi.org/10.1093/cercor/bhq064>
- Halonen, R., Kuula, L., Makkonen, T., Kauramäki, J., & Pesonen, A.-K. (2021). Self-Conscious Affect Is Modulated by Rapid Eye Movement Sleep but Not by Targeted Memory Reactivation—A Pilot Study. *Frontiers in Psychology*, 12, 730924. <https://doi.org/10.3389/fpsyg.2021.730924>

- Halonen, R., Kuula, L., Selin, M., Suutari, A., Antila, M., & Pesonen, A.-K. (2024). REM Sleep Preserves Affective Response to Social Stress—Experimental Study. *eNeuro*, 11(6). <https://doi.org/10.1523/ENEURO.0453-23.2024>
- Hornung, O. P., Regen, F., Danker-Hopfe, H., Schredl, M., & Heuser, I. (2007). The Relationship Between REM Sleep and Memory Consolidation in Old Age and Effects of Cholinergic Medication. *Biological Psychiatry*, 61(6), 750–757. <https://doi.org/10.1016/j.biopsych.2006.08.034>
- Hornung, O. P., Regen, F., Schredl, M., Heuser, I., & Danker-Hopfe, H. (2006). Manipulating REM sleep in older adults by selective REM sleep deprivation and physiological as well as pharmacological REM sleep augmentation methods. *Experimental Neurology*, 197(2), 486–494. <https://doi.org/10.1016/j.expneurol.2005.10.013>
- Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). *The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications*. American Academy of Sleep Medicine.
- Irwin, M. R. (2015). Why Sleep Is Important for Health: A Psychoneuroimmunology Perspective. *Annual Review of Psychology*, 66(1), 143–172. <https://doi.org/10.1146/annurev-psych-010213-115205>
- Lange, T., Dimitrov, S., & Born, J. (2010). Effects of sleep and circadian rhythm on the human immune system. *Annals of the New York Academy of Sciences*, 1193(1), 48–59. <https://doi.org/10.1111/j.1749-6632.2009.05300.x>
- Lara-Carrasco, J., Nielsen, T. A., Solomonova, E., Levrier, K., & Popova, A. (2009). Overnight emotional adaptation to negative stimuli is altered by REM sleep deprivation and is correlated with intervening dream emotions. *Journal of Sleep Research*, 18(2), 178–187. <https://doi.org/10.1111/j.1365-2869.2008.00709.x>
- Lipinska, G., Austin, H., Moonsamy, J. R., Henry, M., Lewis, R., Baldwin, D. S., Thomas, K. G. F., & Stuart, B. (2022). Preferential consolidation of emotional reactivity during sleep: A systematic review and meta-analysis. *Frontiers in Behavioral Neuroscience*, 16. <https://doi.org/10.3389/fnbeh.2022.976047>
- Lipinska, G., Stuart, B., Thomas, K. G. F., Baldwin, D. S., & Bolinger, E. (2019). Preferential Consolidation of Emotional Memory During Sleep: A Meta-Analysis. *Frontiers in Psychology*, 10. <https://doi.org/10.3389/fpsyg.2019.01014>
- Mantua, J., & Spencer, R. M. C. (2017). Exploring the nap paradox: Are mid-day sleep bouts a friend or foe? *Sleep Medicine*, 37, 88–97. <https://doi.org/10.1016/j.sleep.2017.01.019>
- McEntire, D. M., Kirkpatrick, D. R., Kerfeld, M. J., Hambsch, Z. J., Reisbig, M. D., Agrawal, D. K., & Youngblood, C. F. (2014). Effect of sedative-hypnotics, anesthetics and analgesics on sleep architecture in obstructive sleep apnea. *Expert Review of Clinical Pharmacology*, 7(6), 787–806. <https://doi.org/10.1586/17512433.2014.966815>
- Mendoza-Alvarez, M., Balthasar, Y., Verbraecken, J., Claes, L., Van Someren, E., Van Marle, H. J. F., Vandekerckhove, M., & De Picker, L. (2025). Systematic review: REM sleep, dysphoric dreams and nightmares as transdiagnostic features of psychiatric disorders with emotion dysregulation - Clinical implications. *Sleep Medicine*, 127, 1–15. <https://doi.org/10.1016/j.sleep.2024.12.037>
- Miller, K. E., & Gehrman, P. R. (2019). REM Sleep: What Is It Good For? *Current Biology*, 29(16), R806–R807. <https://doi.org/10.1016/j.cub.2019.06.074>
- Nicassio, P. M., Mendlowitz, D. R., Fussell, J. J., & Petras, L. (1985). The phenomenology of the pre-sleep state: The development of the pre-sleep arousal scale. *Behaviour Research and Therapy*, 23(3), 263–271. [https://doi.org/10.1016/0005-7967\(85\)90004-X](https://doi.org/10.1016/0005-7967(85)90004-X)
- Nishida, M., Pearsall, J., Buckner, R. L., & Walker, M. P. (2009). REM Sleep, Prefrontal Theta, and the Consolidation of Human Emotional Memory. *Cerebral Cortex*, 19(5), 1158–1166. <https://doi.org/10.1093/cercor/bhn155>
- Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data. *Computational Intelligence and Neuroscience*, 2011, 1–9. <https://doi.org/10.1155/2011/156869>
- Pace-Schott, E. F., Shepherd, E., Spencer, R. M. C., Marcello, M., Tucker, M., Propper, R. E., & Stickgold, R. (2011). Napping promotes inter-session habituation to emotional stimuli.

- Neurobiology of Learning and Memory*, 95(1), 24–36. <https://doi.org/10.1016/j.nlm.2010.10.006>
- Pagel, P., & Parnes, B. L. (2007). Medications for the Treatment of Sleep Disorders: An Overview. *Primary Care Companion to The Journal of Clinical Psychiatry*, 1, 3(3), 118.
- Palmer, C. A., & Alfano, C. A. (2017). Sleep and emotion regulation: An organizing, integrative review. *Sleep Medicine Reviews*, 31, 6–16. <https://doi.org/10.1016/j.smrv.2015.12.006>
- Peever, J., & Fuller, P. M. (2017). The Biology of REM Sleep. *Current Biology*, 27(22), R1237–R1248. <https://doi.org/10.1016/j.cub.2017.10.026>
- Perslev, M., Darkner, S., Kempfner, L., Nikolic, M., Jennum, P. J., & Igel, C. (2021). U-Sleep: Resilient high-frequency sleep staging. *Npj Digital Medicine*, 4(1), 72. <https://doi.org/10.1038/s41746-021-00440-5>
- Poe, G. R., Walsh, C. M., & Bjorness, T. E. (2010). Cognitive neuroscience of sleep. In *Progress in Brain Research* (Vol. 185, pp. 1–19). Elsevier. <https://doi.org/10.1016/B978-0-444-53702-7.00001-4>
- Rasch, B., & Born, J. (2013). About Sleep's Role in Memory. *Physiological Reviews*, 93(2), 681–766. <https://doi.org/10.1152/physrev.00032.2012>
- Rawson, G., & Jackson, M. L. (2024). Sleep and Emotional Memory: A Review of Current Findings and Application to a Clinical Population. *Current Sleep Medicine Reports*, 10(3), 378–385. <https://doi.org/10.1007/s40675-024-00306-8>
- Reinhold, F. L., Gerlicher, A. M. V., van Someren, E. J. W., & Kindt, M. (2022). Do your troubles today seem further away than yesterday? On sleep's role in mitigating the blushing response to a reactivated embarrassing episode. *Sleep*, 45(11), zsac220. <https://doi.org/10.1093/sleep/zsac220>
- Schäfer, S. K., Wirth, B. E., Staginnus, M., Becker, N., Michael, T., & Sopp, M. R. (2020). Sleep's impact on emotional recognition memory: A meta-analysis of whole-night, nap, and REM sleep effects. *Sleep Medicine Reviews*, 51, 101280. <https://doi.org/10.1016/j.smrv.2020.101280>
- Shor, R. E., & Orne, E. C. (1963). Norms on the Harvard Group Scale of Hypnotic Susceptibility, Form A. *International Journal of Clinical and Experimental Hypnosis*, 11(1), 39–47. <https://doi.org/10.1080/00207146308409226>
- Steyer, R. (1997). *Der Mehrdimensionale Befindlichkeitsfragebogen MDBF [Multidimensional mood questionnaire]*. (Hogrefe). Hogrefe.
- van der Helm, E., & Walker, M. P. (2009). Overnight Therapy? The Role of Sleep in Emotional Brain Processing. *Psychological Bulletin*, 135(5), 731–748. <https://doi.org/10.1037/a0016570>
- Vandekerckhove, M., & Cluydts, R. (2010). The emotional brain and sleep: An intimate relationship. *Sleep Medicine Reviews*, 14, 219–226. <https://doi.org/doi:10.1016/j.smrv.2010.01.002>
- Vandekerckhove, M., & Wang, Y. (2018). Emotion, emotion regulation and sleep: An intimate relationship. *AIMS Neuroscience*, 1(1), 1–22. <https://doi.org/10.3934/Neuroscience.2018.1.1>
- Wagner, U., Gais, S., & Born, J. (2001). Emotional Memory Formation Is Enhanced across Sleep Intervals with High Amounts of Rapid Eye Movement Sleep. *Learning & Memory*, 8(2), 112–119. <https://doi.org/10.1101/lm.36801>
- Wassing, R., Benjamins, J. S., Talamini, L. M., Schalkwijk, F., & Van Someren, E. J. W. (2019). Overnight worsening of emotional distress indicates maladaptive sleep in insomnia. *Sleep*, 42(4), zsy268. <https://doi.org/10.1093/sleep/zsy268>
- Wassing, R., Lakbila-Kamal, O., Ramautar, J. R., Stoffers, D., Schalkwijk, F., & Van Someren, E. J. W. (2019). Restless REM Sleep Impedes Overnight Amygdala Adaptation. *Current Biology: CB*, 29(14), 2351–2358.e4. <https://doi.org/10.1016/j.cub.2019.06.034>
- Webb, W. B., Agnew, H. W., & Sternthal, H. (1966). Sleep during the early morning. *Psychonomic Science*, 6(6), 277–278. <https://doi.org/10.3758/BF03328065>
- Werner, G. G., Schabus, M., Blechert, J., Kolodyazhniy, V., & Wilhelm, F. H. (2015). Pre- to postsleep change in psychophysiological reactivity to emotional films: Late-night REM sleep is associated with attenuated emotional processing. *Psychophysiology*, 52(6), 813–825. <https://doi.org/10.1111/psyp.12404>
- Werner, G. G., Schabus, M., Blechert, J., & Wilhelm, F. H. (2021). Differential Effects of REM Sleep on Emotional Processing: Initial Evidence for Increased Short-term Emotional Responses and Reduced Long-term Intrusive Memories. *Behavioral Sleep Medicine*, 19(1), 83–98. <https://doi.org/10.1080/15402002.2020.1713134>

- Wiesner, C. D., Pulst, J., Krause, F., Elsner, M., Baving, L., Pedersen, A., Prehn-Kristensen, A., & Göder, R. (2015). The effect of selective REM-sleep deprivation on the consolidation and affective evaluation of emotional memories. *Neurobiology of Learning and Memory*, 122, 131–141. <https://doi.org/10.1016/j.nlm.2015.02.008>

6.7. Supplementary material

Can hypnotic suggestions and circadian manipulations increase REM sleep and REM-related emotional processing? A proof-of-concept study.

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Figure S1: A) Minutes spent in REM sleep in both conditions (hypnosis, control) for high, medium and low hypnotisable subjects, separated for groups (morning, midday naps): no differences were observed (all p -values > 0.400). **B) SWS in both conditions (hypnosis, control) for high, medium and low hypnotisable subjects, separated for groups (morning, midday naps):** in morning naps, participants spent significantly less time in SWS in the hypnosis condition than in the control condition ($F_{1,23} = 4.60, p = 0.043$). In midday naps, the interaction between conditions and hypnotisability was significant ($F_{2,21} = 4.17, p = 0.030$). Post-hoc pairwise comparisons were not significant (all p -values > 0.092). Means $\pm$ standard errors of the means are displayed. *: $p < 0.05$.

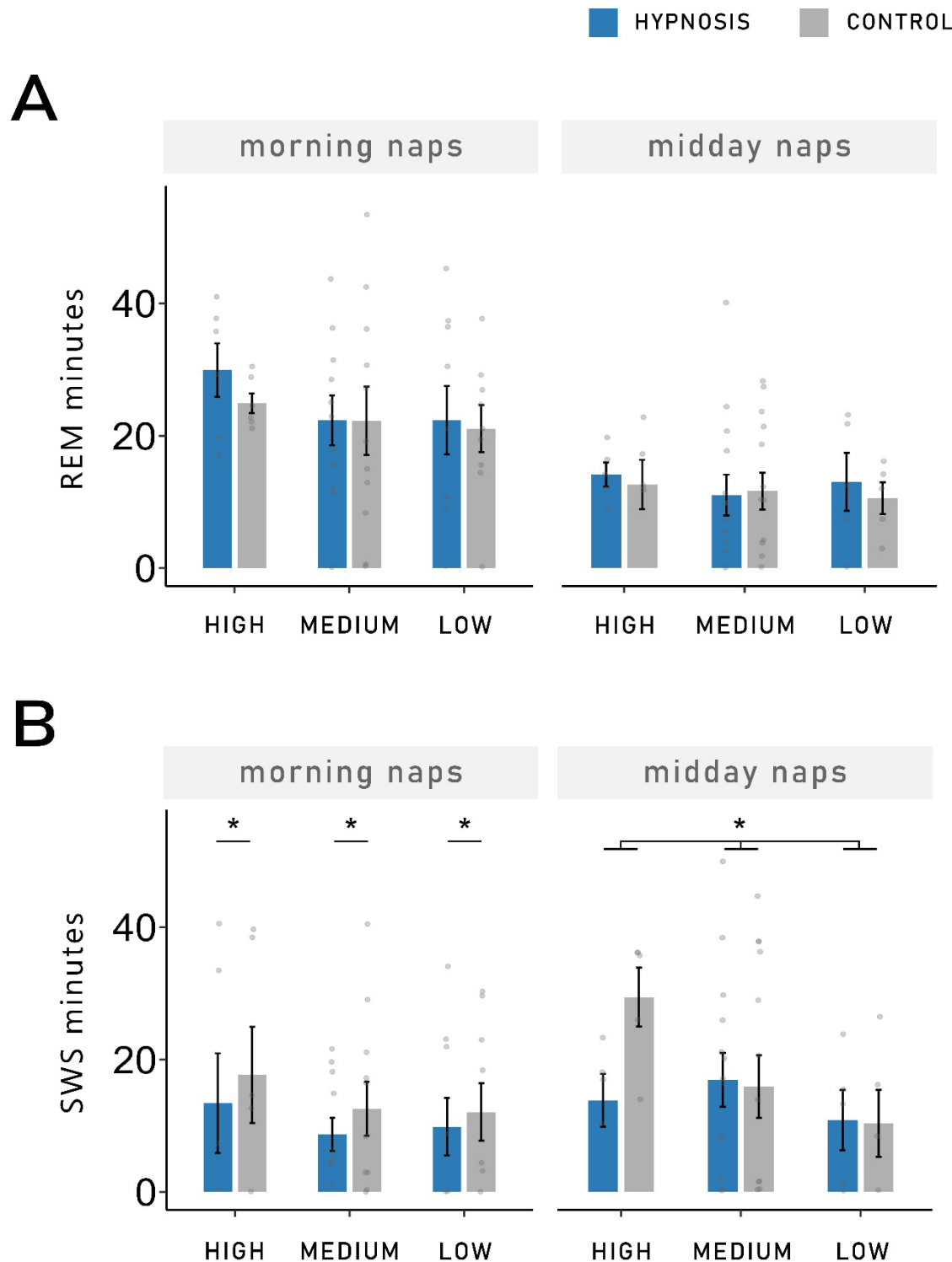


Table S2: Subjective and objective sleep parameters in the morning naps, in the hypnosis and control conditions, separated for hypnotisability.

	High hypnotisable			Medium hypnotisable			Low hypnotisable			Main effect of condition		Main effect of hypnotisability		Interaction	
	Hypnosis	Control		Hypnosis	Control		Hypnosis	Control		p	η^2	p	η^2	p	η^2
Subjective Sleep Parameters															
Sleep Quality	4.21 ± 0.07	3.94 ± 0.21		3.38 ± 0.24	3.40 ± 0.25		3.59 ± 0.23	3.48 ± 0.23		0.526	<0.01	0.053 ^a	0.14	0.825	<0.01
SOL	14.17 ± 3.75	23.33 ± 5.87		16.36 ± 2.95	18.64 ± 2.95		21.11 ± 4.47	17.22 ± 2.65		0.395	0.01	0.891	<0.01	0.243	0.06
Objective Sleep Parameters															
TST [min]	95.67 ± 3.82	94.50 ± 3.07		89.86 ± 3.52	86.77 ± 7.00		91.61 ± 5.11	88.94 ± 4.86		0.516	<0.01	0.590	0.03	0.976	<0.01
WASO [%]	3.08 ± 1.18	10.72 ± 7.42		10.15 ± 4.19	5.65 ± 1.81		6.80 ± 2.16	4.08 ± 1.39		0.956	<0.01	0.775	0.01	0.163	0.06
N1 [%]	6.43 ± 1.04	5.62 ± 1.40		9.55 ± 1.05	9.34 ± 1.80		9.29 ± 1.40	8.56 ± 1.28		0.459	<0.01	0.207	0.10	0.937	<0.01
N2 [%]	45.05 ± 2.34	39.03 ± 5.61		46.45 ± 3.77	48.75 ± 4.51		48.38 ± 3.24	51.31 ± 5.23		0.930	<0.01	0.386	0.06	0.457	0.02
SWS [%]	13.95 ± 7.57	18.20 ± 7.15		9.65 ± 2.75	13.44 ± 3.93		12.04 ± 5.46	13.23 ± 4.75		0.078	0.01	0.810	0.02	0.717	<0.01
REM [%]	31.48 ± 4.23	26.48 ± 1.68		24.19 ± 4.20	22.80 ± 5.13		23.48 ± 5.61	22.81 ± 3.99		0.365	<0.01	0.623	0.03	0.793	<0.01
WASO [min]	3.08 ± 1.18	10.50 ± 7.53		8.00 ± 2.54	4.68 ± 1.61		6.61 ± 2.15	3.17 ± 0.72		0.920	<0.01	0.817	0.01	0.115	0.08
N1 [min]	6.17 ± 1.08	5.17 ± 1.20		8.41 ± 0.85	7.32 ± 1.07		8.83 ± 1.49	7.44 ± 1.13		0.127	0.03	0.243	0.09	0.975	<0.01
N2 [min]	42.08 ± 2.90	36.25 ± 4.36		42.45 ± 4.27	39.95 ± 3.03		44.00 ± 3.62	45.22 ± 4.97		0.240	0.01	0.643	0.03	0.398	0.02
SWS [min]	13.42 ± 7.52	17.67 ± 7.28		8.68 ± 2.51	12.55 ± 4.08		9.83 ± 4.37	12.06 ± 4.35		0.043	0.02	0.735	0.02	0.860	<0.01
REM [min]	29.92 ± 4.04	24.92 ± 1.47		22.32 ± 3.76	22.27 ± 5.16		22.33 ± 5.18	21.06 ± 3.56		0.400	<0.01	0.610	0.03	0.723	<0.01
SWS lat [min]	61.17 ± 17.69	58.50 ± 14.01		56.27 ± 10.42	56.91 ± 9.76		56.17 ± 10.79	57.67 ± 10.50		0.972	<0.01	0.978	<0.01	0.946	<0.01
REM lat [min]	52.58 ± 3.76	57.00 ± 6.40		46.36 ± 7.26	43.59 ± 7.22		57.83 ± 5.75	54.17 ± 4.57		0.882	<0.01	0.259	0.08	0.763	<0.01
SOL [min]	8.92 ± 3.67	7.75 ± 2.70		11.91 ± 1.94	14.32 ± 4.28		13.89 ± 4.55	11.50 ± 2.39		0.888	<0.01	0.474	0.04	0.708	0.01

Notes: Subjective parameters are based on subjective ratings in the SF-A/R questionnaires. Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), sleep onset latency (SOL), SWS latency, REM sleep latency are measured in minutes, and percentages indicate partial percentage of total sleep time (TST). Values are means and standard errors of the mean. Significant results are highlighted in bold. ^a indicates $p \leq .06$. η^2 represents the effect sizes where a value below or equal to .02 reflects a small effect, a value between .02 and .14 reflects a medium effect, and a value above .14 reflects a large effect.

Table S3: Subjective and objective sleep parameters in the midday naps, in the hypnosis and control conditions, separated for hypnotisability.

	High hypnotisable		Medium hypnotisable		Low hypnotisable		Main effect of condition		Main effect of hypnotisability		Interaction	
	Hypnosis	Control	Hypnosis	Control	Hypnosis	Control	<i>p</i>	η^2	<i>p</i>	η^2	<i>p</i>	η^2
Subjective Sleep Parameters												
Sleep Quality	2.87 ± 0.39	3.34 ± 0.42	3.42 ± 0.18	3.51 ± 0.22	3.08 ± 0.20	3.22 ± 0.21	0.198	0.02	0.447	0.06	0.637	0.01
SOL	17.00 ± 5.61	19.00 ± 4.85	18.57 ± 2.64	21.07 ± 3.79	28.00 ± 8.00	36.00 ± 6.00	0.052 ^a	0.02	0.135	0.16	0.460	<0.01
Objective Sleep Parameters												
TST [min]	83.00 ± 8.21	95.90 ± 3.07	83.96 ± 5.67	88.29 ± 3.50	77.60 ± 7.02	88.40 ± 2.48	0.018	0.07	0.765	0.02	0.521	0.02
WASO [%]	7.30 ± 4.28	2.76 ± 0.70	9.51 ± 2.57	6.83 ± 1.42	9.24 ± 2.55	12.72 ± 6.80	0.607	<0.01	0.385	0.06	0.435	0.03
N1 [%]	8.78 ± 2.64	6.08 ± 1.27	11.39 ± 1.88	10.35 ± 1.47	11.06 ± 2.31	11.56 ± 1.16	0.446	<0.01	0.346	0.07	0.711	<0.01
N2 [%]	49.54 ± 4.14	47.62 ± 4.11	47.91 ± 3.78	52.64 ± 3.45	49.68 ± 3.80	52.16 ± 4.50	0.651	<0.01	0.904	<0.01	0.751	0.01
SWS [%]	17.22 ± 4.50	30.86 ± 4.93	18.84 ± 4.20	17.28 ± 5.26	14.64 ± 5.89	11.40 ± 5.54	0.347	<0.01	0.486	0.06	0.089	0.04
REM [%]	17.18 ± 1.77	12.70 ± 3.67	12.36 ± 3.20	12.92 ± 3.15	15.38 ± 4.77	12.14 ± 2.91	0.484	0.01	0.835	<0.01	0.762	0.01
WASO [min]	6.60 ± 4.05	2.60 ± 0.64	8.29 ± 2.47	5.82 ± 1.14	6.90 ± 1.78	11.50 ± 6.40	0.787	<0.01	0.495	0.04	0.331	0.04
N1 [min]	7.30 ± 2.35	5.70 ± 1.11	8.79 ± 1.25	8.86 ± 1.13	8.40 ± 1.71	10.20 ± 0.99	0.924	<0.01	0.410	0.06	0.438	0.02
N2 [min]	41.20 ± 5.82	45.60 ± 4.04	39.00 ± 3.58	46.11 ± 3.22	38.50 ± 4.89	45.90 ± 3.63	0.125	0.06	0.971	<0.01	0.949	<0.01
SWS [min]	13.80 ± 3.99	29.40 ± 4.46	16.89 ± 4.09	15.89 ± 4.75	10.80 ± 4.56	10.30 ± 5.08	0.085	0.02	0.436	0.06	0.030	0.06
REM [min]	14.10 ± 1.81	12.60 ± 3.73	11.00 ± 3.08	11.61 ± 2.79	13.00 ± 4.37	10.50 ± 2.40	0.706	<0.01	0.866	<0.01	0.882	<0.01
SWS lat [min]	41.70 ± 15.32	20.00 ± 1.96	39.21 ± 8.37	47.11 ± 10.08	41.30 ± 15.76	53.10 ± 15.57	0.946	<0.01	0.558	0.03	0.369	0.04
REM lat [min]	45.10 ± 6.32	62.90 ± 6.37	66.68 ± 5.60	67.14 ± 5.28	57.90 ± 2.89	64.30 ± 7.17	0.173	0.05	0.163	0.09	0.438	0.04
SOL [min]	12.70 ± 4.28	8.50 ± 3.07	11.32 ± 1.61	11.29 ± 2.62	21.90 ± 6.97	16.60 ± 2.65	0.116	0.03	0.148	0.13	0.413	0.02

Notes: Subjective parameters are based on subjective ratings in the SF-A/R questionnaires. Objective values are based on polysomnographic recordings. Sleep stages N1, N2, slow-wave sleep (SWS), rapid-eye movement (REM) sleep, wake after sleep onset (WASO), sleep onset latency (SOL), SWS latency, REM sleep latency are measured in minutes, and percentages indicate partial percentage of total sleep time (TST). Values are means and standard errors of the mean. Significant results are highlighted in bold. ^a indicates $p \leq .06$. η^2 represents the effect sizes where a value below or equal to .02 reflects a small effect, a value between .02 and .14 reflects a medium effect, and a value above .14 reflects a large effect.

Supplementary results:

For completeness, we report here the results of interaction effects involving the factor group from the main analyses of objective and subjective sleep parameters (see *Effects of hypnotic suggestions on REM sleep parameters* in the main text). Significant interactions between group (morning vs midday naps) and condition (hypnosis vs control) were found for the time spent in N2 sleep ($F_{1,44} = 4.23$, $p = 0.046$, $\eta^2 = 0.03$; see Figure S3A) and for total sleep time (TST; $F_{1,44} = 5.23$, $p = 0.027$, $\eta^2 = 0.03$; see Figure S3B). Post-hoc comparisons revealed that participants in midday naps slept less (82.44 ± 3.89 min) and showed less N2 sleep (39.35 ± 2.52 min) in the hypnosis condition than in the control condition (TST: 89.90 ± 2.24 min; $t_{23} = -2.32$, $p = 0.029$, $d = 0.475$; N2: 45.96 ± 2.12 min; $t_{23} = -1.96$, $p = 0.062$, $d = 0.401$); while no difference was observed in morning naps (both p -values > 0.317). No other significant effects were found in objective sleep parameters (all p -values > 0.064). Regarding subjective sleep quality, an interaction emerged between the factors group and hypnotisability ($F_{2,44} = 3.11$, $p = 0.055$, $\eta^2 = 0.09$; see Figure S3C), where, in the morning naps, the high group reported a higher subjective sleep quality (4.08 ± 0.11) than both the medium (3.39 ± 0.17 ; $t_{31.83} = 3.34$, $p = 0.002$, $d = 0.996$) and the low group (3.53 ± 0.16 ; $t_{27.78} = 2.81$, $p = 0.009$, $d = 0.951$). The other comparisons were not significant (all p -values > 0.156).

Figure S4: A) Minutes spent in sleep stage N2 and B) total sleep time (TST) in both conditions (hypnosis, control) and both groups (morning, midday naps) for high, medium and low hypnotisable subjects: significant interactions between group and condition were found where participants in midday naps slept less and showed less N2 sleep in the hypnosis condition than in the control condition (TST: $t_{23} = -2.32, p = 0.029$; N2: $t_{23} = -1.96, p = 0.062$). C) Subjective sleep quality: an interaction emerged between the factors group and hypnotisability, where, in the morning naps, the high group reported a higher subjective sleep quality than both the medium and the low group (both p -values < 0.009). The other comparisons were not significant (all p -values > 0.156). Means $\pm$ standard errors of the means are displayed. **: $p < 0.01$; *: $p < 0.05$; +: $p < 0.065$.

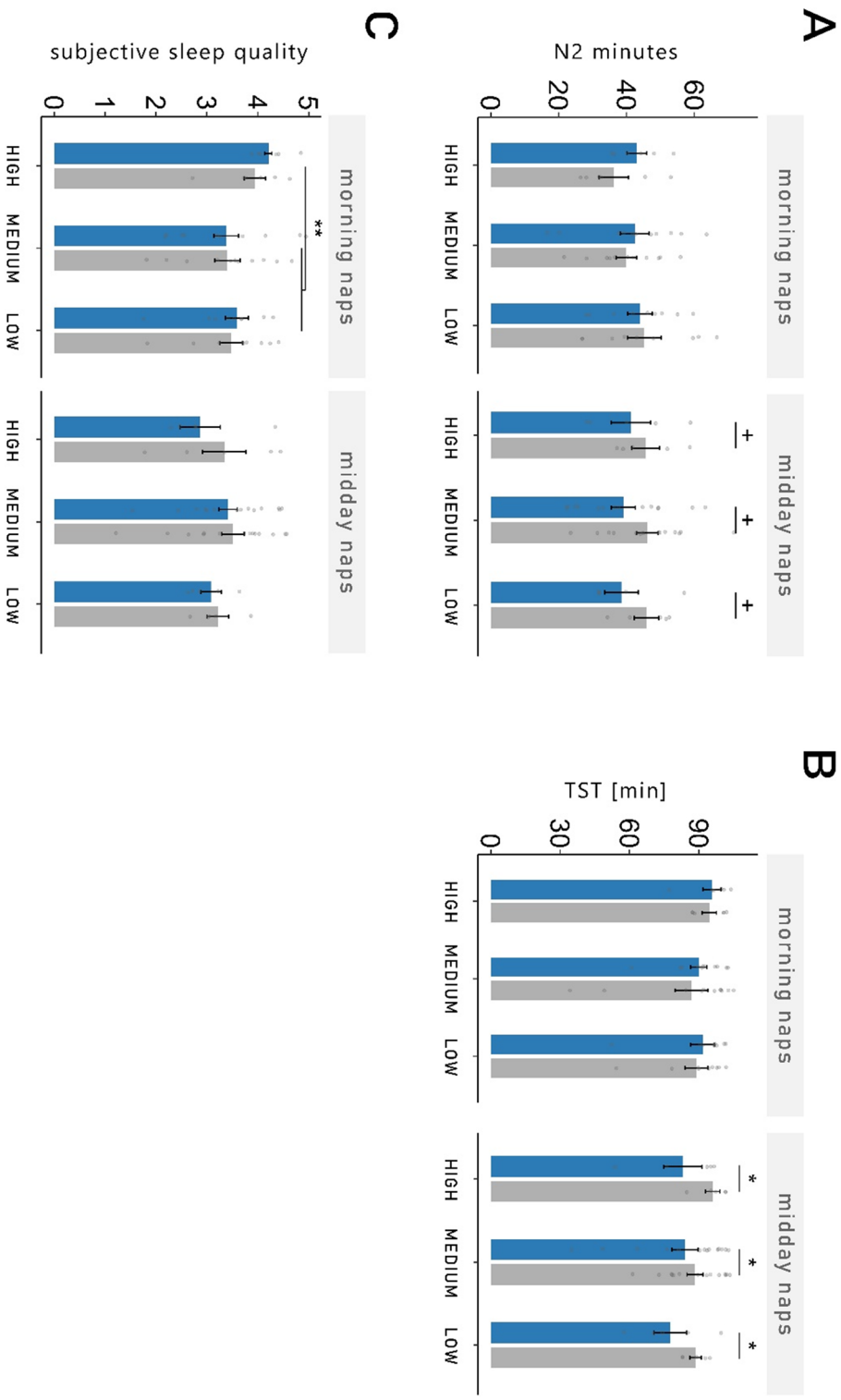
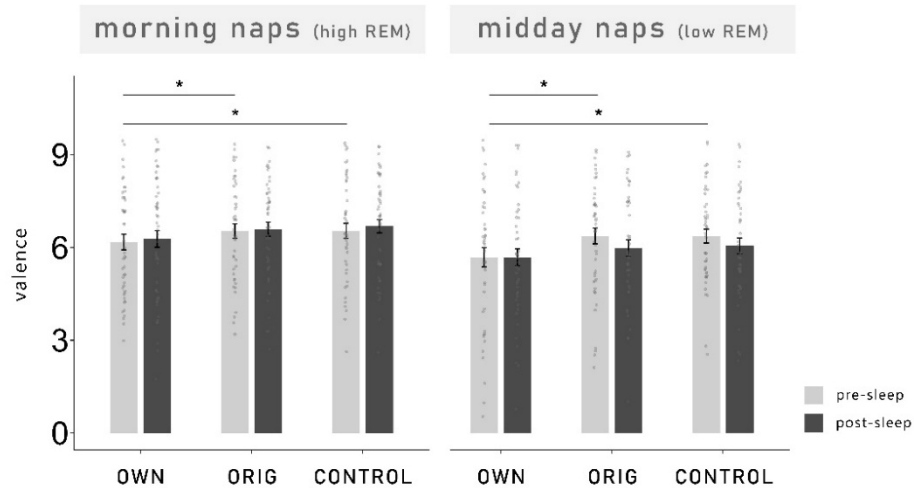
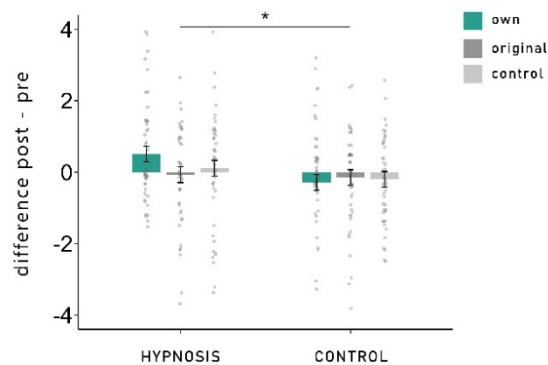


Figure S5: A) Ratings of valence before and after sleep for each group: listening to their own out-of-tune singing led to lower valence ratings compared with both control songs (both p -values = 0.014). However, there was no difference in valence over sleep (all p -values > 0.198). **B) Pre- to post-sleep difference in valence ratings for each song, separated for conditions:** an increase in valence ratings was observed in the hypnosis condition, whereas a decrease was observed in the control condition ($F_{1,232.47} = 5.17, p = 0.024$). No difference emerged between the different songs. **C) Pre- to post-sleep difference in valence ratings for their own singing, separated for hypnotisability:** the difference between both conditions was again significant ($F_{1,84} = 4.77, p = 0.032$), but no main effect of hypnotisability or interaction emerged (both p -values > 0.215). Means $\pm$ standard errors of the means are displayed. *: $p < 0.05$.

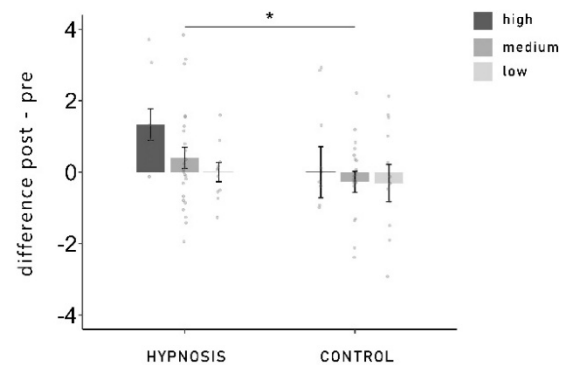
A



B



C



7. Discussion

The aim of the present dissertation was to advance the understanding of how cognitive processes before and during sleep actively shape sleep physiology and subjective experiences. To this end, four empirical studies tested different predictions derived from the MemoSleep hypothesis, providing converging evidence on how waking cognitions influence sleep dynamics and dream experiences, thereby addressing key gaps in the literature. After summarising the main findings, the following discussion first examines how these results provide empirical support for the core mechanism of the MemoSleep hypothesis, while also motivating several theoretically grounded extensions to the original hypothesis. The subsequent section turns to the proposition that dreams may be conceptualised as indicators of reactivation processes during sleep. Finally, the relationship between digital media exposure and sleep is discussed. The discussion concludes with a consideration of general limitations of the present work and open questions that remain to be addressed.

7.1. Summary of the results

Study I examined whether binge-watching suspenseful TV series with and without cliffhangers before sleep would impair sleep through an increased cognitive pre-sleep arousal. Subjective pre-sleep arousal was increased after watching suspenseful content compared to a neutral control documentary, as expected. However, only minor effects were observed on subsequent subjective and objective sleep parameters, with alterations restricted to the first two sleep cycles. Surprisingly, sleep onset latency was even shorter following suspenseful TV series. These findings suggest that, in healthy young adults, the arousal elicited by suspenseful TV content, with or without cliffhangers, does not substantially impair either objective or subjective sleep quality. Nevertheless, the results indicate that, by increasing some aspects of arousal, cliffhangers may still reduce some restorative functions of sleep, such as sleep depth and associated brain oscillations, particularly during the first two sleep cycles. This study thus highlights that unfinished or unresolved cognitive content before sleep can compromise sleep recovery processes by sustaining cognitive engagement beyond sleep onset.

Study II tested whether the reactivation of cognitions during sleep occurs in a time-specific manner, using dream content as an indicator of these reactivation processes. To this end, the effects of pre-sleep and anticipated stress on early and late dreams were compared to pre-sleep or anticipated relaxation. While pre-sleep subjective arousal was increased by both pre-sleep and anticipated stress, there was no increase in the incorporation of stress-related

elements in subsequent dreams. However, evidence for a dynamic reactivation of waking cognitions emerged in other aspects of the dreams, particularly the emotionality. The anticipation of stress led to more stressful dreams in the late sleep period, suggesting that reactivation occurs in temporal proximity to the anticipated event. Unexpectedly, pre-sleep stress led to less stressful dreams in the early sleep period, compared to pre-sleep relaxation. These findings therefore support a dynamic reactivation of cognitions during sleep, observable in dream characteristics.

Study III shifted the focus to positive cognitive activity, postulating that activating the concept of relaxation before sleep improves sleep quality and physiology. By replicating a previous study from our group and introducing a neutral control condition, this study revealed that the anticipation of relaxation may facilitate sleep. While the temporal dynamic observed in our previous work could not be replicated, this study points towards subtle differences in anticipatory implications, even in neutral control conditions. Most importantly, this study highlights the potential of sleep-promoting cognitions for improving sleep quality and further supports the idea that spontaneous reactivations of cognitions during sleep may influence sleep physiology.

Finally, Study IV attempted to modulate REM sleep amount and latency in morning and midday naps, using pre-sleep hypnotic suggestions and circadian manipulation. While circadian manipulation effectively modulated the amount of REM sleep, no effect of REM-targeted hypnotic suggestions was observed on REM sleep. However, SWS was decreased in high hypnotisable subjects. Furthermore, no overall evidence was found for a functional role of REM sleep in emotional regulation; however exploratory analyses suggested a potential differential involvement of morning and midday REM sleep. This study highlights the limits of cognitive influences over biological regulation of sleep, while contributing to a more nuanced understanding of the relationship between REM sleep and emotional processing.

Taken together, these findings invite a theoretical interpretation within the framework of the MemoSleep hypothesis, using the results to evaluate its core assumptions.

7.2. Evaluating and extending the MemoSleep hypothesis

In this section, the present findings are evaluated in the context of the MemoSleep hypothesis. As introduced earlier, the MemoSleep hypothesis proposes that pre-sleep cognitions are likely to be reactivated during subsequent sleep, and that such reactivation triggers associated

physiological responses, thereby influencing sleep physiology and architecture. First, the results are examined in terms of how they provide support for the reactivation of cognitions during sleep. While the four studies contribute to the relevance of the MemoSleep hypothesis, they also help delineate its current limitations, particularly regarding its scope of application. Consequently, building on this evaluation, the discussion proposes several extensions to the original hypothesis. Finally, the theoretical and clinical implications of the proposed extensions are outlined.

7.2.1. Empirical support for the MemoSleep hypothesis

Following a brief overview of how the MemoSleep hypothesis refines classical insomnia models, the present findings are evaluated in how they provide empirical support for the reactivation of cognitions during sleep, as proposed in the MemoSleep hypothesis. Alternative accounts of cognitive activity during sleep are also considered. While the original MemoSleep hypothesis was formulated in terms of sleep physiology, this section also considers findings on dreams, under the assumption that dreams can reflect underlying cognitive reactivation processes. This theoretical extension is developed in detail in section 7.3. *Dreams and reactivation processes during sleep.*

As introduced earlier, pre-sleep cognitive arousal, characterised by intrusive thoughts, worry, rumination or active mental processing, is a central feature of theoretical models of insomnia. In classical models, heightened cognitive activity at bedtime is assumed to interfere with the de-arousal process necessary for sleep onset (e.g., Espie, 2002; Harvey, 2002; Perlis et al., 1997; Riemann et al., 2010). While these models explain delayed sleep initiation, they offer limited explanatory power for sleep disruptions that emerge after sleep onset. Even when heightened arousal delays sleep onset, individuals typically do fall asleep, a process that necessarily involves a downregulation of sympathetic activation (Biabani et al., 2023; Okamoto-Mizuno et al., 2008; Shinar et al., 2006). Consequently, mechanisms other than persistent physiological arousal must contribute to in-sleep disturbances. The MemoSleep hypothesis offers such a mechanism by proposing that pre-sleep embodied, wake-related memories can be reactivated beyond sleep onset, thereby engaging associated neural and physiological processes after sleep initiation. Importantly, the hypothesis generates the prediction that experimentally biasing cognitive activity before sleep should influence subsequent sleep, even after sleep has begun. Studies I, II and III were designed to test this prediction by manipulating different forms of wake-related cognitions before sleep, including

suspense, stress and the anticipation of stress, and examining their effects on subsequent sleep physiology and dream characteristics.

Empirical support for this mechanism is first provided by Study I. In this study, suspenseful cliffhangers shortened sleep onset latency, indicating a successful transition into sleep. However, alterations emerged in early-night sleep architecture and physiology, despite conditions that allowed sleep initiation. This pattern suggests that unresolved narrative tension was reactivated after sleep onset, rather than being carried over as sustained pre-sleep arousal. In this context, lighter sleep appears to reflect ongoing cognitive reactivation during sleep, rather than residual sympathetic activation preventing de-arousal. This pattern refines several insomnia models that emphasise the role of physiological arousal, whether alone or in interaction with cognitive arousal, in sleep disturbances (Espie, 2002; Espie et al., 2006; Harvey, 2002; Riemann et al., 2010). Instead, it supports the notion that cognitive reactivation during sleep can modulate sleep physiology independently of pre-sleep physiological activation. These results thus align with previous literature showing that cognitive load before sleep can influence sleep physiology beyond sleep onset (e.g., Čapková et al., 2018; Takahashi & Arito, 1994; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). Converging evidence for this interpretation is provided by Study II, in which anticipatory stress influenced dream characteristics even though the anticipated stressor had not yet occurred. This finding suggests that the activation of the semantic concept alone may be sufficient to shape subsequent sleep and dream quality, further supporting the idea that pre-sleep cognitive activity can persist in reactivated form during sleep and influence sleep and dream characteristics.

Beyond demonstrating that cognitive reactivation can occur independently of physiological arousal, Studies II and III further show that such reactivation is temporally specific, emerging when contextually relevant. Anticipatory cognitions involve sustained cognitive preoccupation that intensifies as the anticipated event approaches (Kramer et al., 2022; Ouwehand et al., 2008) and engage persistent mental simulations of future scenarios (Engert et al., 2013; Kramer et al., 2022). In Study II, anticipatory stress selectively affected late-night dreams, producing higher stress intensity and a more negative emotional tone. This pattern suggests that cognitive reactivation during sleep is not uniform but emerges when the cognitive content becomes contextually relevant, in a manner that parallels wakeful anticipation. A similar temporal dynamic was reported at the physiological level in previous work from our group, where the anticipation of post-sleep stress or relaxation impacted sleep depth in temporal proximity to the anticipated event (Beck et al., 2023). Together, these findings

suggest that cognitive reactivation during sleep is dynamically modulated by the anticipated relevance of cognitive material, rather than being uniformly expressed across sleep. This temporal specificity is consistent with research on self-awakening, which shows that the cognitive intention to wake at a specific time is sufficient to elicit anticipatory changes in physiological parameters several minutes up to an hour before the intended awakening time (Born et al., 1999; Ikeda & Hayashi, 2008; Kaida et al., 2003, 2005). Importantly, this temporal specificity cannot be explained by classical insomnia models, which primarily emphasise cognitive processes occurring during wakefulness, whether before sleep or during nocturnal awakenings (Espie, 2002; Espie et al., 2006; Harvey, 2002; Spielman et al., 1987). Thus, they offer limited explanatory power for effects that emerge during late-night sleep, while individuals remain asleep.

Findings from Study II further suggest that this mechanism may not be restricted to negatively valenced or stressful experiences, providing empirical support for the MemoSleep assumption that a range of wake-related cognitions can influence subsequent sleep through reactivation processes. In contrast, classical models of insomnia primarily emphasise negatively valenced cognitive and emotional states as drivers of sleep disturbances (e.g., Espie, 2002; Harvey, 2002; Spielman et al., 1987). However, in Study II, pre-sleep stress did not lead to more negative dreams during the early sleep period, despite evidence from previous studies that similar stress manipulations alter physiological markers of arousal during sleep (Ackermann et al., 2019; Beck et al., 2023; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012). The MemoSleep hypothesis offers a potential resolution to this discrepancy, as it predicts that sleep may be influenced by the reactivation of wake-related cognitions, irrespective of its emotional valence. In this view, the early dreams observed in Study II may reflect a reappraisal of the stressful experience, where the stressor is perceived as resolved or no longer threatening. Even though the emotional tone of the dreams is neutral or positive, reactivation of wake-related cognitive content can still engage arousal-related neural and physiological networks, explaining why physiological effects of pre-sleep stress could potentially co-occur with non-negative dream content. Importantly, these effects still depended on the pre-sleep manipulation, indicating that dream content is sensitive to the cognitive material present before sleep. These findings are thus consistent with the MemoSleep hypothesis, which proposes that sleep disruption can arise from the reactivation of any wake-related cognitive representation, as it engages wake-like neural and physiological processes. However, these interpretations remain speculative and future studies combining dream reports and physiological measures are needed

to test whether positive dream content following pre-sleep stress is accompanied by alterations in sleep depth or physiological activation.

One key contribution of the MemoSleep hypothesis is its consideration of sleep-promoting cognitions as potential modulators of sleep, where sleep-related cognitions, such as relaxation or rest, may enhance sleep quality. By replicating a previous study from our group on anticipated stress vs. relaxation (Beck et al., 2023), Study III allowed to directly test this prediction by isolating the effects of activating the semantic concept of relaxation before sleep. Even without performing any actual relaxation, anticipating post-sleep relaxation still increased sleep quality and depth, implying a sleep-promoting effect. Importantly, these effects occurred in the absence of measurable differences in pre-sleep somatic arousal, indicating that the benefits arose from the cognitive-semantic activation of relaxation that re-emerged during sleep, rather than from physiological relaxation before sleep. These findings suggest a complement to classical insomnia models: pre-sleep cognitive activity can not only disrupt sleep through reactivation processes during sleep, but certain sleep-promoting cognitions may conversely enhance sleep quality. This perspective integrates with prior models of insomnia, such as Lundh & Broman (2000), who identify sleep-interfering processes, including cognitive ones, that predispose and maintain a state of hyperarousal incompatible with sleep. Based on our results, it can be speculated that complementary sleep-promoting (cognitive) processes may counteract such hyperarousal (see also Paller et al., 2021). However, it should be noted that in Study IV, REM-sleep-promoting hypnotic suggestions did not lead to an increase in REM sleep duration, suggesting that the effects of sleep-promoting cognitions may be more constrained by biological factors than sleep-disrupting ones and that REM sleep may be less susceptible to cognitive manipulation than other sleep stages (see 7.5. *General limitations*).

Although the present findings provide converging evidence in support of the MemoSleep hypothesis, alternative accounts of cognitive activity during sleep remain conceivable and require explicit evaluation. Indeed, two main alternative accounts can be postulated: (1) there is no reactivation of cognitive material during sleep; and (2) cognitive activity remains continuously active during sleep. In the first account, sleep would be conceptualised as a state in which waking cognitions are largely inactive and with minimal influence on sleep processes. Sleep would thus be primarily for restorative or homeostatic functions (e.g., Adam & Oswald, 1977; Oswald, 1980), and cognitive activity from prior wakefulness would not contribute to sleep processes in any meaningful way. Well-documented memory reactivation processes during sleep demonstrate that waking cognitive activity is not

fully suspended but is re-engaged during sleep (Diekelmann & Born, 2010; Rasch & Born, 2013), however, it remains unclear whether broader, non-mnemonic cognitive content is reactivated. The present work specifically aimed to support this extension and, while the studies do not directly measure neural reactivation, the observed effects on dream- and sleep-related measures are inconsistent with the view that waking cognitions are entirely inactive during sleep. A recent study also supports the MemoSleep assumption of cognitive reactivation by demonstrating neural reinstatement of pre-sleep material during REM sleep (Kumral et al., 2025). A second alternative to the reactivation process is that pre-sleep cognitions remain continuously active throughout the night rather than being reactivated at specific time points. This view is theoretically plausible and could align with models emphasising persistent cognitive arousal (e.g., Riemann et al., 2010). However, as discussed above, several lines of research suggest that cognitive influences during sleep may be temporally specific rather than uniform. For example, pre-sleep stress has been shown to modulate sleep physiology primarily in the early sleep period (Ackermann et al., 2019; Beck et al., 2023; Wuyts, De Valck, Vandekerckhove, Pattyn, Bulckaert, et al., 2012), and the intention to wake at a particular time can selectively alter sleep parameters near the expected waking time (Born et al., 1999; Ikeda & Hayashi, 2008; Kaida et al., 2003, 2005). Results from Study II complement these findings as dream content varied systematically across conditions and groups, suggesting that the effects of pre-sleep cognitive activity emerge at specific points during the night rather than being continuously activated.

Overall, the studies presented in this dissertation provide empirical support for the core assumption of the MemoSleep hypothesis that pre-sleep cognitive activity can be reactivated during sleep and influence ongoing sleep processes. The present results situate the MemoSleep framework within a broader body of work highlighting the enduring influence of pre-sleep cognitive activity on sleep, such as the perseverative cognition hypothesis (Brosschot et al., 2006), which proposes that cognitive representations of stressors can prolong physiological effects, including during sleep (Brosschot et al., 2007; Verkuil et al., 2011). By proposing that such persistence may operate, at least in part, through reactivations during sleep, this work converges with prior evidence that pre-sleep cognitions can modulate sleep physiology (e.g., Ackermann et al., 2019; Beck, Cordi, et al., 2021; Beck et al., 2023; Cordi et al., 2020; Feng et al., 2023). By supporting the MemoSleep hypothesis, the present results also refine classical insomnia models in several important ways. First, they show that cognitive and physiological arousal are partially dissociable, with cognitive activation exerting effects on sleep even when

physiological arousal has subsided. Second, the findings reveal a temporal specificity of these effects, where reactivated cognitions influence sleep and dreams in a contextually specific manner rather than being continuously maintained across the night. Third, they indicate that this mechanism is not restricted to negatively valenced experiences but applies more broadly to wake-related cognitive states. Finally, the results invite for the consideration of sleep-promoting cognitions as being beneficial for sleep quality. Taken together, these findings support the idea that cognitive reactivation during sleep may be a key mechanism in the modulation of sleep. Importantly, they motivate theoretical extensions of the MemoSleep hypothesis, which are discussed in the next section.

7.2.2. Extensions of the MemoSleep hypothesis

While the findings discussed above support the core mechanism proposed by the MemoSleep hypothesis, they also suggest several refinements and extensions. First, I propose a broader conceptualisation of reactivation beyond memory processes to include a wider range of cognitions. Second, the present findings suggest that the likelihood for a cognition to be reactivated during sleep is not only dependent on its recency or strength, but also on its salience. Finally, I propose to include dream experiences in the hypothesis, and view them as indicators of the reactivation processes during sleep.

7.2.2.1. From memory to cognition: broadening the scope of reactivation

The first extension proposed is to broaden the range of reactivated material outlined by the MemoSleep hypothesis beyond memory traces. The initial formulation of the hypothesis was grounded in the active system consolidation framework, which describes how memories are reactivated during sleep to support their consolidation (Diekelmann & Born, 2010). Consequently, the MemoSleep hypothesis primarily focused on the reactivation of wake- and sleep-related memories. However, across the studies presented in this work, systematic effects on sleep and dream characteristics emerged in the absence of explicitly learned declarative material before sleep. Instead, experimental manipulations primarily targeted abstract cognitive-emotional states, such as stress, anticipation, or unresolved narrative tension. These manipulations altered sleep and dream outcomes even when no discrete memory trace was available for reactivation, suggesting that a broader spectrum of pre-sleep cognitions and emotional states can undergo spontaneous reactivation during sleep. Extending the framework

beyond memory traces would allow to capture cognitive-emotional material that can remain mentally active during sleep, including perceptual contexts or emotional states that may not be encoded as discrete memories. This interpretation aligns with previous accounts that have suggested that reactivation during sleep may extend beyond discrete memories, involving overlapping schemas and integrated memory networks (Lewis & Durrant, 2011; Wamsley, 2022). Under this extended framework, the term “memories” may therefore be insufficient to capture the diversity of cognitive and affective material that can be reactivated and influence sleep and dreams, motivating a shift towards a terminology that encompasses a wider range of pre-sleep mental states.

The motivation to broaden the hypothesis beyond memory traces is specifically supported by the frequent incorporation of the experimental context into dreams in Study II, suggesting that laboratory environment and experimental procedures were spontaneously reactivated during sleep. The phenomenon of “laboratory dreams” may be conceptually linked to the first-night effect (FNE), where sleep quality is typically reduced during the initial night in a novel environment (Ding et al., 2022). Both effects could reflect a form of continued monitoring of contextually relevant cognitions, such as novelty, uncertainty, or perceived threat (Tamaki et al., 2016). Within the MemoSleep framework, it is predicted that the embodied cognitions of “novelty” and “danger” during sleep in a novel environment are reactivated, resulting in changes in sleep architecture and reduced sleep quality (Rasch, 2016). Accordingly, both the FNE and laboratory dreams may illustrate the fact that broad conceptual representations, beyond discrete episodic memories, can persist into sleep and influence both sleep physiology and dreaming. No study to date has specifically investigated the influence of FNE on dreams. Future studies may want to explore whether the incorporation of laboratory elements into dreams covaries with physiological markers of arousal or sleep fragmentation. It would be particularly worthwhile to characterise the time course of laboratory-related dreams, to determine whether they are evenly distributed across the night, as suggested by the idea of a “night watch” system that remains active across the entire night (Tamaki et al., 2016) or whether they are concentrated in particular sleep stages or time periods.

7.2.2.2. Salience-dependent reactivation: emotional and personal significance

The second proposition of extension of the MemoSleep hypothesis is to consider a salience-based view of sleep-related reactivations, in which salience is understood as arising

from multiple factors, including emotional relevance, personal significance, motivational importance and contextual novelty. Under this view, the likelihood that a given cognitive or emotional state is reactivated during sleep depends not only on its recency, but also on its emotional relevance and personal significance. This is consistent with prior work suggesting that emotionally relevant material may be preferentially processed and reactivated during sleep (e.g., Payne & Kensinger, 2010; Van der Helm & Walker, 2009) and incorporated into dreams (e.g., Malinowski & Horton, 2014a; Schredl, 2006). Importantly, the proposed salience-based mechanism does not overrule the effect of recency but modulates it: recency remains a contributing factor to sleep-related reactivations, but its influence is weighted by salience. Moreover, this broader conceptualisation accommodates individual differences in how pre-sleep experiences influence subsequent sleep. Because individuals differ in how they interpret, evaluate and respond to waking experiences, the content and intensity of what is reactivated during sleep are likely to depend on these subjective appraisals rather than on objective features of the experience alone. This perspective may provide an explanation for why certain waking experiences can continue to influence sleep and dreams while others do not, even when they occur in close temporal proximity to sleep onset.

The laboratory dreams observed in Study II also illustrate this second extension. Indeed, the laboratory situation constitutes a novel and salient experience (Picard-Deland, Nielsen, et al., 2021) and is known to be frequently incorporated into dreams in experimental settings (Picard-Deland, Nielsen, et al., 2021; Schredl, 2008). Consistent with prior work showing that current concerns and emotional significant experiences are preferentially incorporated into dream content (Baylor & Cavallero, 2001; Hoelscher et al., 1981; Malinowski & Horton, 2021; Nikles et al., 1998), laboratory-related elements were frequently reported in dreams from Study II. Notably, laboratory incorporations occurred more often than stress-related content (24.96% vs. 14.68%), an effect already reported in previous findings (Picard-Deland, Nielsen, et al., 2021). This pattern suggests that the likelihood of incorporation was not determined solely by the experimental manipulation, but also by the subjective salience of the context in which participants slept. The novelty and attentional demands of the laboratory setting may therefore have constituted the most salient cognitive elements during sleep, shaping dream content independently of the intended stress manipulation. These findings support a salience-based account of reactivation, in which cognitively prominent contexts persist into sleep and influence dream experiences.

Converging evidence for a salience-based reactivation mechanism can be drawn from Study III, in which sleep quality was unexpectedly poorer in the neutral control condition than in the anticipated stress condition. One possible explanation for these findings is that when participants anticipated leaving the laboratory immediately after the nap, this may have inadvertently facilitated the reactivation of personally relevant thoughts, such as academic, social, or daily obligations. Consequently, this suggests that participants' own ongoing concerns carried greater subjective salience, leading to stronger sleep disruption than the experimentally induced stress. Thus, a condition defined as "neutral" experimentally may have provided the opportunity for highly salient personal cognitions to dominate sleep-associated processing. However, this interpretation remains speculative, as subjective responses to the neutral condition were not assessed. Nonetheless, together with the findings from Study II, this pattern supports the view that reactivation during sleep may be guided not only by experimental valence and recency, but by the personal relevance and emotional significance of pre-sleep cognitive material, highlighting cognitive-emotional salience as a key determinant of reactivation during sleep.

7.2.2.3. Dreams as windows into cognitive reactivation

The third proposed extension is motivated by findings from Study II, which suggest that dreams may provide valuable information on the reactivation process proposed in the MemoSleep hypothesis. While the original formulation did not include explicit predictions about dreaming, the present findings indicate that dreams may be meaningfully integrated into the framework. Specifically, Study II showed that dream characteristics were differentially influenced by distinct pre-sleep manipulations: pre-sleep stress was associated with changes in dreams occurring in the early part of the night, whereas anticipated post-sleep stress primarily affected dreams from the late part of the night. This temporal specificity suggests that the influence of stress-related cognitions on dreaming depends on their temporal proximity to the stressor, plausibly reflecting the reactivation of these cognitions during sleep. These findings raise the possibility that reactivation processes during sleep may be partially expressed in dream content and characteristics, thereby providing an additional window into reactivation mechanisms. This proposition is examined in detail in section 7.3. *Dreams and reactivation processes during sleep.*

7.2.3. *Theoretical and clinical implications of the extended MemoSleep framework*

Overall, the present findings support three extensions to the MemoSleep hypothesis: (1) reactivation encompasses a broad range of cognitions, including but not only memories; (2) the likelihood and impact of reactivation are not only modulated by recency, but also by salience, including emotional and personal relevance of experiences; and (3) dreams should be incorporated into the hypothesis as reflections of reactivation processes during sleep. These refinements integrate and extend the original framework, providing further understanding of how pre-sleep mental activity shapes both sleep physiology and dream experiences. Having established these extensions, several theoretical and clinical implications for understanding cognitive activity and its role in sleep disturbances can be derived. These implications are outlined in the present section as theoretical propositions that invite further empirical investigation, starting with the conceptualisation of cognitive activity across sleep as a continuum rather than as a categorical phenomenon. This continuum naturally accommodates inter-individual differences in cognitive reactivation during sleep. Finally, the clinical relevance of these insights is highlighted, including the use of dreams as indicators of in-sleep cognition and the identification of promising targets for cognitive interventions.

First, by extending the concept of cognitive reactivation to encompass a broader range of cognitions that can persist into sleep and shape sleep processes, the present findings support a continuum perspective of cognitive activation across sleep, rather than a categorical distinction between normal sleep and pathological cognitive overactivation (e.g., Harvey, 2002; Spielman et al., 1987). Within this framework, cognition during sleep is not defined solely by its presence or absence but varies along three continuous dimensions: (1) intensity, (2) content, and (3) functional impact. Regarding the dimension of intensity, the cognitive overactivation observed in individuals with insomnia (e.g., Tang et al., 2023) can be understood as one end of a continuous dimension of cognitive activation, rather than as an abnormal deviation from healthy sleep. This view is consistent with Espie's revised model (Espie, 2023), which conceptualises sleep-related cognition along a continuum from hyperarousal to de-arousal, the latter representing the prerequisite for sleep initiation rather than the absence of hyperarousal.

The second continuous dimension concerns the content of cognitive activity during sleep. The extended MemoSleep framework encourages a content-based continuum view, supported by evidence demonstrating that activating sleep-related cognitions before and during sleep can enhance physiological sleep depth (Beck, Cordi, et al., 2021; Beck, Loretz, et al., 2021). Cognitive activation would thus span a continuum from sleep-interfering to sleep-

promoting forms of cognition. Existing theoretical models support this logic. For example, Beaudoin's cognitive model of sleep onset and insomnia (Beaudoin, 2014) distinguishes between insomnolent and hypersomnolent cognitions: insomnolent cognitions are defined as goal-directed, emotionally salient, and self-referential thought patterns that sustain wakefulness, whereas hypersomnolent cognitions are spontaneous and associative supporting the cognitive shift towards sleep onset. Although Beaudoin's model primarily addresses the wake-sleep transition, it recognises the significance of cognitive form and content in sleep initiation. The extended MemoSleep hypothesis applies the same principles to in-sleep cognition, proposing that sleep-promoting cognitive representations activated before sleep can be spontaneously reactivated during sleep and have beneficial impact on it. From this perspective, pre-sleep cognitions not only shape the transition into sleep but continue to structure the mental and emotional landscape of sleep itself.

The third continuous dimension concerns the functional impact of cognitive activity, namely whether a given form of cognition interferes with or supports sleep processes. Importantly, the same level or type of cognitive activation may have different functional consequences across individuals or contexts. Taken together, framing cognitive activity across sleep as a multidimensional continuum provides a conceptual foundation for understanding the heterogeneity of sleep complaints, in which individuals may differ not only in the intensity of cognitive activation, but also in its qualitative content and functional consequences.

Within this continuum perspective, the extended MemoSleep framework highlights the role of individual differences and vulnerabilities in sleep-related cognitive processing. These differences would arise because cognitive reactivation during sleep is not only determined by recency, but also modulated by the salience, emotional intensity, and personal relevance of waking cognitions. Consequently, the specific cognitions reactivated during sleep are expected to differ across individuals as a function of their personal history, cultural background and biographical context. Notably, such inter-individual variability may not be detectable at the group level, particularly in resilient populations or under conditions of limited or acute exposure. Consistent with this view, the present findings suggest that sleep in healthy young adults is relatively robust: aside from subtle alterations, neither acute stress nor a single binge-watching session before sleep produced substantial impairments, indicating that isolated exposures to such interventions may have limited impact on sleep in this population. However, this apparent robustness does not preclude increased susceptibility in individuals with specific traits or vulnerabilities, nor does it rule out cumulative effects of repeated or chronic exposure.

For example, binge-watching has been associated with mental health problems (Alimoradi et al., 2022), which may account in the relationship between digital media consumption and sleep outcomes (Lemola et al., 2015). Therefore, within the continuum perspective proposed above, individual vulnerabilities or repeated challenges may shift cognitive activity during sleep towards levels that interfere with sleep and contribute to disturbances such as insomnia.

On the clinical level, an important implication of the proposed extensions is that dreams may serve as a valuable indicator of mental activity during sleep. By providing access to the subjective content of sleep, dream reports may offer a unique window into which cognitions and emotional concerns are being reactivated and processed once sleep has begun. Within the extended MemoSleep framework, this suggests that dreams may reflect ongoing cognitive dynamics that are relevant for sleep quality. This perspective has implications across a range of clinical contexts. In sleep disorders such as insomnia or nightmares, dream content may provide insight into persistent pre-sleep cognitions or unresolved concerns that continue to shape sleep beyond sleep onset (see for e.g., Delage et al., 2024; Schredl et al., 1998). More broadly, in mental health conditions such as anxiety or depression, dreams may offer information about the emotional themes and cognitive material that remain active during sleep, potentially reflecting maladaptive processing or heightened salience of specific concerns (see for e.g., Rimsh & Pietrowsky, 2020; Solomonova et al., 2021). Integrating dream evaluation alongside objective sleep measures could therefore enrich both theoretical models and clinical assessments by capturing aspects of sleep-related cognition that are not accessible through physiological markers alone.

Finally, another clinical implication concerns the target of cognitive interventions. Whereas traditional cognitive models of insomnia have primarily focused on the suppression or control of negative pre-sleep thoughts (e.g., Harvey, 2003; Harvey & Payne, 2002; Ree et al., 2005; Schmidt et al., 2011), the present work suggests that deliberately fostering positive, sleep-congruent cognitions, such as anticipating rest, comfort, or safety, may actively promote restorative sleep processes. This opens a promising avenue for cognitive and behavioural interventions, suggesting that therapeutic approaches might focus on modulating, rather than suppressing, cognitive activity to promote restorative sleep. In practice, such interventions could aim to reshape the content of pre-sleep thoughts, for example by modifying their salience or emotional load and by actively cultivating adaptive, sleep-promoting mental states. Consequently, interventions could target not only the intensity but also the qualitative content of pre-sleep cognition. Rash et al. (2019) have considered mindfulness-based interventions to

promote sleep, arguing that they facilitate psychological flexibility which would allow better coping with sleep-interfering cognitive activity. If this proposition does not attempt to suppress negative pre-sleep thoughts, it offers only an indirect mechanism to influence cognitive activity. Within the MemoSleep framework, this logic is extended by explicitly emphasising the role of positive, sleep-congruent cognitions in shaping sleep, providing a theoretical rationale for interventions that could actively cultivate adaptive mental states and complement approaches that primarily focus on reducing pre-sleep arousal.

In sum, the extensions proposed to the MemoSleep hypothesis generate several important implications. They support a multidimensional continuum of cognitive activation across sleep, encompassing intensity, content, and functional impact, which accommodates individual differences and vulnerabilities to sleep disturbance. Clinically, these insights highlight the value of dreams as indicators of in-sleep mental content and point to promising avenues for interventions that actively modulate cognitive activity to promote restorative sleep. By framing cognitive activation as a continuum, this perspective also opens the door to future research exploring which types of cognition are most sleep-promoting and how interventions can be tailored to individual needs. Building on this framework, the following section examines in greater detail the proposition that dreams may reflect underlying reactivation processes during sleep and evaluates their potential role as empirical markers of cognitive reactivation.

7.3. Dreams and reactivation processes during sleep

In the previous section, dreams were proposed as a potential window into reactivation processes during sleep. This extension was motivated by results from Study II, which suggest that dream characteristics are influenced by pre-sleep manipulations in a temporally specific manner, possibly reflecting the reactivation of cognitions during sleep. Accordingly, the aim of the present section is to integrate the empirical findings from Study II within existing theoretical and empirical work on dreaming to propose a coherent framework for understanding dreams as indicators of cognitive reactivation during sleep. First, dreams are examined in relation to memory reactivation processes, a central component of the MemoSleep hypothesis. While some aspects of dreaming are consistent with memory-related reactivation, I propose that dreams may be better understood as reflections of broader cognitive and emotional reactivation, including memory traces. This is followed by an examination of the temporal dynamics observed in Study II, demonstrating that the content and emotional tone of dreams shift systematically across the

night in ways that point to distinct underlying sources of reactivation. Given the central role of REM sleep in dreaming, the subsequent part focuses specifically on REM dreams and their involvement in emotional processing, integrating findings from Study IV. Taken together, these arguments support a model in which dreams may, at least in part, emerge from the interaction of multiple forms of cognitive-emotional reactivation, modulated notably by sleep stage, temporal dynamics, and ongoing concerns. This interpretation is summarised in the final part of this section, alongside the consideration of alternative accounts, as well as open questions.

7.3.1. From memory replay to broader cognitive reactivation in dreams

Although the original formulation of the MemoSleep hypothesis primarily focused on the physiological consequences of reactivation, I propose to extend this notion to dreaming, on the premise that dream mentation constitutes the phenomenological reflection of ongoing cognitive-emotional activity during sleep. Because the MemoSleep hypothesis is rooted in models of active memory consolidation, a natural starting point for considering the role of dreams in this framework is the literature linking dreaming to memory reactivation during sleep. Several accounts have proposed that dreams reflect memory consolidation processes (e.g., Horton & Malinowski, 2015; Wamsley, 2014), raising the possibility that dream mentation could provide an empirical window into reactivation mechanisms. Since the present work proposes to extend the MemoSleep hypothesis beyond strictly memory-based reactivation to encompass a broader range of cognitive and emotional processes, the following section first examines evidence relating dreams to memory reactivation as a theoretical baseline, before considering whether dream experiences more broadly reflect ongoing cognitive-emotional reactivation beyond memory.

Correlational evidence suggests that dream content can, in some cases, reflect and contribute to sleep-associated memory processing. For example, participants who report dreaming about a pre-sleep learning task showed greater gains in post-sleep performance (e.g., Hudachek & Wamsley, 2023; Picard-Deland, Aumont, et al., 2021; Plailly et al., 2019; Schoch et al., 2019; Wamsley, 2014; Wamsley, Tucker, et al., 2010; Wamsley & Stickgold, 2019). These findings are often interpreted as evidence for a functional role of dreams in sleep-associated memory processing and thus, that the dream itself participates in or facilitates consolidation. However, such interpretations rely on the assumption that the conscious expression of reactivated material in dreams is causally involved in memory processing, rather

than co-occurring with underlying reactivation processes. Targeted memory reactivation (TMR) studies have experimentally tested this interpretation: the presentation during sleep of cues linked to learned material can increase the likelihood of task-related elements appearing in dreams (Konkoly et al., 2025; Picard-Deland, Aumont, et al., 2021; Picard-Deland & Nielsen, 2022), and influence dream characteristics (Carr et al., 2023; Mundt et al., 2025; Schwartz et al., 2022). However, such changes are not consistently accompanied by improved next-day performance. Moreover, several limitations moderate the interpretation of these findings. Reports of memory-related dream incorporation occur in only a minority of dreamers (see also Nguyen et al., 2013), and results suffer from interpretative confounds, including individual differences in emotional engagement, motivation, baseline performance, and dream recall propensity (Konkoly et al., 2025). Beyond these concerns, recent findings show that, although neural reinstatement of pre-sleep material can occur during REM sleep and is more pronounced in individuals who dream about the learned content, this reinstatement is not associated with improved next-day memory retention (Kumral et al., 2025; see also Wamsley et al., 2016). This pattern challenges the interpretation that the appearance of task-related material in dreams functionally contributes to effective memory consolidation. Crucially, the reactivation of task-related neural patterns during sleep predict memory stabilisation in studies that do not assess dream content (for a review see Brodt et al., 2023). This suggests that the reactivation of cognitions during sleep is primarily a physiological process that may not require conscious dream experience to exert its effect on memory. At the same time, the appearance of task-related elements in dreams indicates that dream experience can reflect cognitive reactivation processes, including mnemonic ones, without implying a direct functional role in consolidation. Accordingly, I propose that dreaming may be best understood as a phenomenological manifestation of cognitive reactivation, encompassing memory-related as well as broader cognitive and emotional material.

Supporting this broader view, Study II demonstrated that pre-sleep stress and stress anticipation altered dream characteristics, such as emotional tone and length, without producing direct incorporations of the stressor. This suggests that dreams are sensitive to the overall cognitive-emotional context of sleep, rather than solely reflecting straightforward memory reactivation, which would represent one of several processes that can shape dream construction (see also Wamsley, 2022). Within this perspective, the findings from Study II are consistent with the continuity hypothesis of dreaming, which posits that dreams reflect ongoing concerns, emotions, and cognitive themes from waking life (Bell & Hall, 1971; Domhoff, 1996, 2003).

In Study II, the emergence of more negative and distressing late-night dreams under stress anticipation fits well within this continuity framework: participants' concern about the upcoming stressor appears to have shaped the emotional tone of their late-night dreams, even in the absence of explicit stress-related imagery.

However, earlier work has suggested that the continuity hypothesis, in its broad and descriptive form, cannot fully explain why some waking experiences are incorporated into dreams while others are not (e.g., Schredl, 2000; Schredl & Hofmann, 2003). Evidence has shown that incorporation depends on the emotional investment and personal significance of the events (e.g., Eichenlaub, Van Rijn, Phelan, et al., 2018; Malinowski & Horton, 2014a; Schredl, 2000, 2003, 2006), further supporting the idea that reactivation during sleep, whether memory-related or reflecting other cognitive and emotional processes, is influenced by factors such as emotional salience or personal relevance as proposed earlier (see 7.2.2.2. *Salience-dependent reactivation: ...*). The extended MemoSleep hypothesis thus provides a mechanistic explanation: if emotionally salient concerns are more likely to undergo cognitive reactivation during sleep, these reactivations offer a physiological pathway through which waking concerns can influence dream content and emotional tone. In this integrated view, dreams do not only reflect continuity with waking life; they reflect the selective reactivation of personally relevant cognitions during sleep, thereby linking the continuity theory with sleep-associated neural processes. This theoretical integration is further supported by the temporal dynamics observed in Study II. As detailed in the next section, the emotional tone and thematic characteristics of dreams change systematically across the night, suggesting that different cognitive-emotional representations become accessible at different sleep periods, and providing a further empirical basis for interpreting dreams as indicators of ongoing reactivation processes.

7.3.2. *Temporal dynamics of dreams*

Further supporting the framework proposed above, a key finding of Study II is the temporal organisation observed across the night. Consequently, the aim of this section is to examine how differences in early- and late-night dream characteristics may provide insight into the dynamics of cognitive reactivation during sleep.

Rather than being uniform, dream content and emotional tone shift systematically across the night, suggesting that different forms of cognitive activation dominate at specific times.

This temporally specific pattern aligns with the view that dreaming depends on both circadian fluctuations in global cortical activation and sleep-stage-specific patterns of regional neural activation (Wamsley et al., 2007). Within this framework, general dream characteristics are shaped first by ultradian and circadian activation cycles and further modulated by distinctive regional activity associated with each sleep stage. This would explain why early-night dreams, whether arising from NREM or REM sleep, tend to be more thought-like, less elaborate and less affectively and visually involving than late dreams, which emerge during the circadian peak of cortical activation. At the same time, certain dream features are specific to REM sleep, reflecting characteristic regional activation. For example, the emotional intensity of dreams increases across the night only for dreams collected during REM sleep (Wamsley et al., 2007), likely due to heightened limbic activity in this stage (Braun et al., 1997; Maquet et al., 1996). Moreover, temporal specificity has also been observed in the temporal focus of dreams, with early-night dreams often reflecting immediate residues of recent experiences and late-night dreams more strongly shaped by remote memories as well as future-oriented or prospective cognitions (Picard-Deland et al., 2022, 2023; Wamsley et al., 2024). Study II illustrates this pattern: the effects of completed stress and relaxation were expressed in early dreams, whereas the influence of anticipated stress emerged only in late dreams. This temporal pattern provides insight into the characteristics of cognitive reactivation, suggesting that the accessibility of cognitive and emotional material varies across the night and is mirrored in dream experiences. From the perspective of the extended MemoSleep framework, these dynamics underscore the value of dreams as indicators of ongoing reactivation processes, as the timing of a dream may reveal which types of cognitive material are most influential at that moment.

First, early-night dreams can be examined in terms of which cognitive reactivation processes are most likely to influence dream content at this point in the night. Early-night dreams, which occur predominantly during NREM sleep, often contain elements of pre-sleep learning task (see meta-analysis Hudachek & Wamsley, 2023), and this observation has sometimes been interpreted as support for a role of dreaming in memory consolidation (e.g., Fogel et al., 2018; Hudachek & Wamsley, 2023; Schoch et al., 2019; Wamsley, Tucker, et al., 2010; Wamsley & Stickgold, 2019). However, such interpretations warrant careful consideration since incorporations of pre-sleep learning task into dreams may be influenced by two factors. First, memory reactivation processes are mostly active during NREM sleep, specifically SWS (Rasch & Born, 2013), which primarily unfolds in the early sleep period. Second, early-night dreams, regardless of sleep stage, tend to incorporate recent pre-sleep

experiences, irrespective of their mnemonic relevance (e.g., Kusse et al., 2012; Schredl, 2003; Wamsley, Perry, et al., 2010; Wamsley, Tucker, et al., 2010; Wamsley & Stickgold, 2019). Therefore, the presence of task-related material in early dreams may reflect a combination of sleep-stage-specific memory reactivation and general salience of recent experiences rather than providing a direct or exclusive index of memory consolidation.

On the other hand, the late sleep period is characterised by a shift in brain state that is likely to alter the dynamics of cognitive reactivation. As the night progresses, REM sleep becomes increasingly dominant, accompanied by increases in global cortical activation and shifts in regional activation. While the predominance of REM sleep may bias reactivation processes towards emotionally salient material, likely due to its characteristic limbic activation, this notion is developed in a following section (see 7.3.3. *The role of REM sleep and REM dreams in emotional processing*) and is therefore not addressed here to focus on the hyperassociative nature of REM sleep cognition. Neuroimaging and electrophysiological studies show that REM sleep is associated with widespread cortical activation resembling wakefulness, as evidenced by broadly distributed responses to transcranial magnetic stimulation (Massimini et al., 2010), and engagement of large-scale cortical networks (Achermann et al., 2016; Hong et al., 2009; Uitermarkt et al., 2020). Consequently, such a brain state may support a form of cognitive reactivation that is less focal and more broadly associative. Consistent with this view, cognition upon awakening from REM sleep has been described as highly associative, facilitating the integration of weakly related cognitive elements in novel ways (Stickgold et al., 1999). Importantly, this associative cognition does not appear to be exclusive to REM sleep: late-night NREM sleep has also been associated with increased associative processing, relative to early-night NREM sleep (Walker et al., 2002), suggesting that broader changes in brain state, beyond REM-specific regional activation, may contribute to late-night reactivation dynamics. In line with this interpretation, hyperassociative features of dreaming have been shown to increase as the night progresses (Malinowski & Horton, 2021), mirroring both the growing predominance of REM sleep and the rise in circadian-driven cortical activation. Indeed, cortical excitability increases as a function of circadian phase (Ly et al., 2016), potentially facilitating broader network-level activation regardless of sleep stage. Elevated cortical activation during late-night sleep may therefore facilitate the spread of cognitive reactivation across large-scale networks, allowing initially salient cognitions to activate emotionally or autobiographically related material (see Horton & Malinowski, 2015; Paller et al., 2021). This hyperassociative nature has frequently been used to describe late-night REM dreams (e.g., Horton & Malinowski,

2015; Llewellyn, 2013; Stickgold et al., 2001), which tend to integrate distant, fragmented and conceptually unrelated waking-life material (Horton & Malinowski, 2015; Malinowski & Horton, 2021). From this perspective, late-night dreams may reflect not the replay of a single waking event, but the broader associative reactivation of interconnected cognitive-emotional concerns. Applied to Study II, the anticipation of stress may have been preferentially reactivated during late-night sleep due to its temporal proximity to the upcoming stressor. This reactivation may have propagated to related stress memories or personally relevant experiences (e.g., previous stressful events or evaluative situations), biasing dream emotionality towards more negative affect without necessitating direct representation of the anticipated event. While this interpretation remains speculative and cannot be conclusively established, such findings are consistent with the view that late-night dreams reflect a form of cognitive reactivation that is increasingly associative, integrative, and sensitive to future-oriented concerns.

This view aligns with recent models of dreaming that propose that the broadened associative mode described above enables the formation of links between loosely related past and present memory traces or experiences, links that are less accessible or less likely to occur during wakefulness. For example, the NEXTUP model (Wamsley et al., 2024; Zadra & Stickgold, 2021) suggests that dreaming explores weak associations between recent and remote memories (see also for e.g., Deperrois et al., 2022; Hartmann, 2001; Shuster et al., 2025). These associations are proposed to promote creativity, emotional processing, or memory functions such as abstraction, integration and schema formation (Hartmann, 2010b; Malinowski & Horton, 2015; Wamsley & Stickgold, 2010; Zadra & Stickgold, 2021). In these models, memory traces are rarely directly replayed in dreams; instead they are often reactivated in metaphorical or thematically transformed forms (Hartmann, 2010a; Malinowski & Horton, 2014b, 2015; Picard-Deland et al., 2022; Wamsley, 2022; Wamsley, Perry, et al., 2010). Within this perspective, the increase in negative emotionality observed in late-night dreams in Study II may be understood as a consequence of associative reactivation of stress-related material. Dreams may thus reflect how waking cognitions are integrated and transformed during sleep.

Taken together, these findings indicate that dream experiences vary systematically across the night as a function of both circadian fluctuations in cortical activation and the shifting architecture of NREM and REM sleep. Early-night dreams, emerging during circadian troughs and NREM-dominant periods, tend to be less elaborate, more thought-like and more directly tied to recent waking experiences and memory consolidation processes (e.g., Martin et al., 2020; McNamara et al., 2010; Nielsen, 2000). In contrast, late-night dreams, shaped by heightened

cortical activation and increased associative processing, exhibit greater hyperassociative integration of disparate cognitive and emotional elements (e.g., Horton & Malinowski, 2015; Llewellyn, 2013; Stickgold et al., 2001). Thus, the temporal progression of sleep modulates not only the type of waking material incorporated into dreams but also the qualitative form that dream cognition takes. Although we did not directly examine the memory sources of dreams in Study II, our results also align with prior research indicating that recent memories are preferentially incorporated in early-night dreams, whereas more remote memories or future-oriented cognitions tend to appear towards the end of the night (Picard-Deland et al., 2022; Picard-Deland, Nielsen, et al., 2021). Overall, the temporal dynamics observed in Study II reinforce the extensions of the MemoSleep framework proposed earlier: reactivation, including a broad spectrum of cognitive and emotional material, can be reflected in dream characteristics. Further supporting this interpretation, the next section explores in greater detail the specific role of REM sleep and REM dreams in emotional processing.

7.3.3. The role of REM sleep and REM dreams in emotional processing

Given the central role of REM sleep in dreaming, this section explores the role of REM sleep and REM dreams in emotional processing, providing additional support for the idea that dreams may reflect, at least in part, reactivation processes during sleep. First, REM sleep neurophysiology is considered in terms of the conditions it provides for the reactivation of emotional material, with findings from Study IV supporting this perspective. Next, the characteristics of REM dreams are examined to evaluate how they may reflect the selective reactivation of emotional content during sleep. Overall, this section draws on the association between REM sleep, REM dreaming, and emotional processing to illustrate how dream experience may reflect underlying reactivation processes during sleep. It is important to note that the purpose of this discussion is to illustrate one example of the processes that may occur during REM sleep and REM dreams, without implying that all dreams or all REM dreams serve the same function or are limited to emotional processing.

As introduced earlier, several influential models have proposed that REM sleep supports emotional processing through a specific neurochemical and neurophysiological profile, such as low noradrenergic tone, high cholinergic activity, heightened limbic activation and elevated theta oscillations (e.g., Hutchison & Rathore, 2015; Payne & Kensinger, 2010; Van der Helm & Walker, 2009). For example, the “sleep to forget, sleep to remember” (SFSR) hypothesis

proposes that REM sleep both stabilises the informational content of emotional memories and attenuates their emotional charge. However, recent meta-analyses indicate that sleep does not selectively enhance emotional memory relative to neutral material, nor does REM sleep consistently confer additional retention or emotional dampening effects (Lipinska et al., 2019, 2022; Morgenthaler et al., 2014; Rawson & Jackson, 2024; Schäfer et al., 2020). Consistent with this literature, Study IV found no overall evidence that greater amounts of REM sleep reduced subjective embarrassment, which does not support a simple, uniform link between REM sleep quantity and affective modulation. Nevertheless, exploratory analyses point towards a potential differential involvement of midday and morning REM sleep in emotional processing, suggesting a role for features beyond the quantity of REM sleep. This interpretation aligns with accumulating evidence that qualitative characteristics of REM sleep (e.g., rapid eye movements, noradrenergic decrease, stability), rather than its quantity, provide stronger predictive value in emotional outcomes (Halonen et al., 2021; Mendoza-Alvarez et al., 2025; Miller & Gehrman, 2019). Within this perspective, within-night timing (early vs. late REM sleep) becomes particularly relevant, as these REM episodes differ substantially in their physiological profile: late-night REM sleep is longer, occurs at a later circadian phase associated with increased cortical activation, contains more eye movements, and follows greater amounts of prior NREM sleep. Each of these factors may shape the functional role of REM in emotional processing. Under the full expression of REM-specific neurochemical and physiological features (Antrobus et al., 1995; Endo et al., 1981; Webb et al., 1966), late-night REM sleep may be particularly favourable for the reactivation of emotional material, ultimately supporting its regulation. Rather than supporting a straightforward consolidation of emotional memories, REM sleep may thus provide optimal conditions for the modulation, recalibration, or integration of affective experiences. Importantly, the characteristics of REM dreams may offer a window into how these processes unfold.

As noted above, the emotional profile of dreams varies systematically across the night: although early-night REM and NREM dreams show similar levels of emotionality, late-night REM dreams exhibit markedly higher affective intensity (e.g., Wamsley et al., 2007), a variation confirmed in Study II. These within-night changes mirror the evolving physiological landscape of sleep, driven both by sleep-stage-specific mechanisms and circadian increases in cortical activation. Two broad interpretations can be proposed to explain why late-night REM dreams are especially emotional. One possibility is that dreams themselves play a causal role in emotional regulation, actively processing affective experiences (e.g., Cartwright, 2010;

Cartwright et al., 1984; Hartmann, 2010a; Levin et al., 2010). Alternatively, and in line with recent accounts (Malinowski & Horton, 2021; Palmieri et al., 2025), dream content may reflect the preferential reactivation of emotional material during REM sleep, rather than constituting the mechanism of regulation per se. Based on the evidence reviewed in this dissertation, the latter interpretation appears more compelling. Nevertheless, this does not exclude a functional contribution of dreams: by providing a phenomenological window into reactivation processes, late-night REM dreams may still facilitate the iterative re-experiencing of emotional material in ways that support longer-term affective adjustment (Malinowski & Horton, 2021; Palmieri et al., 2025). These observations align with the results of Study IV, which point to late-night REM sleep as particularly relevant for the processing of emotional experiences. The heightened emotionality of late-night REM dreams is therefore consistent with the proposition that this later REM sleep period may be especially conducive to the neural processes supporting affective recalibration. Similarly, the hyperassociative character of REM sleep cognition discussed in the previous section may index the reorganisation and integration of reactivated material within broader autobiographical and semantic networks, as illustrated in models of post-traumatic dreaming (Hartmann, 1998) and neurocognitive accounts of nightmares (e.g., Levin & Nielsen, 2009; Nielsen & Germain, 2000; Nielsen & Levin, 2007; see also NEXTUP model by Zadra & Stickgold, 2021). Accordingly, late-night REM dream experience may thus be understood as a phenomenological expression of underlying REM-related neurobiological processes that accompany emotional recalibration.

Overall, the evidence reviewed in this section, together with the results of Study IV, suggests that the emotional functions of REM sleep may depend less on the quantity of REM sleep and more on its qualitative features and timing. REM sleep may provide neurophysiological conditions that are particularly favourable for the reactivation of emotionally salient cognitive material. From this perspective, REM dreams may reflect, at least in part, these reactivations and the ways in which they are being processed. Under this assumption, the analysis of the content and characteristics of REM dreams may provide insights into how these reactivations operate and what consequences they have on emotional outcomes.

To move the field forward, testable predictions emerge from this integrated account which conceptualises REM dreams as reflections of reactivation processes during sleep. First, within-night comparison designs could examine whether late-night REM sleep preferentially supports emotional recalibration by assessing affective reactivity before and after REM awakenings at different times of night. Second, future work should investigate how qualitative

features of REM dreams interact with underlying REM physiology: rather than focusing on sleep stage duration, studies may emphasise physiological markers as potential moderators of overnight emotional change. For example, rapid eye movements occurring during REM sleep have been associated with mood disorders such as depression (Palagini et al., 2013; Steiger & Pawlowski, 2019), which suggests that rapid eye movements may serve as markers of, or contributors to, REM-related emotional processing mechanisms (see also Kheirkhah et al., 2025; Maranci et al., 2022). Third, clarifying whether REM dream content plays an active role in emotional processing or merely reflects underlying reactivation processes will require mediation models jointly investigating dream emotionality, REM physiology, and next-day affect. In this context, research on lucid dreaming has shown that deliberate rehearsal of motor actions during lucid REM dreams can enhance subsequent waking performance (Erlacher & Schredl, 2010; Schädlich & Erlacher, 2018; Stumbrys et al., 2016). These findings provide a proof of principle that dream experience can, under certain conditions, function as a simulation space in which reactivated cognitive and motor representations are actively engaged, which contribute to behavioural changes. Whether similar mechanisms extend to emotional processing and non-lucid REM dreams remains an important question for future research. Finally, clinical studies in patients suffering from nightmares remain a particularly relevant context for examining the role of REM dreams in emotional processing. Nightmares may reflect disrupted REM dreaming (Levin & Nielsen, 2009; Nielsen & Germain, 2000; Nielsen & Levin, 2007), and interventions such as imagery rehearsal therapy have been shown to reduce nightmare severity and to be associated with concurrent improvements in depressive, anxiety and post-traumatic stress symptoms (e.g., Maruani et al., 2026; Sheaves et al., 2023). However, the mechanisms linking nightmare resolution to emotional improvements remain unclear. Systematically investigating this relationship may offer a promising paradigm for clarifying the role of REM sleep in emotional processing. Together, these directions provide a roadmap for disentangling how REM dreams and REM physiology may jointly contribute to emotional recalibration, and for clarifying the functional role of dreams across different sleep stages.

7.3.4. Evaluation of alternative accounts and theoretical integration

While the previous sections have examined how dreams may reflect reactivation processes as an extension of the original MemoSleep hypothesis, the current section evaluates alternative interpretations and proposes a theoretical integration of this perspective.

The main alternative account to the proposed extension is that in-sleep reactivation occurs at a non-conscious level, without reaching the phenomenological threshold necessary for incorporation into dream experience. Indeed, studies utilising TMR have shown that cued reactivations can enhance memory consolidation without investigating for corresponding dream imagery or conscious awareness of the cues (e.g., Oudiette & Paller, 2013; Schreiner & Rasch, 2017). However, while this account is theoretically plausible, it appears to be incongruent with the range of phenomena observed in dreams. During wakefulness, distinct thoughts and internally generated mental imagery are associated with differentiable and recognisable neural patterns (Haxby et al., 2001; Horikawa & Kamitani, 2017; Naselaris et al., 2015), suggesting that physiologically meaningful reactivations would be expected to modulate at least some aspects of subjective experience. Consistent with this view, converging evidence indicates that neural activity during sleep reliably shapes dream characteristics (Hobson & McCarley, 1977; Nir & Tononi, 2010; Wamsley, 2014). For example, fluctuations in a posterior “hot zone” predict the presence and complexity of conscious experience in both NREM and REM dreams (Siclari et al., 2017) and dream content has been partially linked to specific neural activity (Kumral et al., 2025). Additionally, experimental manipulations of neural activity through stimulation, sensory cues, or pharmacological interventions reliably alter dream features (for reviews see Carr et al., 2020; Salvesen et al., 2024). Overall, these findings suggest that sleep physiology and subjective cognition are tightly interwoven. While subtle or fragmented reactivation processes may occur without being fully incorporated into dream content, robust cognitive reactivation would be expected to leave detectable traces in dream experience, whether in emotional tone, narrative structure, or qualitative aspects. Consequently, if stress-related cognitions had been meaningfully reactivated during sleep in Study II, they would be expected to influence some aspect of the dream experience, as was indeed observed.

The view that dreams reflect underlying reactivation processes rather than constituting a functionally necessary component of sleep-related processing can also be challenged. Indeed, functional accounts of dreaming posit that dream experience itself is required for certain sleep-related processes to occur. For example, the threat simulation hypothesis proposes that dreaming serves an evolutionary function by simulating threatening situations and allowing the rehearsal of perceptual and behavioural responses in the safety of sleep (Revonsuo, 2000; Revonsuo et al., 2016b; see also social simulation theory; Revonsuo et al., 2016a; Tuominen et al., 2019). While such interpretation may apply to some dreams, it does not account for the substantial proportion of dreams that contain neutral, mundane or even positive content and

therefore appears unlikely to explain the full range of dream experiences. Instead, one possibility is that dreaming provides an internally generated, primarily visual representation that could interact with ongoing sleep-associated processing, without being essential to it. Importantly, dream phenomenology may neither be required, nor uniquely responsible for the underlying processes supporting sleep-associated functions such as memory consolidation, emotional regulation, or cognitive integration. Accordingly, dreams may be conceptualised not as the mechanism of sleep-associated processing, but as a phenomenological layer that can reflect, interact with, or modulate ongoing dynamics. Empirically, addressing this question will require innovative approaches such as experimentally reducing dream experience (e.g., through pharmacological suppression) or examining populations who report minimal or absent dream experience, to determine whether dreaming is necessary for sleep-associated processing or whether it primarily co-occurs with the relevant neural mechanisms.

In sum, given the literature presented above, dreams could be considered as a phenomenological readout of the reactivation processes occurring during sleep, providing a window into the cognitive and emotional material that is reengaged. Additionally, it appears important to consider not only dream content and imagery, but also other specific characteristics of dreams such as the emotional tone and intensity. These elements of dreaming could serve as valuable indicators of how reactivation shapes the subjective dimension of sleep, including perceived sleep quality and restoration. Indeed, as dreams constitute part of the cognitive landscape of sleep, they should be expected both to reflect underlying reactivation patterns while also informing on the subjective experience of sleep. In this conceptualisation, dreaming is not considered to serve a highly specific or unique function, such as memory consolidation. Instead, dreams may contribute more broadly by amplifying, contextualising, or providing additional internal input to the cognitive processes naturally active during sleep. This perspective situates dreaming between two classical extremes: on one hand, rejecting the view that dreams are random epiphenomena of REM sleep physiology (Hobson & McCarley, 1977; Hobson et al., 1998); on the other hand, moderating the idea that dreaming plays a singular functional role (e.g., Crick & Mitchison, 1983; Revonsuo, 2000; Revonsuo et al., 2016a). Rather, dreams may be best understood as emergent products of ongoing neural and cognitive activity, without requiring a dedicated function exclusive to dreaming.

This extended view also has implications for the longstanding REM-centric framing of dream research, that still tend to bias models of dreaming (e.g., Hartmann, 2010a; Zadra & Stickgold, 2021), despite the accumulating evidence demonstrating that meaningful dream

experiences arise throughout the sleep cycle. While REM dreams, particularly those occurring late at night, may illustrate how emotionally salient material can be selectively reactivated during specific sleep periods, this example should not be taken to imply that REM sleep is uniquely responsible for dreaming or its cognitive and emotional functions. Rather, dreaming appears to depend less on a REM-specific system and more on the evolving physiological profile of sleep, including circadian-driven fluctuations of cortical activation and patterns of regional brain activation (Wamsley et al., 2007). Within the extended MemoSleep framework, this implies that dreams may be understood as expressions of state-dependent cognitive reactivation. Accordingly, jointly considering when a dream occurs during the night and the underlying brain state may provide a more complete understanding of sleep-associated cognitive and emotional processing.

7.4. The relationship between digital media use and sleep

Building on the preceding sections, which examined cognitive-emotional reactivation during sleep as proposed by the MemoSleep hypothesis, the aim of the present section is to highlight how this framework can complement existing hypotheses on the relationship between digital media exposure and sleep. Drawing on the results of Study I, cognitive and emotional processes elicited by digital media exposure may continue to influence sleep depth and architecture through reactivation during sleep, offering one possible mechanistic pathway that complements traditional accounts. Individual differences in traits such as rumination or vulnerabilities to mental health disorders, as well as the timing and repetition of media exposure may modulate these effects, suggesting potential clinical and practical implications.

Several hypotheses have been proposed to explain why digital media use can negatively affect sleep (e.g., Bauducco et al., 2024; Ellithorpe et al., 2025; Exelmans & Van Den Bulck, 2019). The screen light hypothesis posits that wavelength of light emitted by electronic devices is responsible for the delaying of circadian timing and melatonin release (see reviews Shechter et al., 2020; Silvani et al., 2022). The sleep displacement hypothesis suggests that engaging in media use delays bedtime and consequently reduces total sleep duration. Moreover, this media-induced sleep displacement is associated with worse sleep quality and increased daytime sleepiness (Custers & Van den Bulck, 2012; Exelmans & Van den Bulck, 2017a). The arousal hypothesis links pre-sleep digital media consumption to poorer sleep outcomes, due to increased levels of pre-sleep arousal (e.g., Combertaldi et al., 2021; Exelmans & Van den

Bulck, 2017b; Harbard et al., 2016; Kinsella & Chin, 2024; Wang & Scherr, 2022). However, recent research highlights a more nuanced picture, with some evidence suggesting that digital media use can, depending on the context, be less detrimental for sleep than initially thought (e.g., Ellithorpe et al., 2022). For example, the media recovery hypothesis suggests that media can serve as a relaxing activity that can help cope with or distract from daily stressors (Reinecke et al., 2011, 2014). From this perspective, individuals use media to reduce stress, which may enhance sleep quality. While each of these hypotheses can explain certain aspects of media-induced sleep changes, none can fully explain the complete pattern of effects. Indeed, light exposure explains general physiological sleep disruptions, but not content-specific effects that operate through cognitive and emotional engagement. The displacement hypothesis focuses on behavioural mechanisms that leads to reduction of sleep duration but cannot account for changes in sleep quality. And while both the media recovery and arousal hypotheses allow for the consideration of content-specific cognitive-emotional processes, they cannot fully explain changes occurring during sleep itself, once sleep initiation is successful. These gaps point to the need for a framework that can link pre-sleep cognitive-emotional engagement with in-sleep processes. Indeed, while these accounts highlight complementary mechanisms through which digital media use can affect sleep, the MemoSleep hypothesis can offer an integrative framework that connects these perspectives by proposing a common within-sleep mechanism, whereby media-induced cognitive and emotional material can be reactivated during sleep.

The media recovery hypothesis offers an explanation for the findings of a shorter sleep onset latency (SOL) after watching suspenseful TV series in Study I (see also Ellithorpe et al., 2022). Indeed, media can serve various recovery functions, such as providing an escape from problems, regulating affective states, and improving mood (Ellithorpe et al., 2025; Reinecke et al., 2014). As such, media use can effectively shift attention away from personal concerns, thereby reducing self-referential cognitive activity before sleep. In Study I, watching suspenseful TV series before bedtime may have facilitated sleep onset by engaging participants' attention and distracting them from stress-related thoughts, whereas the less stimulating, neutral documentary may not have provided the same level of cognitive absorption. Furthermore, when the episode ended with an open or unresolved narrative, this attentional shift may have been intensified: participants focused their thoughts on the storyline and its resolution, rather than on their own personal worries. Within cognitive models of insomnia, it is proposed that individuals with insomnia engage in excessive internal monitoring of sleep-related cues and pre-sleep cognitive activity, which heightens arousal and interferes with sleep onset (e.g., Espie, 2002;

Harvey, 2002; Perlis et al., 1997). From this perspective, distraction can serve as a strategy to counteract maladaptive self-focused attention by directing cognitive resources away from worry and sleep-related monitoring. A similar mechanism may explain why healthy young adults who watched suspenseful content in Study I experienced a shorter SOL: the engaging narrative may have temporarily shifted their attention from self-related concerns towards the storyline, thereby replacing worry-related cognitive activity with media-related thoughts and facilitating the transition to sleep. This interpretation aligns with the media recovery hypothesis, suggesting that under certain conditions, cognitive engagement in media can promote adaptive pre-sleep cognitive states and support sleep initiation rather than disrupt it (Ellithorpe et al., 2025).

Regarding the arousal hypothesis, the binge-watching session with a cliffhanger did, as expected, increase both physiological and cognitive arousal before sleep compared to a non-suspenseful documentary. However, this elevation did not translate into marked impairments in overall objective and subjective sleep quality. Our findings therefore challenge the notion that the association between media use and sleep disturbances is primarily mediated by media-induced increases in arousal. Indeed, in recent years, the arousal hypothesis has received limited empirical support from experimental studies (for a review see Bauducco et al., 2024), motivating researchers to explore alternative explanatory frameworks. Nevertheless, despite the absence of major sleep impairments, subtle alterations emerged during the early sleep period, suggesting more complex underlying processes. Specifically, during the first two sleep cycles, participants who watched the suspenseful series with cliffhangers showed reduced SWS and lower SWA/beta ratio, accompanied by elevated heart rate. This pattern suggests that suspense-induced pre-sleep arousal can exert lingering effects on sleep physiology that extend beyond sleep onset. Within the MemoSleep framework, these effects can be understood as reflecting the reactivation of media-related cognitive and emotional material during sleep, which may in turn elicit associated physiological response.

As explained in the introduction, incomplete intentions tend to remain cognitively active and can manifest as persistent thoughts until they are resolved (Ghibellini & Meier, 2025; Goschke & Kuhl, 1997). Due to their unresolved narrative structure, cliffhangers may thus be particularly likely to be reactivated during sleep, compared to neutral content with lower emotional salience and narrative uncertainty. From this perspective, the extended MemoSleep framework offers a possible explanation for why not all media affect sleep in the same way: rather than depending solely on exposure duration or arousal level, sleep-related effects may

depend on the cognitive and emotional properties of the content itself. To further evaluate this account, future studies could examine dream content to assess whether unresolved media-related material is preferentially reactivated during sleep, under the assumption that dream experiences partially reflect ongoing reactivation. Importantly, it is highly recommended to further investigate individual differences as they are likely to play a critical role in shaping these effects. Traits such as rumination tendencies, resilience-related characteristics, or sensitivity to and engagement with specific types of media may modulate the extent to which media-related content is reactivated during sleep and influences sleep physiology.

Indeed, emerging work increasingly points to the role of individual factors, such as personality traits and affective states, in moderating the effects of digital media use on sleep (e.g., Kinsella & Chin, 2024; Rahman et al., 2024; Shiraly et al., 2024). Moreover, growing evidence suggests that the relationship between media use and sleep is bidirectional: rather than media use solely impairing sleep, sleep difficulties themselves may foster increased media consumption as a coping or distraction strategy (Bauducco et al., 2024; Exelmans & Van den Bulck, 2019; Tavernier & Willoughby, 2014). Differences in media usage patterns also appear to be relevant, with effects varying as a function of timing, chronicity, and usage style, including media multitasking or nighttime media-related sleep interruptions (Alfonsi et al., 2023; Bauducco et al., 2024; Exelmans & Van den Bulck, 2019; Siebers et al., 2024). Together, these perspectives highlight the need for a more nuanced understanding of how digital media use and sleep interact across behavioural, cognitive, and emotional dimensions. The extended MemoSleep hypothesis offers a framework well-suited to integrating these perspectives, as it allows for interindividual differences in susceptibility to within-sleep reactivation. Indeed, within this framework, the likelihood and impact of reactivation during sleep are proposed to be moderated by factors such as salience, emotional load and individual vulnerability. This perspective may help explain variability in the sleep-related impact of digital media use, with effects depending on both the nature of the media content and individual vulnerability.

This approach also has important clinical and practical implications, as it may help delineate forms of media use that are more likely to interfere with sleep from those that may be relatively benign or even beneficial. For example, identifying media content that supports stress recovery without promoting persistent reactivation during sleep could inform recommendations for individuals with sleep-onset insomnia or affective disorders, who may be particularly prone to using media as pre-sleep coping strategy (Alimoradi et al., 2022; Reinecke et al., 2011). Future research may thus benefit from adopting a resilience-oriented perspective by examining

individuals who appear relatively unaffected by pre-sleep media. Characterising the types of media content, usage patterns, and cognitive-emotional features associated with preserved sleep in these individuals could help identify media-related factors that are not detrimental to sleep or may even be sleep-compatible.

Despite the explanatory value of the MemoSleep framework in the domain of media use and sleep, several limitations should be acknowledged. First, the present interpretation assumes that changes in sleep physiology and architecture reflect the reactivation of pre-sleep cognitive and emotional material; however, these measures are indirect which limits the strength of inferences. Alternative neural or physiological mechanisms may also contribute. Second, as a cognitive framework, the MemoSleep hypothesis cannot account for other influences of digital media on sleep, such as light exposure or circadian effects. Accordingly, this account is best considered as complementary, rather than sufficient to explain the full range of media-related effects on sleep. Third, while the MemoSleep hypothesis can generate specific predictions about pre-sleep or in-sleep media use, it may have limited explanatory power for the impact of daytime media habits on sleep. While the MemoSleep framework may be a valuable tool for investigating cognitive mechanisms linking media use and sleep, these limitations highlight important avenues for future research.

7.5. General limitations

This section reflects on methodological aspects highlighted by the four studies presented in this work and discusses broader limitations that constrain the interpretation and generalisability of the findings.

The studies presented in this work particularly highlight three methodological aspects that deserve consideration: (1) the importance of within-subjects designs in sleep and dream research; (2) the careful selection of control conditions, and (3) the value of multimodal assessments. First, findings from Study III underscore the importance of within-subject comparisons for sleep measures, as between-group differences may reflect individual variability. Indeed, sleep is known to vary substantially between individuals, largely due to differences in circadian rhythm (Papatsimpa et al., 2021; Tucker et al., 2007). Given that cognitive activity during sleep is also likely influenced by personal factors as argued previously, within-subject designs are of particular value, as they allow for better control of inter-individual differences. This consideration is equally relevant for dream research, where substantial

variability has been reported in measures such as dream recall frequency (e.g., Schredl, 2004; Schredl et al., 2003). Second, Studies I, II, and III also highlight the importance of carefully selecting control conditions. The neutral documentary used in Study I and the neutral control condition from Study III may have elicited unintended experiences such as boredom, frustration or a sense of pointlessness, which could have impacted mood and subsequent sleep. Similarly, the use of a relaxation condition in Study II prevents a direct comparison with an intervention-free night. While these conditions provided valuable insights into the impact of pre-sleep cognitive activity, they also illustrate that apparent neutral conditions may not be affectively neutral. Finally, Studies II and III point to the value of combining physiological and subjective measures. Although both studies employed similar paradigms, the extent to which their findings can be directly compared remains uncertain. It can be speculated that the same pre-sleep manipulations produced comparable effects on subsequent sleep in both studies; however, without concurrent assessment of physiological sleep parameters and dream-related subjective reports, such conclusions remain speculative. A combined multimodal approach would therefore allow for a more comprehensive understanding of how pre-sleep cognitive activity influences both sleep physiology and dream experience.

While the methodological considerations outlined above reflect design-related lessons that can inform future research, the present work is also subject to several broader limitations that constrain the interpretation and generalisability of the findings. First, an important limitation concerns the limits of cognitive influence on sleep. The present studies highlight that cognitive processes operate alongside, and in interaction with, biological determinants of sleep, such as homeostatic sleep pressure and circadian regulation. Across our studies, sleep in healthy young adults appeared largely resilient to single exposures of pre-sleep cognitive activation, emphasising that cognitive factors do not act in isolation but alongside biological sleep-regulatory processes. Study IV illustrates this limitation particularly clearly: the inability to reliably modulate REM sleep parameters suggests that top-down cognitive processes during sleep compete with stronger endogenous pressures. Intentions to modulate sleep therefore operate within the constraints imposed by homeostatic and circadian mechanisms, which ultimately govern sleep (Borbély et al., 2016; Deboer, 2018). This aspect was also shown in previous work from our group, in which healthy participants were unable to improve their sleep merely by intending to “sleep as well as possible” (Combertaldi & Rasch, 2020). Taken together, the present findings delineate a key limitation of cognitive approaches to sleep modulation, namely that their effects are bounded by homeostatic and circadian regulation.

Regarding the scientific study of dreaming, a fundamental challenge lies in the absence of method for directly observing dream experience. Because researchers cannot access the dream itself, they must rely almost exclusively on retrospective dream reports. However, the pathway from the original dream experience to the final verbal report involves multiple cognitive, perceptual, and linguistic operations that each introduce opportunities for information loss or distortion (Mallett et al., 2024). Memory-related distortions are particularly prevalent: recall bias and retrospective bias can lead individuals to forget or reconstruct dream events, while emotional salience biases reporting towards more vivid or affectively intense dreams, making the reports unrepresentative of typical dream experience (e.g., Scarpelli et al., 2022; Schredl, 1999). Additional sources of unreliability arise from differences in verbalisation capacity: participants with more advanced narrative or linguistic skills often provide richer, more coherent reports regardless of the underlying dream (Ficca et al., 2024). Methodological challenges persist at the stage of dream analysis. Dream coding systems depend on human interpretation, and substantial heterogeneity has been documented both across independent raters and between external raters and the dreamers themselves (Schredl, 2018; Schredl & Doll, 1998). Such variability introduces measurement noise and raises concerns about the reliability and comparability of coded dream features across studies. These limitations underscore the importance of maintaining a critical perspective when interpreting findings from dream research or conducting dream analyses. Because dream reports are shaped by layers of memory, cognition, and interpretation, they must always be treated as indirect and imperfect approximations of the original experience. At the same time, these challenges point towards several promising directions for future research. The acquisition of extensive and longitudinal data sets, further integration of objective physiological markers, standardised coding frameworks, and computational tools capable of quantifying linguistic and structural features of dreams may help reduce the impact of current biases (Mallett et al., 2024). Although current dream research remains meaningful, continued progress in these areas are essential for developing a more robust and empirically grounded science of dreaming.

A further limitation concerns the ecological validity of laboratory studies. The experimental procedure and material can directly impact sleep; furthermore, it is important to consider the limits of experimental manipulation with regard to how they translate to real life experiences. In the context of this work, the use of experimental stress in particular should be considered. Previous studies have demonstrated that anticipatory stress related to personally meaningful events (e.g., sport competition, exam, surgery) can be incorporated into dreams

(Arnulf et al., 2014; Breger et al., 1971; Erlacher et al., 2011). In Study II, however, experimentally induced anticipatory stress did not increase the proportion of stress-related dreams, a discrepancy which may be explained by the experimental nature of the stressor, which may have lacked the same personal relevance or emotional salience necessary for dream incorporation.

Finally, it should be noted that the present work focused on healthy young adults from educated and industrialised backgrounds. Consequently, the findings may not generalise to other populations, such as older adults, clinical groups, or individuals from different cultural and socioeconomic backgrounds.

7.6. Open questions

Beyond the methodological constraints outlined above, several important questions remain open and point to promising directions for future research. First, it would be worthwhile to address whether cognitive reactivations during sleep can influence subjective sleep experience and dream mentation independently of measurable physiological changes. Indeed, it can be hypothesised that some cognitive reactivations affect only the subjective experience of sleep, such as the feelings of restoration or alertness upon awakening, without producing detectable disruptions in sleep architecture and physiology. Investigating dream content alongside physiological measures may help clarify when and how cognitive activity during sleep translates into physiological consequences and whether specific characteristics of pre-sleep cognitions, such as their emotional load or repetition, are more likely to trigger alterations in sleep processes. This question is particularly relevant in the context of paradoxical insomnia, in which individuals report being awake despite objective indications of sleep (Mercer et al., 2002). This pattern suggests that the cognitive landscape during sleep can shape the experience of sleep partially independently of objective markers. Thus, cognitive reactivation during sleep, even in the absence of physiological alterations, may be highly significant for understanding how people evaluate their sleep and how rested they feel upon awakening.

Second, although current evidence suggests that patterns of neural activation can shape the cognitive and emotional qualities of dreams (e.g., Hobson & McCarley, 1977; Nir & Tononi, 2010; Siclari et al., 2017; Wamsley, 2014), it remains unclear whether physiologically meaningful brain activity is reflected in dream experience, and, if so, under which conditions.

A related question concerns the presence of dreaming itself: is mentation continuously generated throughout sleep, or are there periods of sleep in which no dream experience emerges? Addressing these issues will require approaches that more directly relate neural dynamics to dream reports, such as combining high-density electrophysiological recordings with systematic awakenings, or using closed-loop paradigms to probe whether specific neural events reliably produce specific dream mentation. Experimental manipulations, including TMR or stimulation protocols, may further clarify whether inducing specific neural patterns have measurable effects on dream content or characteristics.

Third, the neural mechanisms of reactivation need to be further investigated. The MemoSleep hypothesis is grounded in the active system consolidation hypothesis, which precisely describes the neural mechanisms of memory reactivation during sleep through the synchronisation of hippocampal sharp-wave ripples and thalamocortical sleep spindles (Diekelmann & Born, 2010). In the context of broader cognitive and emotional material, it remains unclear whether their reactivation elicits a distinct neural signature. It appears possible that such reactivation would involve a broader network of activity, engaging multiple brain regions simultaneously. Reactivation of cognitive and emotional material during sleep may not be limited to hippocampal-neocortical circuits typically implicated in memory reactivation but may instead engage distributed affective-cognitive networks. Such mechanism could help explain the frequent involvement of limbic structures during REM sleep, which is often linked to heightened emotional intensity in dreams (e.g., Hobson et al., 2000; Maquet et al., 2005; Revonsuo, 2000). Future studies are needed to address these questions. For example, brain activation patterns elicited when a specific cognitive concept is engaged during wakefulness could be compared with those triggered with its reactivation during sleep (see for e.g., Kumral et al., 2025). This approach could clarify whether similar neural networks are involved.

Finally, an important open question concerns which specific qualities render cognitions genuinely sleep-promoting and compatible with sleep-inducing physiological states, as argued earlier. As cognitive activation competes with homeostatic and circadian regulation, it is likely that only mental content that is highly compatible with low-arousal, sleep-congruent physiological states can exert beneficial effects. Labelling cognitions as merely “positive” may thus be insufficient, since positive thoughts can also trigger arousal (McManus et al., 2019), such as anticipatory excitement or post-success elation. Similarly, even the intention to sleep well can generate additional sleep-related expectancies that paradoxically impair sleep (Jansson-Fröjmark et al., 2022; see also Combertaldi & Rasch, 2020). Consequently, future

research should examine the specific qualities that make cognitive states genuinely sleep-promoting, particularly those whose content and experiential tone facilitate calmness and low arousal. Moreover, the effectiveness of such sleep-promoting cognitions is likely influenced by individual factors, including personality traits, cultural background and personal history. The present work did not examine these differences, but the extended MemoSleep framework suggests that cognitive reactivation during sleep depends on characteristics such as emotional load and personal relevance. These characteristics, in turn, are shaped by individual traits and experiences. Therefore, future studies should investigate how such individual differences modulate cognitive reactivation during sleep and how they impact sleep physiology and dream experiences.

8. Conclusion

The present research aimed to investigate how cognitive processes before and during sleep influence sleep physiology, dream content and subjective experience. To address this question, four studies were conducted within the framework of the MemoSleep hypothesis which posits that pre-sleep cognitions can be reactivated during subsequent sleep and that such reactivation influences sleep physiology and architecture. Together, these studies provide a multilevel analysis of the dynamic interplay between cognition and sleep. Study I examined the effects of pre-sleep media exposure with unfinished narrative on subsequent sleep. While engaging media before sleep appeared to serve a distraction function and facilitate sleep onset, unfinished narratives nonetheless led to subtle alterations in the early sleep period, supporting the notion of in-sleep cognitive reactivation of pre-sleep material. Study II introduced dreams as a window into these reactivation processes, demonstrating that in-sleep reactivation occurs in a temporally specific manner. These findings enabled the development of a comprehensive model of dynamic reactivation processes, shaped by both circadian-driven cortical activation and sleep-stage-specific regional activity. Study III reflected on the benefits of identifying sleep-promoting cognitions, highlighting a promising avenue for actively shaping cognitive activity before sleep to optimise subsequent sleep quality. Finally, Study IV contrasted cognitive and circadian influences on sleep, while exploring how reactivation processes may be leveraged to investigate the functional role of sleep-related mechanisms.

The findings provide converging evidence for the reactivation mechanism proposed in the MemoSleep hypothesis, while also motivating three extensions of the framework: (1) reactivation may not be restricted to memory-related processes but may encompass a broader range of cognitive and emotional material; (2) reactivation appears to operate through a salience-based mechanism; and (3) dreams may reflect ongoing reactivation processes. Building on the results of Study II, this last extension seems particularly promising, as dreams may provide valuable insights into the cognitive and emotional processes engaged during sleep. The extended MemoSleep framework developed in the present work aims to propose a model of cognitive-emotional reactivation during sleep and its consequences on sleep physiology and dreams. By specifying a mechanism linking waking cognition to sleep-related physiology and dream mentation, without presupposing the functional outcomes of such reactivation, this framework may be applied to diverse research domains with the aim of generating testable predictions regarding the functions of sleep-related mechanisms.

This perspective has several important implications. First, it enables the conceptualisation of cognitive activity during sleep as a multidimensional continuum

encompassing its intensity, content, and functional impact. In turn, this continuum allows for the consideration of individual differences and supports the development of novel interventions in which sleep-promoting cognitions may actively be fostered to improve sleep quality. More specifically, this perspective opens the door to exploring and better understanding the relationship between digital media use and sleep, potentially allowing for the identification of media content and usage patterns that are not detrimental to sleep, or may even be beneficial.

Despite methodological and population-specific constraints inherent to laboratory-based sleep research, the present work provides important insights into the influence of cognitive-emotional processes on sleep physiology and dreams. Building on the present findings, future research is needed to further delineate the scope and mechanisms through which cognition can influence sleep. In particular, the investigation of sleep-promoting cognitions appears particularly promising, as it holds substantial potential for improving sleep quality and developing interventions for clinical populations. Overall, this work proposes a unifying cognitive-emotional framework through which mental processes shape sleep physiology and dreaming, providing a foundation for future research into broader sleep-related mechanisms and functions.

References

- Achermann, P., Rusterholz, T., Dürr, R., König, T., & Tarokh, L. (2016). Global field synchronization reveals rapid eye movement sleep as most synchronized brain state in the human EEG. *Royal Society Open Science*, 3(10), 160201. <https://doi.org/10.1098/rsos.160201>
- Ackermann, S., Cordi, M. J., La Marca, R., Seifritz, E., & Rasch, B. (2019). Psychosocial stress before a nap increases sleep latency and decreases early slow-wave activity. *Frontiers in Psychology*, 10, 20. <https://doi.org/10.3389/fpsyg.2019.00020>
- Adam, K., & Oswald, I. (1977). Sleep is for tissue restoration. *Journal of the Royal College of Physicians of London*, 11(4), 376–388. [https://doi.org/10.1016/S0035-8819\(25\)02990-3](https://doi.org/10.1016/S0035-8819(25)02990-3)
- Agnew Jr., H. W., Webb, W. B., & Williams, R. L. (1966). The first night effect: An EEG study of sleep. *Psychophysiology*, 2(3), 263–266. <https://doi.org/10.1111/j.1469-8986.1966.tb02650.x>
- Åkerstedt, T. (2006). Psychosocial stress and impaired sleep. *Scandinavian Journal of Work, Environment & Health*, 32(6), 493–501.
- Åkerstedt, T., Kecklund, G., & Axelsson, J. (2007). Impaired sleep after bedtime stress and worries. *Biological Psychology*, 76(3), 170–173. <https://doi.org/10.1016/j.biopsycho.2007.07.010>
- Alfonsi, V., Varallo, G., Scarpelli, S., Gorgoni, M., Filosa, M., De Gennaro, L., Musetti, A., & Franceschini, C. (2023). ‘This is the last episode’: The association between problematic binge-watching and loneliness, emotion regulation, and sleep-related factors in poor sleepers. *Journal of Sleep Research*, 32(1), e13747. <https://doi.org/10.1111/jsr.13747>
- Alimoradi, Z., Jafari, E., Potenza, M. N., Lin, C.-Y., Wu, C.-Y., & Pakpour, A. H. (2022). Binge-watching and mental health problems: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, 19(15), 9707. <https://doi.org/10.3390/ijerph19159707>
- Allredge, C. T., Snyder, M., Stork, S. R., & Elkins, G. R. (2024). Exploring variables associated with the effects of a self-administered hypnosis intervention for improving sleep quality. *International Journal of Clinical and Experimental Hypnosis*, 72(2), 94–108. <https://doi.org/10.1080/00207144.2023.2278720>
- Allen, M. S., Magee, C. A., & Vella, S. A. (2016). Personality, hedonic balance and the quality and quantity of sleep in adulthood. *Psychology & Health*, 31(9), 1091–1107. <https://doi.org/10.1080/08870446.2016.1178745>
- Alvaro, P. K., Roberts, R. M., & Harris, J. K. (2013). A systematic review assessing bidirectionality between sleep disturbances, anxiety, and depression. *Sleep*, 36(7), 1059–1068. <https://doi.org/10.5665/sleep.2810>
- Antrobus, J. S., Kondo, T., & Reinsel, R. (1995). Dreaming in the late morning: Summation of REM and diurnal cortical activation. *Consciousness and Cognition*, 4, 275–299.
- Arnulf, I., Grosliere, L., Le Corvec, T., Golmard, J.-L., Lascols, O., & Duguet, A. (2014). Will students pass a competitive exam that they failed in their dreams? *Consciousness and Cognition*, 29, 36–47.

- Aserinsky, E., & Kleitman, N. (1953). Regularly occurring periods of eye motility, and concomitant phenomena, during sleep. *Science*, 118(3062), 273–274.
- Aston-Jones, G., & Bloom, F. E. (1981a). Activity of norepinephrine-containing locus coeruleus neurons in behaving rats anticipates fluctuations in the sleep-waking cycle. *The Journal of Neuroscience*, 1(8), 876–886. <https://doi.org/10.1523/JNEUROSCI.01-08-00876.1981>
- Aston-Jones, G., & Bloom, F. E. (1981b). Nonrepinephrine-containing locus coeruleus neurons in behaving rats exhibit pronounced responses to non-noxious environmental stimuli. *Journal of Neuroscience*, 1(8), 887–900. <https://doi.org/10.1523/JNEUROSCI.01-08-00887.1981>
- Baekeland, F., Resch, F., & Katz, D. (1968). Presleep mentation and dream reports: I. Cognitive style, contiguity to sleep, and time of night. *Archives of General Psychiatry*, 19(3), 300–311. <https://doi.org/10.1001/archpsyc.1968.01740090044005>
- Bandla, S., Lella, S., Kola, A., Parvathaneni, K. M., & Rani, J. (2024). Association of anxiety, depression and sleep quality with binge-watching behavior in college students – An observational study. *Archives of Mental Health*, 25(2), 107–111. https://doi.org/10.4103/amh.amh_11_24
- Bang, D., Luo, Y., Barbosa, L. S., Batten, S. R., Hadj-Amar, B., Twomey, T., Melville, N., White, J. P., Torres, A., Celaya, X., Ramaiah, P., McClure, S. M., Brewer, G. A., Bina, R. W., Lohrenz, T., Casas, B., Chiu, P. H., Vannucci, M., Kishida, K. T., ... Montague, P. R. (2023). Noradrenaline tracks emotional modulation of attention in human amygdala. *Current Biology*, 33(22), 5003–5010. <https://doi.org/10.1016/j.cub.2023.09.074>
- Baran, B., Pace-Schott, E. F., Ericson, C., & Spencer, R. M. C. (2012). Processing of emotional reactivity and emotional memory over sleep. *Journal of Neuroscience*, 32(3), 1035–1042. <https://doi.org/10.1523/JNEUROSCI.2532-11.2012>
- Barnier, A. J., McConkey, K. M., & Wright, J. (2004). Posthypnotic Amnesia For Autobiographical Episodes: Influencing Memory Accessibility and Quality. *International Journal of Clinical and Experimental Hypnosis*, 52(3), 260–279. <https://doi.org/10.1080/0020714049052351>
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59(1), 617–645. <https://doi.org/10.1146/annurev.psych.59.103006.093639>
- Baselgia, S., Kasten, F. H., Herrmann, C. S., Rasch, B., & Paßmann, S. (2024). No benefit in memory performance after nocturnal memory reactivation coupled with theta-tACS. *Clocks & Sleep*, 6, 211–233.
- Baselgia, S., & Rasch, B. (2025). Hypnotic suggestions in the modulation of sleep. In *International Review of Neurobiology* (Vol. 184, pp. 151–178). Elsevier. <https://doi.org/10.1016/bs.irn.2025.04.015>
- Bauducco, S., Pillion, M., Bartel, K., Reynolds, C., Kahn, M., & Gradisar, M. (2024). A bidirectional model of sleep and technology use: A theoretical review of How much, for whom, and which mechanisms. *Sleep Medicine Reviews*, 76, 101933. <https://doi.org/10.1016/j.smrv.2024.101933>
- Baylor, G. W., & Cavallero, C. (2001). Memory sources associated with REM and NREM dream reports throughout the night: A new look at the data. *Sleep*, 24(2), 165–170.
- Beaudoin, L. P. (2014). A design-based approach to sleep-onset and insomnia: Super-somnolent mentation, the cognitive shuffle and serial diverse imagining. *Computational Modeling of Cognition-Emotion Interactions: Relevance to Mechanisms of Affective Disorders and Therapeutic Action*. <https://summit.sfu.ca/item/17237>
- Beck, J., Cordi, M. J., & Rasch, B. (2021). Hypnotic suggestions increase slow-wave parameters but decrease slow-wave spindle coupling. *Nature and Science of Sleep*, 13, 1383–1393. <https://doi.org/10.2147/NSS.S316997>
- Beck, J., Loretz, E., & Rasch, B. (2021). Exposure to relaxing words during sleep promotes slow-wave sleep and subjective sleep quality. *Sleep*, 44(11), zsab148. <https://doi.org/10.1093/sleep/zsab148>
- Beck, J., Loretz, E., & Rasch, B. (2023). Stress dynamically reduces sleep depth: Temporal proximity to the stressor is crucial. *Cerebral Cortex*, 33(1), 96–113. <https://doi.org/10.1093/cercor/bhac055>
- Becker, L., & Rohleder, N. (2019). Time course of the physiological stress response to an acute stressor and its associations with the primacy and recency effect of the serial position curve. *PLOS ONE*, 14(5), e0213883. <https://doi.org/10.1371/journal.pone.0213883>

- Beckmann, J. (1998). Intrusive thoughts, rumination, and incomplete intentions. In M. Kofta, G. Weary, & G. Sedek (Eds.), *Personal Control in Action* (pp. 259–278). Springer US. https://doi.org/10.1007/978-1-4757-2901-6_10
- Bei, B., Wiley, J. F., Trinder, J., & Manber, R. (2016). Beyond the mean: A systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. *Sleep Medicine Reviews*, 28, 108–124. <https://doi.org/10.1016/j.smrv.2015.06.003>
- Bell, A., & Hall, C. (1971). *The personality of a child molester: An analysis of dreams*. Routledge.
- Bellingrath, S., Rohleder, N., & Kudielka, B. M. (2013). Effort–reward-imbalance in healthy teachers is associated with higher LPS-stimulated production and lower glucocorticoid sensitivity of interleukin-6 in vitro. *Biological Psychology*, 92(2), 403–409. <https://doi.org/10.1016/j.biopsycho.2012.12.003>
- Besedovsky, L., Cordi, M. J., Wißlicen, L., Martínez-Albert, E., Born, J., & Rasch, B. (2022). Hypnotic enhancement of slow-wave sleep increases sleep-associated hormone secretion and reduces sympathetic predominance in healthy humans. *Communications Biology*, 5(1), 747. <https://doi.org/10.1038/s42003-022-03643-y>
- Besedovsky, L., Lange, T., & Born, J. (2012). Sleep and immune function. *Pflügers Archiv - European Journal of Physiology*, 463(1), 121–137. <https://doi.org/10.1007/s00424-011-1044-0>
- Besedovsky, L., Lange, T., & Haack, M. (2019). The sleep-immune crosstalk in health and disease. *Physiological Reviews*, 99(3), 1325–1380. <https://doi.org/10.1152/physrev.00010.2018>
- Biabani, N., Birdseye, A., Higgins, S., Delogu, A., Rosenzweig, J., Cvetkovic, Z., Nesbitt, A., Drakatos, P., Steier, J., Kumari, V., O'Regan, D., & Rosenzweig, I. (2023). The neurophysiologic landscape of the sleep onset: A systematic review. *Journal of Thoracic Disease*, 15(8), 4530–4543. <https://doi.org/10.21037/jtd-23-325>
- Blanaru, M., Bloch, B., Vadas, L., Arnon, Z., Ziv, N., Kremer, I., & Haimov, I. (2012). The effects of music relaxation and muscle relaxation techniques on sleep quality and emotional measures among individuals with posttraumatic stress disorder. *Mental Illness*, 4(2), 59–65. <https://doi.org/10.4081/mi.2012.e13>
- Blume, C., del Giudice, R., Wisłowska, M., Heib, D. P. J., & Schabus, M. (2018). Standing sentinel during human sleep: Continued evaluation of environmental stimuli in the absence of consciousness. *NeuroImage*, 178, 638–648. <https://doi.org/10.1016/j.neuroimage.2018.05.056>
- Bonnet, M. H., & Arand, D. L. (2010). Hyperarousal and insomnia: State of the science. *Sleep Medicine Reviews*, 14(1), 9–15. <https://doi.org/10.1016/j.smrv.2009.05.002>
- Borbély, A. A. (1982). A two process model of sleep regulation. *Human Neurobiology*, 1(3), 195–204.
- Borbély, A. A., Daan, S., Wirz-Justice, A., & Deboer, T. (2016). The two-process model of sleep regulation: A reappraisal. *Journal of Sleep Research*, 25(2), 131–143. <https://doi.org/10.1111/jsr.12371>
- Borkovec, T. D., & Fowles, D. C. (1973). Controlled investigation of the effects of progressive and hypnotic relaxation on insomnia. *Journal of Abnormal Psychology*, 82(1), 153–158. <https://doi.org/10.1037/h0034970>
- Born, J., Hansen, K., Marshall, L., Mölle, M., & Fehm, H. L. (1999). Timing the end of nocturnal sleep. *Nature*, 397(6714), 29–30. <https://doi.org/10.1038/16166>
- Boulenger, V., Shtyrov, Y., & Pulvermüller, F. (2012). When do you grasp the idea? MEG evidence for instantaneous idiom understanding. *NeuroImage*, 59(4), 3502–3513. <https://doi.org/10.1016/j.neuroimage.2011.11.011>
- Braun, A., Balkin, T. J., Wesensten, N. J., Carson, R. E., Varga, M., Baldwin, P., Selbie, S., Belenky, G., & Herscovitch, P. (1997). Regional cerebral blood flow throughout the sleep-wake cycle. An H2(15)O PET study. *Brain*, 120(7), 1173–1197. <https://doi.org/10.1093/brain/120.7.1173>
- Brautsch, L. A.S., Lund, L., Andersen, M. M., Jennum, P. J., Folker, A. P., & Andersen, S. (2023). Digital media use and sleep in late adolescence and young adulthood: A systematic review. *Sleep Medicine Reviews*, 68, 101742. <https://doi.org/10.1016/j.smrv.2022.101742>
- Breger, L., Hunter, I., & Lane, R. W. (1971). The effect of stress on dreams. *Psychological Issues*, 7.
- Brodt, S., Inostroza, M., Niethard, N., & Born, J. (2023). Sleep—A brain-state serving systems memory consolidation. *Neuron*, 111(7), 1050–1075. <https://doi.org/10.1016/j.neuron.2023.03.005>

- Brosschot, J. F. (2010). Markers of chronic stress: Prolonged physiological activation and (un)conscious perseverative cognition. *Neuroscience & Biobehavioral Reviews, Psychophysiological Biomarkers of Health*, 35(1), 46–50. <https://doi.org/10.1016/j.neubiorev.2010.01.004>
- Brosschot, J. F., Gerin, W., & Thayer, J. F. (2006). The perseverative cognition hypothesis: A review of worry, prolonged stress-related physiological activation, and health. *Journal of Psychosomatic Research*, 60(2), 113–124. <https://doi.org/10.1016/j.jpsychores.2005.06.074>
- Brosschot, J. F., Van Dijk, E., & Thayer, J. F. (2007). Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period. *International Journal of Psychophysiology*, 63(1), 39–47. <https://doi.org/10.1016/j.ijpsycho.2006.07.016>
- Buzsáki, G. (2002). Theta oscillations in the hippocampus. *Neuron*, 33(3), 325–340. [https://doi.org/10.1016/S0896-6273\(02\)00586-X](https://doi.org/10.1016/S0896-6273(02)00586-X)
- Buzsáki, G. (2015). Hippocampal sharp wave-ripple: A cognitive biomarker for episodic memory and planning. *Hippocampus*, 25(10), 1073–1188. <https://doi.org/10.1002/hipo.22488>
- Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., & Mednick, S. C. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences*, 106(25), 10130–10134. <https://doi.org/10.1073/pnas.0900271106>
- Cain, N., & Gradisar, M. (2010). Electronic media use and sleep in school-aged children and adolescents: A review. *Sleep Medicine*, 11(8), 735–742. <https://doi.org/10.1016/j.sleep.2010.02.006>
- Čapková, K., Vaculík, M., Ellis, J., & Šípula, M. (2018). The impact of pre-sleep arousal state and strategy to control unwanted thoughts on sleep quality. *Anxiety, Stress, & Coping*, 31(3), 338–347. <https://doi.org/10.1080/10615806.2017.1421843>
- Caporro, M., Haneef, Z., Yeh, H. J., Lenartowicz, A., Buttinelli, C., Parvizi, J., & Stern, J. M. (2012). Functional MRI of sleep spindles and K-complexes. *Clinical Neurophysiology*, 123(2), 303–309. <https://doi.org/10.1016/j.clinph.2011.06.018>
- Cappuccio, F. P., Cooper, D., D’Elia, L., Strazzullo, P., & Miller, M. A. (2011). Sleep duration predicts cardiovascular outcomes: A systematic review and meta-analysis of prospective studies. *European Heart Journal*, 32(12), 1484–1492. <https://doi.org/10.1093/eurheartj/ehr007>
- Cappuccio, F. P., D’Elia, L., Strazzullo, P., & Miller, M. A. (2010). Sleep duration and all-cause mortality: A systematic review and meta-analysis of prospective studies. *Sleep*, 33(5), 585–592. <https://doi.org/10.1093/sleep/33.5.585>
- Carr, M., Haar, A., Amores, J., Lopes, P., Bernal, G., Vega, T., Rosello, O., Jain, A., & Maes, P. (2020). Dream engineering: Simulating worlds through sensory stimulation. *Consciousness and Cognition*, 83, 102955. <https://doi.org/10.1016/j.concog.2020.102955>
- Carr, M., Konkoly, K., Mallett, R., Edwards, C., Appel, K., & Blagrove, M. (2023). Combining presleep cognitive training and REM-sleep stimulation in a laboratory morning nap for lucid dream induction. *Psychology of Consciousness: Theory, Research, and Practice*, 10(4), 413–430. <https://doi.org/10.1037/cns0000227>
- Carr, M., & Nielsen, T. (2015). Morning REM sleep naps facilitate broad access to emotional semantic networks. *Sleep*, 38(3), 433–443. <https://doi.org/10.5665/sleep.4504>
- Carskadon, M. A., & Dement, W. C. (2005). Normal human sleep: An overview. In M. H. Kryger, T. Roth, & W. Dement (Eds.), *Principles and Practice of Sleep Medicine* (4th ed., pp. 13–23). Elsevier Saunders. <https://doi.org/10.1016/b978-0-323-24288-2.00002-7>
- Carter, B., Rees, P., Hale, L., Bhattacharjee, D., & Paradkar, M. (2016). A meta-analysis of the effect of media devices on sleep outcomes. *JAMA Pediatrics*, 170(12), 1202–1208. <https://doi.org/10.1001/jamapediatrics.2016.2341>
- Cartwright, R. D. (2010). *The twenty-four hour mind: The role of sleep and dreaming in our emotional lives*. Oxford University Press.
- Cartwright, R. D., Lloyd, S., Knight, S., & Trenholme, I. (1984). Broken dreams: A study of the effects of divorce and depression on dream content. *Psychiatry*, 47(3), 251–259. <https://doi.org/10.1080/00332747.1984.11024246>
- Casagrande, M., Violani, C., Lucidi, F., Buttinelli, E., & Bertini, M. (1996). Variations in sleep mentation as a function of time of night. *International Journal of Neuroscience*, 85(1–2), 19–30. <https://doi.org/10.3109/00207459608986348>

- Castiglione-Fontanellaz, C. E. G., Schaufler, S., Wild, S., Hamann, C., Kaess, M., & Tarokh, L. (2023). Sleep regularity in healthy adolescents: Associations with sleep duration, sleep quality, and mental health. *Journal of Sleep Research*, 32(4), e13865. <https://doi.org/10.1111/jsr.13865>
- Cellini, N., Torre, J., Stegagno, L., & Sarlo, M. (2016). Sleep before and after learning promotes the consolidation of both neutral and emotional information regardless of REM presence. *Neurobiology of Learning and Memory*, 133, 136–144. <https://doi.org/10.1016/j.nlm.2016.06.015>
- Chamine, I., Atchley, R., & Oken, B. S. (2018). Hypnosis intervention effects on sleep outcomes: A systematic review. *Journal of Clinical Sleep Medicine*, 14(02), 271–283. <https://doi.org/10.5664/jcsm.6952>
- Chennaoui, M., Léger, D., & Gomez-Merino, D. (2020). Sleep and the GH/IGF-1 axis: Consequences and countermeasures of sleep loss/disorders. *Sleep Medicine Reviews*, 49, 101223. <https://doi.org/10.1016/j.smr.2019.101223>
- Cincotta, A. L., Gehrman, P., Gooneratne, N. S., & Baime, M. J. (2011). The effects of a mindfulness-based stress reduction programme on pre-sleep cognitive arousal and insomnia symptoms: A pilot study. *Stress and Health*, 27(3), e299–e305. <https://doi.org/10.1002/smi.1370>
- Clancy, F., Prestwich, A., Caperon, L., Tsipa, A., & O'Connor, D. B. (2020). The association between worry and rumination with sleep in non-clinical populations: A systematic review and meta-analysis. *Health Psychology Review*, 14(4), 427–448. <https://doi.org/10.1080/17437199.2019.1700819>
- Combataldi, S. L., Ort, A., Cordi, M. J., Fahr, A., & Rasch, B. (2021). Pre-sleep social media use does not strongly disturb sleep: A sleep laboratory study in healthy young participants. *Sleep Medicine*, 87, 191–202. <https://doi.org/10.1016/j.sleep.2021.09.009>
- Combataldi, S. L., & Rasch, B. (2020). Healthy sleepers can worsen their sleep by wanting to do so: The effects of intention on objective and subjective sleep parameters. *Nature and Science of Sleep, Volume 12*, 981–997. <https://doi.org/10.2147/NSS.S270376>
- Combataldi, S. L., Wick, A. Z., & Rasch, B. (2022). The intention to react to sounds induces sleep disturbances and alters brain responses to sounds during sleep: A pilot study. *Clocks & Sleep*, 4(4), 561–576. <https://doi.org/10.3390/clockssleep4040044>
- Cordi, M. J., Hirsiger, S., Mérellat, S., & Rasch, B. (2015). Improving sleep and cognition by hypnotic suggestion in the elderly. *Neuropsychologia*, 69, 176–182. <https://doi.org/10.1016/j.neuropsychologia.2015.02.001>
- Cordi, M. J., & Rasch, B. (2021). Systematic decrease of slow-wave sleep after a guided imagery designed to deepen sleep in low hypnotizable subjects. *Journal of Sleep Research*, 30(3), e13168. <https://doi.org/10.1111/jsr.13168>
- Cordi, M. J., Rossier, L., & Rasch, B. (2020). Hypnotic suggestions given before nighttime sleep extend slow-wave sleep as compared to a control text in highly hypnotizable subjects. *International Journal of Clinical and Experimental Hypnosis*, 68(1), 105–129. <https://doi.org/10.1080/00207144.2020.1687260>
- Cordi, M. J., Schlarb, A. A., & Rasch, B. (2014). Deepening sleep by hypnotic suggestion. *Sleep*, 37(6), 1143–1152. <https://doi.org/10.5665/sleep.3778>
- Cox, R. C., & Olatunji, B. O. (2020). Sleep in the anxiety-related disorders: A meta-analysis of subjective and objective research. *Sleep Medicine Reviews*, 51, 101282. <https://doi.org/10.1016/j.smr.2020.101282>
- Crick, F., & Mitchison, G. (1983). The function of dream sleep. *Nature*, 304(5922), 111–114. <https://doi.org/10.1038/304111a0>
- Cunningham, T. J., Pardilla-Delgado, E., Alger, S. E., & Payne, J. D. (2014). The role of REM sleep in emotional memory and affective reactivity in humans. In *REM sleep: Characteristics, disorders and physiological affects* (pp. 1–28). Nova Science.
- Custers, K., & Van den Bulck, J. (2012). Television viewing, internet use, and self-reported bedtime and rise time in adults: Implications for sleep hygiene recommendations from an exploratory cross-sectional study. *Behavioral Sleep Medicine*, 10(2), 96–105. <https://doi.org/10.1080/15402002.2011.596599>

- Dang-Vu, T. T., Schabus, M., Desseilles, M., Sterpenich, V., Bonjean, M., & Maquet, P. (2010). Functional neuroimaging insights into the physiology of human sleep. *Sleep*, 33(12), 1589–1603. <https://doi.org/10.1093/sleep/33.12.1589>
- Davidson, J., & Lynch, S. (2012). Thematic, literal and associative dream imagery following a high-impact event. *Dreaming*, 22(1), 58–69. <https://doi.org/10.1037/a0026273>
- De Niet, G., Tiemens, B., Lendemeijer, B., & Hutschemaekers, G. (2009). Music-assisted relaxation to improve sleep quality: Meta-analysis. *Journal of Advanced Nursing*, 65(7), 1356–1364. <https://doi.org/10.1111/j.1365-2648.2009.04982.x>
- Deak, M. C., & Stickgold, R. (2010). Sleep and cognition. *WIREs Cognitive Science*, 1(4), 491–500. <https://doi.org/10.1002/wcs.52>
- Deboer, T. (2018). Sleep homeostasis and the circadian clock: Do the circadian pacemaker and the sleep homeostat influence each other's functioning? *Neurobiology of Sleep and Circadian Rhythms*, 5, 68–77. <https://doi.org/10.1016/j.nbscr.2018.02.003>
- Delage, J.-P., Côté, J., Journault, W.-G., Lemyre, A., & Bastien, C. H. (2024). The relationships between insomnia, nightmares, and dreams: A systematic review. *Sleep Medicine Reviews*, 75, 101931. <https://doi.org/10.1016/j.smr.2024.101931>
- Deliens, G., & Peigneux, P. (2014). One night of sleep is insufficient to achieve sleep-to-forget emotional decontextualisation processes. *Cognition and Emotion*, 28(4), 698–706. <https://doi.org/10.1080/02699931.2013.844105>
- Dement, W., & Kleitman, N. (1957). The relation of eye movements during sleep to dream activity: An objective method for the study of dreaming. *Journal of Experimental Psychology*, 53(5), 339–346.
- Deperrois, N., Petrovici, M. A., Senn, W., & Jordan, J. (2022). Learning cortical representations through perturbed and adversarial dreaming. *eLife*, 11, e76384. <https://doi.org/10.7554/eLife.76384>
- Desai, D., Momin, A., Hirpara, P., Jha, H., Thaker, R., & Patel, J. (2024). Exploring the role of circadian rhythms in sleep and recovery: A review article. *Cureus*, 16(6), e61568. <https://doi.org/10.7759/cureus.61568>
- Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, 11(2), 114–126. <https://doi.org/10.1038/nrn2762>
- Ding, L., Chen, B., Dai, Y., & Li, Y. (2022). A meta-analysis of the first-night effect in healthy individuals for the full age spectrum. *Sleep Medicine*, 89, 159–165. <https://doi.org/10.1016/j.sleep.2021.12.007>
- Domhoff, G. W. (1996). *Finding meaning in dreams: A quantitative approach*. Springer Science + Business Media. <https://doi.org/10.1007/978-1-4899-0298-6>
- Domhoff, G. W. (2003). *The scientific study of dreams: Neural networks, cognitive development, and content analysis*. American Psychological Association.
- Domhoff, G. W. (2017). The invasion of the concept snatchers: The origins, distortions, and future of the continuity hypothesis. *Dreaming*, 27(1), 14–39. <https://doi.org/10.1037/drm0000047>
- Dworak, M., Schierl, T., Bruns, T., & Strüder, H. K. (2007). Impact of singular excessive computer game and television exposure on sleep patterns and memory performance of school-aged children. *Pediatrics*, 120(5), 978–985. <https://doi.org/10.1542/peds.2007-0476>
- Eggermont, S., & Van den Bulck, J. (2006). Nodding off or switching off? The use of popular media as a sleep aid in secondary-school children. *Journal of Paediatrics and Child Health*, 42(7–8), 428–433. <https://doi.org/10.1111/j.1440-1754.2006.00892.x>
- Eichenlaub, J.-B., Cash, S. S., & Blagrove, M. (2017). Daily life experiences in dreams and sleep-dependent memory consolidation. In N. Axmacher & B. Rasch (Eds.), *Cognitive Neuroscience of Memory Consolidation* (pp. 161–172). Springer International Publishing. https://doi.org/10.1007/978-3-319-45066-7_10
- Eichenlaub, J.-B., Van Rijn, E., Gaskell, M. G., Lewis, P. A., Maby, E., Malinowski, J. E., Walker, M. P., Boy, F., & Blagrove, M. (2018). Incorporation of recent waking-life experiences in dreams correlates with frontal theta activity in REM sleep. *Social Cognitive and Affective Neuroscience*, 13(6), 637–647. <https://doi.org/10.1093/scan/nsy041>
- Eichenlaub, J.-B., Van Rijn, E., Phelan, M., Ryder, L., Gaskell, M. G., Lewis, P. A., Walker, M. P., & Blagrove, M. (2018). The nature of delayed dream incorporation ('dream-lag effect'): Personally

- significant events persist, but not major daily activities or concerns. *Journal of Sleep Research*, 28(1). <https://doi.org/DOI:%252010.1111/jsr.12697>
- Elkins, G. (2024). Clinical hypnosis intervention for improving sleep quality: Emerging research and future directions. *International Journal of Clinical and Experimental Hypnosis*, 72(2), 91–93. <https://doi.org/10.1080/00207144.2024.2321103>
- Elkins, G. R., Barabasz, A. F., Council, J. R., & Spiegel, D. (2015). Advancing research and practice: The revised APA division 30 definition of hypnosis. *International Journal of Clinical and Experimental Hypnosis*, 63(1), 1–9. <https://doi.org/10.1080/00207144.2014.961870>
- Ellithorpe, M. E., Eden, A., Ulusoy, E., Wirz, D., & Grady, S. (2025). Is bedtime media use good or bad? A competitive analysis between the sleep displacement hypothesis and the media recovery hypothesis. *Media Psychology*, 28(4), 516–547. <https://doi.org/10.1080/15213269.2024.2400571>
- Ellithorpe, M. E., Ulusoy, E., Eden, A., Hahn, L., Yang, C.-L., & Tucker, R. M. (2022). The complicated impact of media use before bed on sleep: Results from a combination of objective EEG sleep measurement and media diaries. *Journal of Sleep Research*, 31(5), e13551. <https://doi.org/10.1111/jsr.13551>
- Elman, J. L. (2005). Connectionist models of cognitive development: Where next? *Trends in Cognitive Sciences*, 9(3), 111–117. <https://doi.org/10.1016/j.tics.2005.01.005>
- Endo, S., Kobayashi, T., Yamamoto, T., Fukuda, H., Sasaki, M., & Ohta, T. (1981). Persistence of the circadian rhythm of REM sleep: A variety of experimental manipulations of the sleep-wake cycle. *Sleep*, 4(3), 319–328. <https://doi.org/10.1093/sleep/4.3.319>
- Engert, V., Efanov, S. I., Duchesne, A., Vogel, S., Corbo, V., & Pruessner, J. C. (2013). Differentiating anticipatory from reactive cortisol responses to psychosocial stress. *Psychoneuroendocrinology*, 38(8), 1328–1337. <https://doi.org/10.1016/j.psyneuen.2012.11.018>
- Erdelyi, M. H. (2017). The continuity hypothesis. *Dreaming*, 27(4), 334–344. <https://doi.org/10.1037/drm0000063>
- Erlacher, D., Ehrlenspiel, F., & Schredl, M. (2011). Frequency of nightmares and gender significantly predict distressing dreams of german athletes before competitions or games. *The Journal of Psychology*, 145(4), 331–342.
- Erlacher, D., & Schredl, M. (2010). Practicing a motor task in a lucid dream enhances subsequent performance: A pilot study. *The Sport Psychologist*, 24(2), 157–167. <https://doi.org/10.1123/tsp.24.2.157>
- Espie, C. A. (2002). Insomnia: Conceptual issues in the development, persistence, and treatment of sleep disorder in adults. *Annual Review of Psychology*, 53(1), 215–243. <https://doi.org/10.1146/annurev.psych.53.100901.135243>
- Espie, C. A. (2023). Revisiting the psychobiological inhibition model: A conceptual framework for understanding and treating insomnia using cognitive and behavioural therapeutics (CBTx). *Journal of Sleep Research*, 32(6), e13841. <https://doi.org/10.1111/jsr.13841>
- Espie, C. A., Broomfield, N. M., MacMahon, K. M. A., Macphee, L. M., & Taylor, L. M. (2006). The attention–intention–effort pathway in the development of psychophysiologic insomnia: A theoretical review. *Sleep Medicine Reviews*, 10(4), 215–245. <https://doi.org/10.1016/j.smr.2006.03.002>
- Exelmans, L., & Van den Bulck, J. (2017a). Bedtime, shuteye time and electronic media: Sleep displacement is a two-step process. *Journal of Sleep Research*, 26(3), 364–370. <https://doi.org/10.1111/jsr.12510>
- Exelmans, L., & Van den Bulck, J. (2017b). Binge viewing, sleep, and the role of pre-sleep arousal. *Journal of Clinical Sleep Medicine*, 13(08), 1001–1008. <https://doi.org/10.5664/jcsm.6704>
- Exelmans, L., & Van den Bulck, J. (2019). Sleep research: A primer for media scholars. *Health Communication*, 34(5), 519–528. <https://doi.org/10.1080/10410236.2017.1422100>
- Fairholme, C. P., & Manber, R. (2015). Sleep, emotions, and emotion regulation. In *Sleep and Affect* (pp. 45–61). Elsevier. <https://doi.org/10.1016/B978-0-12-417188-6.00003-7>
- Feinberg, I., Maloney, T., & March, J. D. (1992). Precise Conservation of NREM Period 1 (NREMP1) Delta Across Naps and Nocturnal Sleep: Implications for REM Latency and NREM/REM Alternation. *Sleep*, 15(5), 400–403.

- Feng, Y.-Z., Chen, J.-T., Hu, Z.-Y., Liu, G.-X., Zhou, Y.-S., Zhang, P., Su, A.-X., Yang, S., Zhang, Y.-M., Wei, R.-M., & Chen, G.-H. (2023). Effects of sleep reactivity on sleep macro-structure, orderliness, and cortisol after stress: A preliminary study in healthy young adults. *Nature and Science of Sleep*, 15, 533–546. <https://doi.org/10.2147/NSS.S415464>
- Ficca, G., De Rosa, O., Giangrande, D., Mazzei, T., Marzolo, S., Albinni, B., Coppola, A., Lustro, A., & Conte, F. (2024). Quantitative–qualitative assessment of dream reports in schizophrenia and their correlations with illness severity. *Brain Sciences*, 14(6), 568. <https://doi.org/10.3390/brainsci14060568>
- Fogel, S. M., Ray, L. B., Sergeeva, V., De Koninck, J., & Owen, A. M. (2018). A novel approach to dream content analysis reveals links between learning-related dream incorporation and cognitive abilities. *Frontiers in Psychology*, 9. <https://doi.org/10.3389/fpsyg.2018.01398>
- Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(3), 319–325. <https://doi.org/10.1002/wcs.1226>
- Forte, G., Favieri, F., Tambelli, R., & Casagrande, M. (2023). To binge watch TV series: How a leisure activity may affect sleep, mood and quality of life. *Psychology Research and Behavior Management*, 16, 2395–2405. <https://doi.org/10.2147/PRBM.S407854>
- Fosse, M. J., Fosse, R., Hobson, J. A., & Stickgold, R. (2003). Dreaming and episodic memory: A functional dissociation? *Journal of Cognitive Neuroscience*, 15(1), 1–9. <https://doi.org/10.1162/089892903321107774>
- Fosse, R., Stickgold, R., & Hobson, J. A. (2004). Thinking and hallucinating: Reciprocal changes in sleep. *Psychophysiology*, 41(2), 298–305. <https://doi.org/10.1111/j.1469-8986.2003.00146.x>
- Freud, S. (1913). *The interpretation of dreams* (A. A. Brill, Trans.). Macmillan.
- Geldenhuys, C., van den Heuvel, L. L., Steyn, P., & Seedat, S. (2022). Pharmacological management of nightmares associated with posttraumatic stress disorder. *CNS Drugs*, 36(7), 721–737. <https://doi.org/10.1007/s40263-022-00929-x>
- Ghibellini, R., & Meier, B. (2023). The hypnagogic state: A brief update. *Journal of Sleep Research*, 32(1), e13719. <https://doi.org/10.1111/jsr.13719>
- Ghibellini, R., & Meier, B. (2025). Interruption, recall and resumption: A meta-analysis of the Zeigarnik and Ovsiankina effects. *Humanities and Social Sciences Communications*, 12(1), 962. <https://doi.org/10.1057/s41599-025-05000-w>
- Goldberg, Z., Thomas, K. G. F., & Lipinska, G. (2020). Bedtime stress increases sleep latency and impairs next-day prospective memory performance. *Frontiers in Neuroscience*, 14, 756. <https://doi.org/10.3389/fnins.2020.00756>
- Goldstein, A. N., & Walker, M. P. (2014). The role of sleep in emotional brain function. *Annual Review of Clinical Psychology*, 10(1), 679–708. <https://doi.org/10.1146/annurev-clinpsy-032813-153716>
- Gorgoni, M., D’Atri, A., Scarpelli, S., Ferrara, M., & De Gennaro, L. (2019). Timing and topography of sleep onset: Asynchronies and regional changes of brain activity. In H. C. Dringenberg (Ed.), *Handbook of Behavioral Neuroscience* (Vol. 30, pp. 19–31). Elsevier. <https://doi.org/10.1016/B978-0-12-813743-7.00002-5>
- Goschke, T., & Kuhl, J. (1997). Representation of intentions: Persisting activation in memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 19(5), 1211–1226.
- Graveline, Y. M., & Wamsley, E. J. (2015). Dreaming and waking cognition. *Translational Issues in Psychological Science*, 1(1), 97–105. <https://doi.org/10.1037/tps0000018>
- Groch, S., Wilhelm, I., Diekelmann, S., & Born, J. (2013). The role of REM sleep in the processing of emotional memories: Evidence from behavior and event-related potentials. *Neurobiology of Learning and Memory*, 99, 1–9. <https://doi.org/10.1016/j.nlm.2012.10.006>
- Groch, S., Zinke, K., Wilhelm, I., & Born, J. (2015). Dissociating the contributions of slow-wave sleep and rapid eye movement sleep to emotional item and source memory. *Neurobiology of Learning and Memory*, REM Sleep and Memory, 122, 122–130. <https://doi.org/10.1016/j.nlm.2014.08.013>
- Gross, R. T., & Borkovec, T. D. (1982). Effects of a cognitive intrusion manipulation on the sleep-onset latency of good sleepers. *Behavior Therapy*, 13(1), 112–116. [https://doi.org/10.1016/S0005-7894\(82\)80054-3](https://doi.org/10.1016/S0005-7894(82)80054-3)
- Guilliams, T. G., & Edwards, L. (2010). Chronic stress and the HPA axis. *The Standard*, 9(2), 1–12.

- Gujar, N., McDonald, S. A., Nishida, M., & Walker, M. P. (2011). A role for REM sleep in recalibrating the sensitivity of the human brain to specific emotions. *Cerebral Cortex*, 21(1), 115–123. <https://doi.org/10.1093/cercor/bhq064>
- Halonen, R., Kuula, L., Makkonen, T., Kauramäki, J., & Pesonen, A.-K. (2021). Self-conscious affect is modulated by rapid eye movement sleep but not by targeted memory reactivation—A pilot study. *Frontiers in Psychology*, 12, 730924. <https://doi.org/10.3389/fpsyg.2021.730924>
- Hammond, D. C. (2010). Hypnosis in the treatment of anxiety- and stress-related disorders. *Expert Review of Neurotherapeutics*, 10(2), 263–273. <https://doi.org/10.1586/ern.09.140>
- Han, X., Zhou, E., & Liu, D. (2024). Electronic media use and sleep quality: Updated systematic review and meta-analysis. *Journal of Medical Internet Research*, 26(1), e48356. <https://doi.org/10.2196/48356>
- Hantsoo, L., Khou, C. S., White, C. N., & Ong, J. C. (2013). Gender and cognitive–emotional factors as predictors of pre-sleep arousal and trait hyperarousal in insomnia. *Journal of Psychosomatic Research*, 74(4), 283–289. <https://doi.org/10.1016/j.jpsychores.2013.01.014>
- Harbard, E., Allen, N. B., Trinder, J., & Bei, B. (2016). What’s keeping teenagers up? Prebedtime behaviors and actigraphy-assessed sleep over school and vacation. *Journal of Adolescent Health*, 58(4), 426–432. <https://doi.org/10.1016/j.jadohealth.2015.12.011>
- Hartmann, E. (1998). Nightmare after trauma as paradigm for all dreams: A new approach to the nature and functions of dreaming. *Psychiatry*, 61(3), 223–238. <https://doi.org/10.1080/00332747.1998.11024834>
- Hartmann, E. (2001). *Dreams and nightmares: The origin and meaning of dreams*. Basic Books.
- Hartmann, E. (2010a). The dream always makes new connections: The dream is a creation, not a replay. *Sleep Medicine Clinics*, 5(2), 241–248. <https://doi.org/10.1016/j.jsmc.2010.01.009>
- Hartmann, E. (2010b). *The nature and functions of dreaming*. Oxford University Press.
- Harvey, A. G. (2000). Pre-sleep cognitive activity: A comparison of sleep-onset insomniacs and good sleepers. *British Journal of Clinical Psychology*, 39(3), 275–286. <https://doi.org/10.1348/014466500163284>
- Harvey, A. G. (2002). A cognitive model of insomnia. *Behaviour Research and Therapy*, 40(8), 869–893. [https://doi.org/10.1016/s0005-7967\(01\)00061-4](https://doi.org/10.1016/s0005-7967(01)00061-4)
- Harvey, A. G. (2003). The attempted suppression of presleep cognitive activity in insomnia. *Cognitive Therapy and Research*, 27(6), 593–602.
- Harvey, A. G., & Payne, S. (2002). The management of unwanted pre-sleep thoughts in insomnia: Distraction with imagery versus general distraction. *Behaviour Research and Therapy*, 40(3), 267–277. [https://doi.org/10.1016/S0005-7967\(01\)00012-2](https://doi.org/10.1016/S0005-7967(01)00012-2)
- Hauri, P. J., Silber, M. H., & Boeve, B. F. (2007). The treatment of parasomnias with hypnosis: A 5-year follow-up study. *Journal of Clinical Sleep Medicine*, 3(4), 369–373.
- Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, 293(5539), 2425–2430. <https://doi.org/10.1126/science.1063736>
- Haynes, S. N., Adams, A., & Franzen, M. (1981). The effects of presleep stress on sleep-onset insomnia. *Journal of Abnormal Psychology*, 90(6), 601–606.
- Higuchi, S., Motohashi, Y., Liu, Y., & Maeda, A. (2005). Effects of playing a computer game using a bright display on presleep physiological variables, sleep latency, slow wave sleep and REM sleep. *Journal of Sleep Research*, 14(3), 267–273. <https://doi.org/10.1111/j.1365-2869.2005.00463.x>
- Hobson, A., & McCarley, R. W. (1977). The brain as a dream state generator: An activation-synthesis hypothesis of the dream process. *American Journal of Psychiatry*, 134(12), 1335–1348.
- Hobson, J. A., & Pace-Schott, E. F. (2002). The cognitive neuroscience of sleep: Neuronal systems, consciousness and learning. *Nature Reviews Neuroscience*, 3(9), 679–693. <https://doi.org/10.1038/nrn915>
- Hobson, J. A., Pace-Schott, E. F., & Stickgold, R. (2000). Dreaming and the brain: Toward a cognitive neuroscience of conscious states. *Behavioral and Brain Sciences*, 23(6), 793–842.
- Hobson, J. A., Stickgold, R., & Pace-Schott, E. F. (1998). The neuropsychology of REM sleep dreaming: *NeuroReport*, 9(3), R1–R14. <https://doi.org/10.1097/00001756-199802160-00033>

- Hoelscher, T. J., Klinger, E., & Barta, S. G. (1981). Incorporation of concern- and nonconcern-related verbal stimuli into dream content. *Journal of Abnormal Psychology, 90*(1), 88–91.
- Hong, C. C.-H., Harris, J. C., Pearlson, G. D., Kim, J.-S., Calhoun, V. D., Fallon, J. H., Golay, X., Gillen, J. S., Simmonds, D. J., van Zijl, P. C. M., Zee, D. S., & Pekar, J. J. (2009). fMRI evidence for multisensory recruitment associated with rapid eye movements during sleep. *Human Brain Mapping, 30*(5), 1705–1722. <https://doi.org/10.1002/hbm.20635>
- Horikawa, T., & Kamitani, Y. (2017). Hierarchical neural representation of dreamed objects revealed by brain decoding with deep neural network features. *Frontiers in Computational Neuroscience, 11*. <https://doi.org/10.3389/fncom.2017.00004>
- Horton, C. L., & Malinowski, J. E. (2015). Autobiographical memory and hyperassociativity in the dreaming brain: Implications for memory consolidation in sleep. *Frontiers in Psychology, 6*, 874. <https://doi.org/10.3389/fpsyg.2015.00874>
- Hu, X., Cheng, L. Y., Chiu, M. H., & Paller, K. A. (2020). Promoting memory consolidation during sleep: A meta-analysis of targeted memory reactivation. *Psychological Bulletin, 146*(3), 218–244. <https://doi.org/10.1037/bul0000223>
- Hudachek, L., & Wamsley, E. J. (2023). A meta-analysis of the relation between dream content and memory consolidation. *SLEEP, 46*(12), zsad111. <https://doi.org/10.1093/sleep/zsad111>
- Hülsemann, M. J., & Rasch, B. (2021). Embodiment of sleep-related words: Evidence from event-related potentials. *Psychophysiology, 58*(8), e13824. <https://doi.org/10.1111/psyp.13824>
- Hutchison, I. C., & Rathore, S. (2015). The role of REM sleep theta activity in emotional memory. *Frontiers in Psychology, 6*, 1439. <https://doi.org/10.3389/fpsyg.2015.01439>
- Ikeda, H., & Hayashi, M. (2008). Electroencephalogram activity before self-awakening. *Sleep and Biological Rhythms, 6*(4), 256–259. <https://doi.org/10.1111/j.1479-8425.2008.00366.x>
- Irwin, M. R. (2015). Why sleep is important for health: A psychoneuroimmunology perspective. *Annual Review of Psychology, 66*(1), 143–172. <https://doi.org/10.1146/annurev-psych-010213-115205>
- Janson, J., & Rohleder, N. (2017). Distraction coping predicts better cortisol recovery after acute psychosocial stress. *Biological Psychology, 128*, 117–124. <https://doi.org/10.1016/j.biopsycho.2017.07.014>
- Jansson-Fröjmark, M., Alfnsson, S., Bohman, B., Rozental, A., & Norell-Clarke, A. (2022). Paradoxical intention for insomnia: A systematic review and meta-analysis. *Journal of Sleep Research, 31*(2), e13464. <https://doi.org/10.1111/jsr.13464>
- Jensen, M. P., & Patterson, D. R. (2014). Hypnotic approaches for chronic pain management: Clinical implications of recent research findings. *American Psychologist, 69*(2), 167–177. <https://doi.org/10.1037/a0035644>
- Joliot, M., Ribary, U., & Llinás, R. (1994). Human oscillatory brain activity near 40 Hz coexists with cognitive temporal binding. *Proceedings of the National Academy of Sciences, 91*(24), 11748–11751. <https://doi.org/10.1073/pnas.91.24.11748>
- Kahn, D., Combs, A., & Krippner, S. (2002). Dreaming as a function of chaos-like stochastic processes in the self-organizing brain. *Nonlinear Dynamics, Psychology, and Life Sciences, 6*(4), 311–322.
- Kaida, K., Nittono, H., Hayashi, M., & Hori, T. (2003). Effect of self-awakening on sleep structure of a daytime short nap and on subsequent arousal levels. *Perceptual and Motor Skills, 97*, 1073–1084.
- Kaida, K., Ogawa, K., Hayashi, M., & Hori, T. (2005). Self-awakening prevents acute rise in blood pressure and heart rate at the time of awakening in elderly people. *Industrial Health, 43*(1), 179–185. <https://doi.org/10.2486/indhealth.43.179>
- Kalmbach, D. A., Anderson, J. R., & Drake, C. L. (2018). The impact of stress on sleep: Pathogenic sleep reactivity as a vulnerability to insomnia and circadian disorders. *Journal of Sleep Research, 27*(6), e12710. <https://doi.org/10.1111/jsr.12710>
- Kheirikhah, M., Duncan, W. C., Yuan, Q., Wang, P. R., Jamalabadi, H., Leistritz, L., Walter, M., Goldman, D., Zarate, C. A., & Hejazi, N. S. (2025). REM density predicts rapid antidepressant response to ketamine in individuals with treatment-resistant depression. *Neuropsychopharmacology, 50*(6), 941–946. <https://doi.org/10.1038/s41386-025-02066-7>

- Kiefer, M., & Pulvermüller, F. (2012). Conceptual representations in mind and brain: Theoretical developments, current evidence and future directions. *Cortex, Language and the Motor System*, 48(7), 805–825. <https://doi.org/10.1016/j.cortex.2011.04.006>
- Kim, H., & Kim, E. J. (2018). Effects of relaxation therapy on anxiety disorders: A systematic review and meta-analysis. *Archives of Psychiatric Nursing*, 32(2), 278–284. <https://doi.org/10.1016/j.apnu.2017.11.015>
- King, D. L., Delfabbro, P. H., Zwaans, T., & Kaptsis, D. (2014). Sleep interference effects of pathological electronic media use during adolescence. *International Journal of Mental Health and Addiction*, 12(1), 21–35. <https://doi.org/10.1007/s11469-013-9461-2>
- King, D. L., Gradisar, M., Drummond, A., Lovato, N., Wessel, J., Micic, G., Douglas, P., & Delfabbro, P. (2013). The impact of prolonged violent video-gaming on adolescent sleep: An experimental study. *Journal of Sleep Research*, 22(2), 137–143. <https://doi.org/10.1111/j.1365-2869.2012.01060.x>
- Kinsella, J. E., & Chin, B. N. (2024). Mechanisms linking social media use and sleep in emerging adults in the United States. *Behavioral Sciences*, 14(9), 794. <https://doi.org/10.3390/bs14090794>
- Klainin-Yobas, P., Oo, W. N., Suzanne Yew, P. Y., & Lau, Y. (2015). Effects of relaxation interventions on depression and anxiety among older adults: A systematic review. *Aging & Mental Health*, 19(12), 1043–1055. <https://doi.org/10.1080/13607863.2014.997191>
- Knezevic, E., Nenic, K., Milanovic, V., & Knezevic, N. N. (2023). The role of cortisol in chronic stress, neurodegenerative diseases, and psychological disorders. *Cells*, 12(23), 2726. <https://doi.org/10.3390/cells12232726>
- Kogler, L., Mueller, V. I., Chang, A., Eickhoff, S. B., Fox, P. T., Gur, R. C., & Derntl, B. (2015). Psychosocial versus physiological stress – meta-analyses on deactivations and activations of the neural correlates of stress reactions. *NeuroImage*, 119, 235–251. <https://doi.org/10.1016/j.neuroimage.2015.06.059>
- Konkoly, K. R., Morris, D., Cho, M., Hurka, K., Torres-Platas, S. G., Baehr, L., & Paller, K. A. (2025). Investigating dreams by strategically presenting sounds during REM sleep to reactivate waking experiences. *PsyArXiv*. https://doi.org/10.31234/osf.io/a3j8w_v1
- Koroma, M., Beck, J., Schmidt, C., Rasch, B., & Demertzi, A. (2024). Probing the embodiment of sleep functions: Insights from cardiac responses to word-induced relaxation during sleep. *Journal of Sleep Research*, 33(5), e14160. <https://doi.org/10.1111/jsr.14160>
- Kouider, S., Andrillon, T., Barbosa, L. S., Goupil, L., & Bekinschtein, T. A. (2014). Inducing task-relevant responses to speech in the sleeping brain. *Current Biology*, 24(18), 2208–2214. <https://doi.org/10.1016/j.cub.2014.08.016>
- Kramer, A. C., Neubauer, A. B., Scott, S. B., Schmiedek, F., Sliwinski, M. J., & Smyth, J. M. (2022). Stressor anticipation and subsequent affective well-being: A link potentially explained by perseverative cognitions. *Emotion*, 22(8), 1787–1800. <https://doi.org/10.1037/emo0000954>
- Kudielka, B. M., & Kirschbaum, C. (2005). Sex differences in HPA axis responses to stress: A review. *Biological Psychology*, 69(1), 113–132. <https://doi.org/10.1016/j.biopsycho.2004.11.009>
- Kumral, D., Palmieri, J., Gais, S., & Schönauer, M. (2025). Pre-sleep experiences shape neural activity and dream content in the sleeping brain. *iScience*, 28(8), 113032. <https://doi.org/10.1016/j.isci.2025.113032>
- Kusse, C., Shaffii-Le Bourdieu, A., Schrouff, J., Matarazzo, L., & Maquet, P. (2012). Experience-dependent induction of hypnagogic images during daytime naps: A combined behavioural and EEG study. *Journal of Sleep Research*, 21(1), 10–20. <https://doi.org/10.1111/j.1365-2869.2011.00939.x>
- Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62(1), 621–647. <https://doi.org/10.1146/annurev.psych.093008.131123>
- Lange, T., Dimitrov, S., & Born, J. (2010). Effects of sleep and circadian rhythm on the human immune system. *Annals of the New York Academy of Sciences*, 1193(1), 48–59. <https://doi.org/10.1111/j.1749-6632.2009.05300.x>
- Lara-Carrasco, J., Nielsen, T. A., Solomonova, E., Levrier, K., & Popova, A. (2009). Overnight emotional adaptation to negative stimuli is altered by REM sleep deprivation and is correlated

- with intervening dream emotions. *Journal of Sleep Research*, 18(2), 178–187. <https://doi.org/10.1111/j.1365-2869.2008.00709.x>
- Lau, E. Y. Y., Li, C., Hui, C. H., Cheung, S. F., Lam, J., & Cheung, S.-H. (2021). A longitudinal investigation of the bidirectional relationship of sleep quality with emotional stability and social cynicism in a large community sample. *Sleep Health*, 7(3), 384–389. <https://doi.org/10.1016/j.sleh.2021.03.007>
- Lauer, C., Riemann, D., Lund, R., & Berger, M. (1987). Shortened REM latency: A consequence of psychological strain? *Psychophysiology*, 24(3).
- Lee-Chiong, T. (2008). *Sleep Medicine: Essentials and Review*. Oxford University Press.
- Lemola, S., Perkinson-Gloor, N., Brand, S., Dewald-Kaufmann, J. F., & Grob, A. (2015). Adolescents' electronic media use at night, sleep disturbance, and depressive symptoms in the smartphone age. *Journal of Youth and Adolescence*, 44(2), 405–418. <https://doi.org/10.1007/s10964-014-0176-x>
- Lemyre, A., Belzile, F., Landry, M., Bastien, C. H., & Beaudoin, L. P. (2020). Pre-sleep cognitive activity in adults: A systematic review. *Sleep Medicine Reviews*, 50, 101253. <https://doi.org/10.1016/j.smrv.2019.101253>
- Levin, R., Fireman, G., & Nielsen, T. (2010). Disturbed dreaming and emotion dysregulation. *Sleep Medicine Clinics*, 5(2), 229–239. <https://doi.org/10.1016/j.jsmc.2010.01.006>
- Levin, R., & Nielsen, T. (2007). Disturbed dreaming, posttraumatic stress disorder, and affect distress: A review and neurocognitive model. *Psychological Bulletin*, 133(3), 482–528. <https://doi.org/10.1037/0033-2909.133.3.482>
- Levin, R., & Nielsen, T. (2009). Nightmares, bad dreams, and emotion dysregulation: A review and new neurocognitive model of dreaming. *Current Directions in Psychological Science*, 18(2), 84–88. <https://doi.org/10.1111/j.1467-8721.2009.01614.x>
- Lewis, P. A., & Durrant, S. J. (2011). Overlapping memory replay during sleep builds cognitive schemata. *Trends in Cognitive Sciences*, 15(8), 343–351. <https://doi.org/10.1016/j.tics.2011.06.004>
- Li, C., Kee, Y. H., & Lam, L. S. (2018). Effect of brief mindfulness induction on university athletes' sleep quality following night training. *Frontiers in Psychology*, 9, 508. <https://doi.org/10.3389/fpsyg.2018.00508>
- Li, S., Jin, X., Wu, S., Jiang, F., Yan, C., & Shen, X. (2007). The Impact of Media Use on Sleep Patterns and Sleep Disorders among School-Aged Children in China. *Sleep*, 30(3), 361–367. <https://doi.org/10.1093/sleep/30.3.361>
- Li, Y., Gu, S., Wang, Z., Li, H., Xu, X., Zhu, H., Deng, S., Ma, X., Feng, G., Wang, F., & Huang, J. H. (2019). Relationship between stressful life events and sleep quality: Rumination as a mediator and resilience as a moderator. *Frontiers in Psychiatry*, 10, 348. <https://doi.org/10.3389/fpsyg.2019.00348>
- Lipinska, G., Austin, H., Moonsamy, J. R., Henry, M., Lewis, R., Baldwin, D. S., Thomas, K. G. F., & Stuart, B. (2022). Preferential consolidation of emotional reactivity during sleep: A systematic review and meta-analysis. *Frontiers in Behavioral Neuroscience*, 16, 976047. <https://doi.org/10.3389/fnbeh.2022.976047>
- Lipinska, G., Stuart, B., Thomas, K. G. F., Baldwin, D. S., & Bolinger, E. (2019). Preferential consolidation of emotional memory during sleep: A meta-analysis. *Frontiers in Psychology*, 10, 1014. <https://doi.org/10.3389/fpsyg.2019.01014>
- Liu, K., Chen, Y., Wu, D., Lin, R., Wang, Z., & Pan, L. (2020). Effects of progressive muscle relaxation on anxiety and sleep quality in patients with COVID-19. *Complementary Therapies in Clinical Practice*, 39, 101132. <https://doi.org/10.1016/j.ctcp.2020.101132>
- Llewellyn, S. (2013). Such stuff as dreams are made on? Elaborative encoding, the ancient art of memory, and the hippocampus. *Behavioral and Brain Sciences*, 36(6), 589–607. <https://doi.org/10.1017/S0140525X12003135>
- Lundh, L.-G., & Broman, J.-E. (2000). Insomnia as an interaction between sleep-interfering and sleep-interpreting processes. *Journal of Psychosomatic Research*, 49(5), 299–310. [https://doi.org/10.1016/S0022-3999\(00\)00150-1](https://doi.org/10.1016/S0022-3999(00)00150-1)
- Ly, J. Q. M., Gaggioni, G., Chellappa, S. L., Papachilleos, S., Brzozowski, A., Borsu, C., Rosanova, M., Sarasso, S., Middleton, B., Luxen, A., Archer, S. N., Phillips, C., Dijk, D.-J., Maquet, P.,

- Massimini, M., & Vandewalle, G. (2016). Circadian regulation of human cortical excitability. *Nature Communications*, 7(1), 11828. <https://doi.org/10.1038/ncomms11828>
- Madrid-Valero, J. J., Martínez-Selva, J. M., Couto, B. R. do, Sánchez-Romera, J. F., & Ordoñana, J. R. (2017). Age and gender effects on the prevalence of poor sleep quality in the adult population. *Gaceta Sanitaria*, 31, 18–22. <https://doi.org/10.1016/j.gaceta.2016.05.013>
- Malinowski, J. E., & Horton, C. L. (2014a). Emotion but not stress modulates the incorporation of waking experiences into dreams. *Dreaming*, 24(1), 18–31.
- Malinowski, J. E., & Horton, C. L. (2014b). Memory sources of dreams: The incorporation of autobiographical rather than episodic experiences. *Journal of Sleep Research*, 23(4), 441–447. <https://doi.org/10.1111/jsr.12134>
- Malinowski, J. E., & Horton, C. L. (2015). Metaphor and hyperassociativity: The imagination mechanisms behind emotion assimilation in sleep and dreaming. *Frontiers in Psychology*, 6, 1132. <https://doi.org/10.3389/fpsyg.2015.01132>
- Malinowski, J. E., & Horton, C. L. (2021). Dreams reflect nocturnal cognitive processes: Early-night dreams are more continuous with waking life, and late-night dreams are more emotional and hyperassociative. *Consciousness and Cognition*, 88, 103071. <https://doi.org/10.1016/j.concog.2020.103071>
- Mallett, R., Konkoly, K. R., Nielsen, T., Carr, M., & Paller, K. A. (2024). New strategies for the cognitive science of dreaming. *Trends in Cognitive Sciences*, 28(12), 1105–1117. <https://doi.org/10.1016/j.tics.2024.10.004>
- Maquet, P., Péters, J., Aerts, J., Delfiore, G., Degueldre, C., Luxen, A., & Franck, G. (1996). Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. *Nature*, 383(6596), 163–166. <https://doi.org/10.1038/383163a0>
- Maquet, P., Ruby, P., Maudoux, A., Albouy, G., Sterpenich, V., Dang-Vu, T., Desseilles, M., Boly, M., Perrin, F., Peigneux, P., & Laureys, S. (2005). Human cognition during REM sleep and the activity profile within frontal and parietal cortices: A reappraisal of functional neuroimaging data. In *Progress in Brain Research* (Vol. 150, pp. 219–595). Elsevier. [https://doi.org/10.1016/S0079-6123\(05\)50016-5](https://doi.org/10.1016/S0079-6123(05)50016-5)
- Maranci, J.-B., Nigam, M., Masset, L., Msika, E.-F., Vionnet, M. C., Chaumereil, C., Vidailhet, M., Leu-Semenescu, S., & Arnulf, I. (2022). Eye movement patterns correlate with overt emotional behaviours in rapid eye movement sleep. *Scientific Reports*, 12(1), 1770. <https://doi.org/10.1038/s41598-022-05905-5>
- Maric, A., Lustenberger, C., Werth, E., Baumann, C. R., Poryazova, R., & Huber, R. (2017). Intraindividual Increase of Homeostatic Sleep Pressure Across Acute and Chronic Sleep Loss: A High-Density EEG Study. *Sleep*, 40(9), zsx122. <https://doi.org/10.1093/sleep/zsx122>
- Martin, J. M., Andriano, D. W., Mota, N. B., Mota-Rolim, S. A., Araújo, J. F., Solms, M., & Ribeiro, S. (2020). Structural differences between REM and non-REM dream reports assessed by graph analysis. *PLOS ONE*, 15(7), e0228903. <https://doi.org/10.1371/journal.pone.0228903>
- Maruani, J., Martins, N., Clerici, E., Lejoyeux, M., & Geoffroy, P. A. (2026). Imagery Rehearsal Therapy (IRT) is associated with reduced nightmare severity and depressive, anxiety and suicidal symptoms in adults with Major Depressive Episode. *International Journal of Clinical and Health Psychology*, 26(1), 100658. <https://doi.org/10.1016/j.ijchp.2025.100658>
- Massimini, M., Ferrarelli, F., Murphy, M., Huber, R., Riedner, B., Casarotto, S., & Tononi, G. (2010). Cortical reactivity and effective connectivity during REM sleep in humans. *Cognitive Neuroscience*, 1(3), 176–183. <https://doi.org/10.1080/17588921003731578>
- McManus, M. D., Siegel, J. T., & Nakamura, J. (2019). The predictive power of low-arousal positive affect. *Motivation and Emotion*, 43(1), 130–144. <https://doi.org/10.1007/s11031-018-9719-x>
- McNamara, P., Johnson, P., McLaren, D., Harris, E., Beauharnais, C., & Auerbach, S. (2010). REM and NREM sleep mentation. In *International Review of Neurobiology* (Vol. 92, pp. 69–86). Elsevier. [https://doi.org/10.1016/S0074-7742\(10\)92004-7](https://doi.org/10.1016/S0074-7742(10)92004-7)
- Mendoza-Alvarez, M., Balthasar, Y., Verbraecken, J., Claes, L., Van Someren, E., Van Marle, H. J. F., Vandekerckhove, M., & De Picker, L. (2025). Systematic review: REM sleep, dysphoric dreams and nightmares as transdiagnostic features of psychiatric disorders with emotion dysregulation - Clinical implications. *Sleep Medicine*, 127, 1–15. <https://doi.org/10.1016/j.sleep.2024.12.037>

- Mercer, J. D., Bootzin, R. R., & Lack, L. C. (2002). Insomniacs' Perception of Wake Instead of Sleep. *Sleep*, 25(5), 559–566. <https://doi.org/10.1093/sleep/25.5.559>
- Merikivi, J., Bragge, J., Scornavacca, E., & Verhagen, T. (2020). Binge-watching Serialized Video Content: A Transdisciplinary Review. *Television & New Media*, 21(7), 697–711. <https://doi.org/10.1177/1527476419848578>
- Merrit, J., Stickgold, R., Pace-Schott, E. F., Williams, J., & Hobson, J. A. (1994). Emotion profiles in the Dreams of Men and Women. *Consciousness and Cognition*, 3, 46–60.
- Michlin, M. (2011). More, more, more: Contemporary American TV Series and the attractions and challenges of serialization as ongoing narrative. *Mise Au Point. Cahiers de l'association Française Des Enseignants et Chercheurs En Cinéma et Audiovisuel*, (3). <https://doi.org/10.4000/map.927>
- Miller, K. E., & Gehrman, P. R. (2019). REM sleep: What is it good for? *Current Biology*, 29(16), R806–R807. <https://doi.org/10.1016/j.cub.2019.06.074>
- Miyauchi, S., Misaki, M., Kan, S., Fukunaga, T., & Koike, T. (2009). Human brain activity time-locked to rapid eye movements during REM sleep. *Experimental Brain Research*, 192(4), 657–667. <https://doi.org/10.1007/s00221-008-1579-2>
- Morgenthaler, J., Wiesner, C. D., Hinze, K., Abels, L. C., Prehn-Kristensen, A., & Göder, R. (2014). Selective REM-sleep deprivation does not diminish emotional memory consolidation in young healthy subjects. *PLOS ONE*, 9(2), e89849. <https://doi.org/10.1371/journal.pone.0089849>
- Morin, C. M., Rodrigue, S., & Ivers, H. (2003). Role of stress, arousal, and coping skills in primary insomnia: *Psychosomatic Medicine*, 65(2), 259–267. <https://doi.org/10.1097/01.PSY.0000030391.09558.A3>
- Mundt, J. M., Pruiksma, K. E., Konkoly, K. R., Casiello-Robbins, C., Nadorff, M. R., Franklin, R.-C., Karanth, S., Byskosh, N., Morris, D. J., Torres-Platas, S. G., Mallett, R., Maski, K., & Paller, K. A. (2025). Treating narcolepsy-related nightmares with cognitive behavioural therapy and targeted lucidity reactivation: A pilot study. *Journal of Sleep Research*, 34(3), e14384. <https://doi.org/10.1111/jsr.14384>
- Murphy, M., & Peterson, M. J. (2015). Sleep disturbances in depression. *Sleep Medicine Clinics*, 10(1), 17–23. <https://doi.org/10.1016/j.jsmc.2014.11.009>
- Naselaris, T., Olman, C. A., Stansbury, D. E., Ugurbil, K., & Gallant, J. L. (2015). A voxel-wise encoding model for early visual areas decodes mental images of remembered scenes. *NeuroImage*, 105, 215–228. <https://doi.org/10.1016/j.neuroimage.2014.10.018>
- Nguyen, N. D., Tucker, M. A., Stickgold, R., & Wamsley, E. J. (2013). Overnight sleep enhances hippocampus-dependent aspects of spatial memory. *Sleep*, 36(7), 1051–1057. <https://doi.org/10.5665/sleep.2808>
- Nielsen, T. (2000). A review of mentation in REM and NREM sleep: “Covert” REM sleep as a possible reconciliation of two opposing models. *Behavioral and Brain Sciences*, 23(6), 851–866. <https://doi.org/10.1017/S0140525X0000399X>
- Nielsen, T. A., Deslauriers, D., & Baylor, G. W. (1991). Emotions in dream and waking event reports. *Dreaming*, 1(4), 287–300. <https://doi.org/10.1037/h0094340>
- Nielsen, T. A., & Germain, A. (2000). Post-traumatic nightmares as a dysfunctional state. *Behavioral and Brain Sciences*, 23(6), 978–979. <https://doi.org/10.1017/S0140525X0070402X>
- Nielsen, T., Kuiken, D., Hoffmann, R., & Moffitt, A. (2001). REM and NREM sleep mentation differences: A question of story structure? *Sleep and Hypnosis*, 3(1), 9–17.
- Nielsen, T., & Levin, R. (2007). Nightmares: A new neurocognitive model. *Sleep Medicine Reviews*, 11(4), 295–310. <https://doi.org/10.1016/j.smr.2007.03.004>
- Nikles, C. D., Brecht, D. L., Klinger, E., & Bursell, A. L. (1998). The effects of current-concern- and nonconcern-related waking suggestions on nocturnal dream content. *Journal of Personality and Social Psychology*, 75(1), 242–255.
- Nir, Y., & Tononi, G. (2010). Dreaming and the brain: From phenomenology to neurophysiology. *Trends in Cognitive Sciences*, 14(2), 88–100. <https://doi.org/10.1016/j.tics.2009.12.001>
- Nishida, M., Pearsall, J., Buckner, R. L., & Walker, M. P. (2009). REM sleep, prefrontal theta, and the consolidation of human emotional memory. *Cerebral Cortex*, 19(5), 1158–1166. <https://doi.org/10.1093/cercor/bhn155>

- Oakley, D. A., & Halligan, P. W. (2009). Hypnotic suggestion and cognitive neuroscience. *Trends in Cognitive Sciences*, 13(6), 264–270. <https://doi.org/10.1016/j.tics.2009.03.004>
- OFS/BFS. (2024). Troubles du sommeil dans la population. *Office Fédérale de La Statistique*.
- Ogilvie, R. D. (2001). The process of falling asleep. *Sleep Medicine Reviews*, 5(3), 247–270. <https://doi.org/10.1053/smr.2001.0145>
- Ohayon, M. M., Carskadon, M. A., Guilleminault, C., & Vitiello, M. V. (2004). Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: Developing normative sleep values across the human lifespan. *Sleep*, 27(7), 1255–1273. <https://doi.org/10.1093/sleep/27.7.1255>
- Öhman, A. (2005). The role of the amygdala in human fear: Automatic detection of threat. *Psychoneuroendocrinology*, 30(10), 953–958. <https://doi.org/10.1016/j.psyneuen.2005.03.019>
- Okamoto-Mizuno, K., Yamashiro, Y., Tanaka, H., Komada, Y., Mizuno, K., Tamaki, M., Kitado, M., Inoue, Y., & Shirakawa, S. (2008). Heart rate variability and body temperature during the sleep onset period. *Sleep and Biological Rhythms*, 6(1), 42–49. <https://doi.org/10.1111/j.1479-8425.2008.00335.x>
- Oldehinkel, A. J., Ormel, J., Bosch, N. M., Bouma, E. M. C., Van Roon, A. M., Rosmalen, J. G. M., & Riese, H. (2011). Stressed out? Associations between perceived and physiological stress responses in adolescents: The TRAILS study. *Psychophysiology*, 48(4), 441–452. <https://doi.org/10.1111/j.1469-8986.2010.01118.x>
- Oswald, I. (1980). Sleep as a restorative process: Human clues. In *Progress in Brain Research* (Vol. 53, pp. 279–288). Elsevier. [https://doi.org/10.1016/S0079-6123\(08\)60069-2](https://doi.org/10.1016/S0079-6123(08)60069-2)
- Oudiette, D., Dealberto, M.-J., Uguccioni, G., Golmard, J.-L., Merino-Andreu, M., Tafti, M., Garma, L., Schwartz, S., & Arnulf, I. (2012). Dreaming without REM sleep. *Consciousness and Cognition*, 21(3), 1129–1140. <https://doi.org/10.1016/j.concog.2012.04.010>
- Oudiette, D., & Paller, K. A. (2013). Upgrading the sleeping brain with targeted memory reactivation. *Trends in Cognitive Sciences*, 17(3), 142–149. <https://doi.org/10.1016/j.tics.2013.01.006>
- Ouwehand, C., de Ridder, D. T. D., & Bensing, J. M. (2008). The characteristics of a potential goal threat predict attention and information-seeking in middle-aged and older adults. *Motivation and Emotion*, 32(2), 90–99. <https://doi.org/10.1007/s11031-008-9088-y>
- Ouyang, M., Hellman, K., Abel, T., & Thomas, S. A. (2004). Adrenergic signaling plays a critical role in the maintenance of waking and in the regulation of REM sleep. *Journal of Neurophysiology*, 92(4), 2071–2082. <https://doi.org/10.1152/jn.00226.2004>
- Pagel, J. F., Blagrove, M., Levin, R., States, B., Stickgold, R., & White, S. (2001). Definitions of dream: A paradigm for comparing field descriptive specific studies of dream. *Dreaming*, 11(4), 195–202. <https://doi.org/10.1023/A:1012240307661>
- Palagini, L., Baglioni, C., Ciapparelli, A., Gemignani, A., & Riemann, D. (2013). REM sleep dysregulation in depression: State of the art. *Sleep Medicine Reviews*, 17(5), 377–390. <https://doi.org/10.1016/j.smr.2012.11.001>
- Paller, K. A., Creery, J. D., & Schechtman, E. (2021). Memory and sleep: How sleep cognition can change the waking mind for the better. *Annual Review of Psychology*, 72(1), 123–150. <https://doi.org/10.1146/annurev-psych-010419-050815>
- Palmer, C. A., & Alfano, C. A. (2017). Sleep and emotion regulation: An organizing, integrative review. *Sleep Medicine Reviews*, 31, 6–16. <https://doi.org/10.1016/j.smr.2015.12.006>
- Palmieri, J., Elce, V., & Schönauer, M. (2025). Nightly dynamics of emotional content in dreams. *Neuropsychologia*, 218, 109248. <https://doi.org/10.1016/j.neuropsychologia.2025.109248>
- Papatsimpa, C., Schlangen, L. J. M., Smolders, K. C. H. J., Linnartz, J.-P. M. G., & de Kort, Y. a. W. (2021). The interindividual variability of sleep timing and circadian phase in humans is influenced by daytime and evening light conditions. *Scientific Reports*, 11(1), 13709. <https://doi.org/10.1038/s41598-021-92863-z>
- Payne, J. D., & Kensinger, E. A. (2010). Sleep's role in the consolidation of emotional episodic memories. *Current Directions in Psychological Science*, 19(5), 290–295. <https://doi.org/10.1177/0963721410383978>
- Peever, J., & Fuller, P. M. (2017). The biology of REM sleep. *Current Biology*, 27(22), R1237–R1248. <https://doi.org/10.1016/j.cub.2017.10.026>

- Perlis, M., Giles, D. E., Mendelson, W. B., Bootzin, R. R., & Wyatt, J. K. (1997). Psychophysiological insomnia: The behavioural model and a neurocognitive perspective. *Journal of Sleep Research*, 6(3), 179–188. <https://doi.org/10.1046/j.1365-2869.1997.00045.x>
- Perlis, M. L., Merica, H., Smith, M. T., & Giles, D. E. (2001). Beta EEG activity and insomnia. *Sleep Medicine Reviews*, 5(5), 365–376. <https://doi.org/10.1053/smr.2001.0151>
- Perlis, M. L., & Nielsen, T. A. (1993). Mood regulation, dreaming and nightmares: Evaluation of a desensitization function for REM sleep. *Dreaming*, 3(4), 243–257. <https://doi.org/10.1037/h0094383>
- Perlis, M. L., Smith, M. T., Andrews, P. J., Orff, H., & Giles, D. E. (2001). Beta/gamma EEG activity in patients with primary and secondary insomnia and good sleeper controls. *Sleep*, 24(1), 110–117. <https://doi.org/10.1093/sleep/24.1.110>
- Perlis, M., Shaw, P. J., Cano, G., & Espie, C. A. (2011). Models of insomnia. In *Principles and Practice of Sleep Medicine* (pp. 850–865). Elsevier. <https://doi.org/10.1016/b978-1-4160-6645-3.00078-5>
- Petersen, H., Kecklund, G., & Åkerstedt, T. (2023). Disturbed sleep and its attribution to stress and other causes: A population-based survey. *Scandinavian Journal of Psychology*, 64(2), 99–104. <https://doi.org/10.1111/sjop.12867>
- Philippens, N., Janssen, E., Kremers, S., & Crutzen, R. (2022). Determinants of natural adult sleep: An umbrella review. *PLOS ONE*, 17(11), e0277323. <https://doi.org/10.1371/journal.pone.0277323>
- Picard-Deland, C., Aumont, T., Samson-Richer, A., Paquette, T., & Nielsen, T. (2021). Whole-body procedural learning benefits from targeted memory reactivation in REM sleep and task-related dreaming. *Neurobiology of Learning and Memory*, 183, 107460. <https://doi.org/10.1016/j.nlm.2021.107460>
- Picard-Deland, C., Bernardi, G., Genzel, L., Dresler, M., & Schoch, S. F. (2023). Memory reactivations during sleep: A neural basis of dream experiences? *Trends in Cognitive Sciences*, 27(6), 568–582. <https://doi.org/10.1016/j.tics.2023.02.006>
- Picard-Deland, C., Konkoly, K., Raider, R., Paller, K. A., Nielsen, T., Pigeon, W. R., & Carr, M. (2022). The memory sources of dreams: Serial awakenings across sleep stages and time of night. *Sleep*, 46(4), zsac292. <https://doi.org/10.1093/sleep/zsac292>
- Picard-Deland, C., & Nielsen, T. (2022). Targeted memory reactivation has a sleep stage-specific delayed effect on dream content. *Journal of Sleep Research*, 31(1). <https://doi.org/10.1111/jsr.13391>
- Picard-Deland, C., Nielsen, T., & Carr, M. (2021). Dreaming of the sleep lab. *PLOS ONE*, 16(10), e0257738. <https://doi.org/10.1371/journal.pone.0257738>
- Picard-Deland, C., Pastor, M., Solomonova, E., Paquette, T., & Nielsen, T. (2020). Flying dreams stimulated by an immersive virtual reality task. *Consciousness and Cognition*, 83, 102958. <https://doi.org/10.1016/j.concog.2020.102958>
- Pieters, D., De Valck, E., Vandekerckhove, M., Pirrera, S., Wuyts, J., Exadaktylos, V., Haex, B., Michiels, N., Verbraecken, J., & Cluydts, R. (2014). Effects of pre-sleep media use on sleep/wake patterns and daytime functioning among adolescents: The moderating role of parental control. *Behavioral Sleep Medicine*, 12(6), 427–443. <https://doi.org/10.1080/15402002.2012.694381>
- Plailly, J., Villalba, M., Vallat, R., Nicolas, A., & Ruby, P. (2019). Incorporation of fragmented visuo-olfactory episodic memory into dreams and its association with memory performance. *Scientific Reports*, 9(1), 15687. <https://doi.org/10.1038/s41598-019-51497-y>
- Poe, G. R., Walsh, C. M., & Bjorness, T. E. (2010). Cognitive neuroscience of sleep. In *Progress in Brain Research* (Vol. 185, pp. 1–19). Elsevier. <https://doi.org/10.1016/B978-0-444-53702-7.00001-4>
- Propper, R. E., Stickgold, R., Keeley, R., & Christman, S. D. (2007). Is television traumatic?: Dreams, stress, and media exposure in the aftermath of September 11, 2001. *Psychological Science*, 18(4), 334–340. <https://doi.org/10.1111/j.1467-9280.2007.01900.x>
- Pulvermüller, F., Eulitz, C., Pantev, C., Mohr, B., Feige, B., Lutzenberger, W., Elbert, T., & Birbaumer, N. (1996). High-frequency cortical responses reflect lexical processing: An MEG study. *Electroencephalography and Clinical Neurophysiology*, 98(1), 76–85. [https://doi.org/10.1016/0013-4694\(95\)00191-3](https://doi.org/10.1016/0013-4694(95)00191-3)

- Rahman, T. U., Jan, Z., Alam, A., & Ali, R. (2024). Smartphone use and personality: Their effects on sleep quality across groups using mediation analysis. *Digital Health*, 10, 20552076241295797. <https://doi.org/10.1177/20552076241295797>
- Rasch, B. (2016). *Longing for a good night's sleep: A memory-based mechanism to improve sleep and cognitive functioning* [European Research Council (ERC)]. <https://cordis.europa.eu/project/id/677875>
- Rasch, B., & Born, J. (2008). Reactivation and consolidation of memory during sleep. *Current Directions in Psychological Science*, 17(3), 188–192.
- Rasch, B., & Born, J. (2013). About sleep's role in memory. *Physiological Reviews*, 93(2), 681–766. <https://doi.org/10.1152/physrev.00032.2012>
- Rasch, B., Büchel, C., Gais, S., & Born, J. (2007). Odor cues during slow-wave sleep prompt declarative memory consolidation. *Science*, 315(5817), 1426–1429. <https://doi.org/10.1126/science.1138581>
- Rash, J. A., Kavanagh, V. A. J., & Garland, S. N. (2019). A meta-analysis of mindfulness-based therapies for insomnia and sleep disturbance: Moving towards processes of change. *Sleep Medicine Clinics, Cognitive Behavioral Therapies for Insomnia*, 14(2), 209–233. <https://doi.org/10.1016/j.jsmc.2019.01.004>
- Rawson, G., & Jackson, M. L. (2024). Sleep and emotional memory: A review of current findings and application to a clinical population. *Current Sleep Medicine Reports*, 10(3), 378–385. <https://doi.org/10.1007/s40675-024-00306-8>
- Reddy, O. C., & Van der Werf, Y. D. (2020). The sleeping brain: Harnessing the power of the glymphatic system through lifestyle choices. *Brain Sciences*, 10(11), 868. <https://doi.org/10.3390/brainsci10110868>
- Ree, M. J., Harvey, A. G., Blake, R., Tang, N. K. Y., & Shawe-Taylor, M. (2005). Attempts to control unwanted thoughts in the night: Development of the thought control questionnaire-insomnia revised (TCQI-R). *Behaviour Research and Therapy*, 43(8), 985–998. <https://doi.org/10.1016/j.brat.2004.07.003>
- Reffi, A. N., Kalmbach, D. A., Cheng, P., & Drake, C. L. (2023). The sleep response to stress: How sleep reactivity can help us prevent insomnia and promote resilience to trauma. *Journal of Sleep Research*, 32(6), e13892. <https://doi.org/10.1111/jsr.13892>
- Reinecke, L., Hartmann, T., & Eden, A. (2014). The guilty couch potato: The role of ego depletion in reducing recovery through media use. *Journal of Communication*, 64(4), 569–589. <https://doi.org/10.1111/jcom.12107>
- Reinecke, L., Klatt, J., & Krämer, N. C. (2011). Entertaining media use and the satisfaction of recovery needs: Recovery outcomes associated with the use of interactive and noninteractive entertaining media. *Media Psychology*, 14(2), 192–215. <https://doi.org/10.1080/15213269.2011.573466>
- Revonsuo, A. (2000). The reinterpretation of dreams: An evolutionary hypothesis of the function of dreaming. *Behavioral and Brain Sciences*, 23(6), 877–901. <https://doi.org/10.1017/S0140525X00004015>
- Revonsuo, A., Tuominen, J., & Valli, K. (2016a). The avatars in the machine: Dreaming as a simulation of social reality. In T. Metzinger & J. M. Windt (Eds.), *Open MIND: Philosophy of the mind sciences in the 21st century* (Vol. 2, pp. 1295–1322). MIT Press. <https://doi.org/10.7551/mitpress/10603.003.0097>
- Revonsuo, A., Tuominen, J., & Valli, K. (2016b). The simulation theories of dreaming: How to make theoretical progress in dream science. In T. Metzinger & J. M. Windt (Eds.), *Open MIND: Philosophy of the mind sciences in the 21st century* (Vol. 2, pp. 1341–1348). MIT Press. <https://doi.org/10.7551/mitpress/10603.003.0099>
- Riemann, D., Espie, C. A., Altena, E., Arnardottir, E. S., Baglioni, C., Bassetti, C. L. A., Bastien, C., Berzina, N., Bjorvatn, B., Dikeos, D., Dolenc Groselj, L., Ellis, J. G., Garcia-Borreguero, D., Geoffroy, P. A., Gjerstad, M., Gonçalves, M., Hertenstein, E., Hoedlmoser, K., Hion, T., ... Spiegelhalder, K. (2023). The European Insomnia Guideline: An update on the diagnosis and treatment of insomnia 2023. *Journal of Sleep Research*, 32(6), e14035. <https://doi.org/10.1111/jsr.14035>

- Riemann, D., Spiegelhalder, K., Feige, B., Voderholzer, U., Berger, M., Perlis, M., & Nissen, C. (2010). The hyperarousal model of insomnia: A review of the concept and its evidence. *Sleep Medicine Reviews*, 14(1), 19–31. <https://doi.org/10.1016/j.smrv.2009.04.002>
- Rimsh, A., & Pietrowsky, R. (2020). Dreams in anxiety disorders and anxiety. *International Journal of Dream Research*, 1–16. <https://doi.org/10.11588/ijodr.2020.1.60789>
- Roth, T. (2004). Characteristics and determinants of normal sleep. *Journal of Clinical Psychiatry*, 65(Suppl 16), 8–11.
- Roussy, F., Raymond, I., Gonthier, I., Grenier, J., & De Koninck, J. (1998). Temporal references in manifest dream content: Confirmation of increased remoteness as the night progresses. *Sleep*, 21, 285.
- Rudoy, J. D., Voss, J. L., Westerberg, C. E., & Paller, K. A. (2009). Strengthening individual memories by reactivating them during sleep. *Science (New York, N.Y.)*, 326(5956), 1079. <https://doi.org/10.1126/science.1179013>
- Rusch, H. L., Rosario, M., Levison, L. M., Olivera, A., Livingston, W. S., Wu, T., & Gill, J. M. (2019). The effect of mindfulness meditation on sleep quality: A systematic review and meta-analysis of randomized controlled trials. *Annals of the New York Academy of Sciences*, 1445(1), 5–16. <https://doi.org/10.1111/nyas.13996>
- Salvesen, L., Capriglia, E., Dresler, M., & Bernardi, G. (2024). Influencing dreams through sensory stimulation: A systematic review. *Sleep Medicine Reviews*, 74, 101908. <https://doi.org/10.1016/j.smrv.2024.101908>
- Scarpelli, S., Alfonsi, V., Gorgoni, M., & De Gennaro, L. (2022). What about dreams? State of the art and open questions. *Journal of Sleep Research*, 31(4), e13609. <https://doi.org/10.1111/jsr.13609>
- Scarpelli, S., Bartolacci, C., D'Atri, A., Gorgoni, M., & De Gennaro, L. (2019). The functional role of dreaming in emotional processes. *Frontiers in Psychology*, 10, 459. <https://doi.org/10.3389/fpsyg.2019.00459>
- Schädlich, M., & Erlacher, D. (2018). Practicing sports in lucid dreams – characteristics, effects, and practical implications. *Current Issues in Sport Science (CISS)*, 3, 007–007. https://doi.org/10.15203/CISS_2018.007
- Schäfer, S. K., Wirth, B. E., Staginnus, M., Becker, N., Michael, T., & Sopp, M. R. (2020). Sleep's impact on emotional recognition memory: A meta-analysis of whole-night, nap, and REM sleep effects. *Sleep Medicine Reviews*, 51, 101280. <https://doi.org/10.1016/j.smrv.2020.101280>
- Schmidt, R. E., Gay, P., Ghisletta, P., & Van Der Linden, M. (2010). Linking impulsivity to dysfunctional thought control and insomnia: A structural equation model. *Journal of Sleep Research*, 19(1-Part-I), 3–11. <https://doi.org/10.1111/j.1365-2869.2009.00741.x>
- Schmidt, R. E., Harvey, A. G., & Van Der Linden, M. (2011). Cognitive and affective control in insomnia. *Frontiers in Psychology*, 2, 349. <https://doi.org/10.3389/fpsyg.2011.00349>
- Schoch, S. F., Cordi, M. J., Schredl, M., & Rasch, B. (2019). The effect of dream report collection and dream incorporation on memory consolidation during sleep. *Journal of Sleep Research*, 28(1), e12754. <https://doi.org/10.1111/jsr.12754>
- Schredl, M. (1999). Dream recall: Research, clinical implications and future directions. *Sleep and Hypnosis*, 1(2), 72–81.
- Schredl, M. (2000). Continuity between waking life and dreaming: Are all waking activities reflected equally often in dreams? *Perceptual and Motor Skills*, 90, 844–846.
- Schredl, M. (2003). Continuity Between Waking and Dreaming: A Proposal for a Mathematical Model. *Sleep and Hypnosis*, 5(1), 26–39.
- Schredl, M. (2004). Reliability and stability of a dream recall frequency scale. *Perceptual and Motor Skills*, 98, 1422–1426.
- Schredl, M. (2006). Factors affecting the continuity between waking and dreaming: Emotional intensity and emotional tone of the waking-life event. *Sleep and Hypnosis*, 8(1), 1–5.
- Schredl, M. (2008). Laboratory references in dreams: Methodological problem and/or evidence for the continuity hypothesis of dreaming? *International Journal of Dream Research*, 1(1). <https://doi.org/10.11588/heidok.00008425>
- Schredl, M. (2018). *Researching dreams: The fundamentals*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-95453-0>

- Schredl, M., Ciric, P., Gotz, S., & Wittmann, L. (2003). Dream recall frequency, attitude towards dreams and openness to experience. *Dreaming*, 13(3), 145–153.
- Schredl, M., & Doll, E. (1998). Emotions in diary dreams. *Consciousness and Cognition*, 7(4), 634–646. <https://doi.org/10.1006/ccog.1998.0356>
- Schredl, M., & Hofmann, F. (2003). Continuity between waking activities and dream activities. *Consciousness and Cognition*, 12(2), 298–308. [https://doi.org/10.1016/S1053-8100\(02\)00072-7](https://doi.org/10.1016/S1053-8100(02)00072-7)
- Schredl, M., Schäfer, G., Weber, B., & Heuser, I. (1998). Dreaming and insomnia: Dream recall and dream content of patients with insomnia. *Journal of Sleep Research*, 7(3), 191–198. <https://doi.org/10.1046/j.1365-2869.1998.00113.x>
- Schreiner, T., & Rasch, B. (2017). The beneficial role of memory reactivation for language learning during sleep: A review. *Brain and Language*, 167, 94–105. <https://doi.org/10.1016/j.bandl.2016.02.005>
- Schwartz, S., Clerget, A., & Perogamvros, L. (2022). Enhancing imagery rehearsal therapy for nightmares with targeted memory reactivation. *Current Biology*, 32(22), 480–4816. <https://doi.org/10.1016/j.cub.2022.09.032>
- Sheaves, B., Rek, S., & Freeman, D. (2023). Nightmares and psychiatric symptoms: A systematic review of longitudinal, experimental, and clinical trial studies. *Clinical Psychology Review*, 100, 102241. <https://doi.org/10.1016/j.cpr.2022.102241>
- Shechter, A., Quispe, K. A., Mizhquiri Barbecho, J. S., Slater, C., & Falzon, L. (2020). Interventions to reduce short-wavelength (“blue”) light exposure at night and their effects on sleep: A systematic review and meta-analysis. *SLEEP Advances*, 1(1), zpaa002. <https://doi.org/10.1093/sleepadvances/zpaa002>
- Shinar, Z., Akselrod, S., Dagan, Y., & Baharav, A. (2006). Autonomic changes during wake–sleep transition: A heart rate variability based approach. *Autonomic Neuroscience*, 130(1–2), 17–27. <https://doi.org/10.1016/j.autneu.2006.04.006>
- Shiraly, R., Yaghooti, F., & Griffiths, M. D. (2024). The mediating and moderating effects of psychological distress on the relationship between social media use with perceived social isolation and sleep quality of late middle-aged and older adults. *BMC Geriatrics*, 24(1), 655. <https://doi.org/10.1186/s12877-024-05252-2>
- Shouse, M. N., Staba, R. J., Saquib, S. F., & Farber, P. R. (2000). Monoamines and sleep: Microdialysis findings in pons and amygdala. *Brain Research*, 860(1–2), 181–189. [https://doi.org/10.1016/S0006-8993\(00\)02013-8](https://doi.org/10.1016/S0006-8993(00)02013-8)
- Shuster, A. E., Morehouse, A., McDevitt, E. A., Chen, P.-C., Whitehurst, L. N., Zhang, J., Sattari, N., Uzoigwe, T., Ekhlesi, A., Cai, D., Simon, K., Niethard, N., & Mednick, S. C. (2025). REM refines and rescues memory representations: A new theory. *SLEEP Advances*, 6(1), zpaf004. <https://doi.org/10.1093/sleepadvances/zpaf004>
- Siclari, F., Baird, B., Perogamvros, L., Bernardi, G., LaRocque, J. J., Riedner, B., Boly, M., Postle, B. R., & Tononi, G. (2017). The neural correlates of dreaming. *Nature Neuroscience*, 20(6), 872–878. <https://doi.org/10.1038/nn.4545>
- Siebers, T., Beyens, I., Baumgartner, S. E., & Valkenburg, P. M. (2024). Adolescents’ digital nightlife: The comparative effects of day- and nighttime smartphone use on sleep quality. *Communication Research*, 00936502241276793. <https://doi.org/10.1177/00936502241276793>
- Silvani, M. I., Werder, R., & Perret, C. (2022). The influence of blue light on sleep, performance and wellbeing in young adults: A systematic review. *Frontiers in Physiology*, 13, 943108. <https://doi.org/10.3389/fphys.2022.943108>
- Simon, K. C., McDevitt, E. A., Ragano, R., & Mednick, S. C. (2022). Progressive muscle relaxation increases slow-wave sleep during a daytime nap. *Journal of Sleep Research*, 31(5), e13574. <https://doi.org/10.1111/jsr.13574>
- Smith, J. C. (2007). The psychology of relaxation. In P. M. Lehrer, R. L. Woolfolk, & E. S. Wesley (Eds.), *Principles and practice of stress management* (3rd ed., pp. 38–52). Guilford Press.
- Smith, J. M., & Alloy, L. B. (2009). A roadmap to rumination: A review of the definition, assessment, and conceptualization of this multifaceted construct. *Clinical Psychology Review*, 29(2), 116–128. <https://doi.org/10.1016/j.cpr.2008.10.003>

- Snyder, M., Alldredge, C. T., Stork, S. R., & Elkins, G. R. (2023). Feasibility of a self-administered hypnosis intervention for improving sleep in college students. *International Journal of Clinical and Experimental Hypnosis*, 71(4), 297–312. <https://doi.org/10.1080/00207144.2023.2249047>
- Solomonova, E., Picard-Deland, C., Rapoport, I. L., Pennestri, M.-H., Saad, M., Kendzerska, T., Veissiere, S. P. L., Godbout, R., Edwards, J. D., Quilty, L., & Robillard, R. (2021). Stuck in a lockdown: Dreams, bad dreams, nightmares, and their relationship to stress, depression and anxiety during the COVID-19 pandemic. *PLOS ONE*, 16(11), e0259040. <https://doi.org/10.1371/journal.pone.0259040>
- Speth, J., Frenzel, C., & Voss, U. (2013). A differentiating empirical linguistic analysis of dreamer activity in reports of EEG-controlled REM-dreams and hypnagogic hallucinations. *Consciousness and Cognition*, 22(3), 1013–1021. <https://doi.org/10.1016/j.concog.2013.07.003>
- Spielman, A. J., Caruso, L. S., & Glovinsky, P. B. (1987). A behavioral perspective on insomnia treatment. *The Psychiatric Clinics of North America*, 10(4), 541–553.
- Steiger, A., & Pawlowski, M. (2019). Depression and sleep. *International Journal of Molecular Sciences*, 20(3), 607. <https://doi.org/10.3390/ijms20030607>
- Stickgold, R., Hobson, J. A., Fosse, R., & Fosse, M. (2001). Sleep, learning, and dreams: Off-line memory reprocessing. *Science*, 294(5544), 1052–1057. <https://doi.org/10.1126/science.1063530>
- Stickgold, R., Malia, A., Fosse, R., Propper, R., & Hobson, J. A. (2001). Brain-mind states: I. Longitudinal field study of sleep/wake factors influencing mentation report length. *Sleep*, 24(2), 171–179. <https://doi.org/10.1093/sleep/24.2.171>
- Stickgold, R., Scott, L., Rittenhouse, C., & Hobson, J. A. (1999). Sleep-induced changes in associative memory. *Journal of Cognitive Neuroscience*, 11(2), 182–193. <https://doi.org/10.1162/089892999563319>
- St-Onge, M.-P. (2017). Sleep–obesity relation: Underlying mechanisms and consequences for treatment. *Obesity Reviews*, 18(S1), 34–39. <https://doi.org/10.1111/obr.12499>
- Stumbrys, T., Erlacher, D., & Schredl, M. (2016). Effectiveness of motor practice in lucid dreams: A comparison with physical and mental practice. *Journal of Sports Sciences*, 34(1), 27–34. <https://doi.org/10.1080/02640414.2015.1030342>
- Suganuma, N., Kikuchi, T., Yanagi, K., Yamamura, S., Morishima, H., Adachi, H., Kumano-Go, T., Mikami, A., Sugita, Y., & Takeda, M. (2007). Using electronic media before sleep can curtail sleep time and result in self-perceived insufficient sleep. *Sleep and Biological Rhythms*, 5(3), 204–214. <https://doi.org/10.1111/j.1479-8425.2007.00276.x>
- Syrek, C. J., & Antoni, C. H. (2014). Unfinished tasks foster rumination and impair sleeping—Particularly if leaders have high performance expectations. *Journal of Occupational Health Psychology*, 19(4), 490–499. <https://doi.org/10.1037/a0037127>
- Takahashi, M., & Arito, H. (1994). Suppression of electroencephalogram Δ power density during non-rapid eye movement sleep as a result of a prolonged cognitive task prior to sleep onset. *European Journal of Applied Physiology and Occupational Physiology*, 68(3), 274–280. <https://doi.org/10.1007/BF00376777>
- Tamaki, M., Bang, J. W., Watanabe, T., & Sasaki, Y. (2016). Night watch in one brain hemisphere during sleep associated with the first-night effect in humans. *Current Biology*, 26(9), 1190–1194. <https://doi.org/10.1016/j.cub.2016.02.063>
- Tang, N. K. Y., & Harvey, A. G. (2004). Effects of cognitive arousal and physiological arousal on sleep perception. *Sleep*, 27(1), 69–78. <https://doi.org/10.1093/sleep/27.1.69>
- Tang, N. K. Y., Saconi, B., Jansson-Fröjmark, M., Ong, J. C., & Carney, C. E. (2023). Cognitive factors and processes in models of insomnia: A systematic review. *Journal of Sleep Research*, 32(6), e13923. <https://doi.org/10.1111/jsr.13923>
- Tavernier, R., & Willoughby, T. (2014). Sleep problems: Predictor or outcome of media use among emerging adults at university? *Journal of Sleep Research*, 23(4), 389–396. <https://doi.org/10.1111/jsr.12132>
- Tempesta, D., De Gennaro, L., Natale, V., & Ferrara, M. (2015). Emotional memory processing is influenced by sleep quality. *Sleep Medicine*, 16(7), 862–870. <https://doi.org/10.1016/j.sleep.2015.01.024>

- Thompson, T., Terhune, D. B., Oram, C., Sharangparni, J., Rouf, R., Solmi, M., Veronese, N., & Stubbs, B. (2019). The effectiveness of hypnosis for pain relief: A systematic review and meta-analysis of 85 controlled experimental trials. *Neuroscience & Biobehavioral Reviews*, 99, 298–310. <https://doi.org/10.1016/j.neubiorev.2019.02.013>
- Tiitinen, H., May, P., & Näätänen, R. (1997). The transient 40-Hz response, mismatch negativity, and attentional processes in humans. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 21(5), 751–771.
- Torsvall, L., & Åkerstedt, T. (1988). Disturbed sleep while being on-call: An EEG study of ships' engineers. *Sleep*, 11(1), 35–38. <https://doi.org/10.1093/sleep/11.1.35>
- Tucker, A. M., Dinges, D. F., & Van Dongen, H. P. A. (2007). Trait interindividual differences in the sleep physiology of healthy young adults. *Journal of Sleep Research*, 16(2), 170–180. <https://doi.org/10.1111/j.1365-2869.2007.00594.x>
- Tuominen, J., Revonsuo, A., & Valli, K. (2019). The social simulation theory. In K. Valli & R. J. Hoss (Eds.), *Dreams: Understanding biology, psychology, and culture* (Vol. 1, pp. 132–137). ABC-CLIO Greenwood.
- Uitermarkt, B. D., Bruss, J., Hwang, K., & Boes, A. D. (2020). Rapid eye movement sleep patterns of brain activation and deactivation occur within unique functional networks. *Human Brain Mapping*, 41(14), 3984–3992. <https://doi.org/10.1002/hbm.25102>
- Underwood, R., Tolmeijer, E., Wibroe, J., Peters, E., & Mason, L. (2021). Networks underpinning emotion: A systematic review and synthesis of functional and effective connectivity. *NeuroImage*, 243, 118486. <https://doi.org/10.1016/j.neuroimage.2021.118486>
- Valck, E. D., Cluydts, R., & Pirrera, S. (2004). Effect of cognitive arousal on sleep latency, somatic and cortical arousal following partial sleep deprivation. *Journal of Sleep Research*, 13(4), 295–304. <https://doi.org/10.1111/j.1365-2869.2004.00424.x>
- Van Cauter, E., & Plat, L. (1996). Physiology of growth hormone secretion during sleep. *The Journal of Pediatrics*, 128(5), S32–S37. [https://doi.org/10.1016/S0022-3476\(96\)70008-2](https://doi.org/10.1016/S0022-3476(96)70008-2)
- Van der Helm, E., & Walker, M. P. (2009). Overnight therapy? The role of sleep in emotional brain processing. *Psychological Bulletin*, 135(5), 731–748. <https://doi.org/10.1037/a0016570>
- Van der Helm, E., Yao, J., Dutt, S., Rao, V., Saletin, J. M., & Walker, M. P. (2011). REM sleep depotentiates amygdala activity to previous emotional experiences. *Current Biology*, 21(23), 2029–2032. <https://doi.org/10.1016/j.cub.2011.10.052>
- Van Reeth, O., Weibel, L., Spiegel, K., Leproult, R., Dugovic, C., & Maccari, S. (2000). Interactions between stress and sleep: From basic research to clinical situations. *Sleep Medicine Reviews*, 4(2), 201–219. <https://doi.org/10.1053/smr.1999.0097>
- Van Stegeren, A. H. (2008). The role of the noradrenergic system in emotional memory. *Acta Psychologica*, 127(3), 532–541. <https://doi.org/10.1016/j.actpsy.2007.10.004>
- Van Stegeren, A. H., Goekoop, R., Everaerd, W., Scheltens, P., Barkhof, F., Kuijer, J. P. A., & Rombouts, S. A. R. B. (2005). Noradrenaline mediates amygdala activation in men and women during encoding of emotional material. *NeuroImage*, 24(3), 898–909. <https://doi.org/10.1016/j.neuroimage.2004.09.011>
- Vandekerckhove, M., & Cluydts, R. (2010). The emotional brain and sleep: An intimate relationship. *Sleep Medicine Reviews*, 14, 219–226. <https://doi.org/10.1016/j.smr.2010.01.002>
- Vandekerckhove, M., & Wang, Y. (2017). Emotion, emotion regulation and sleep: An intimate relationship. *AIMS Neuroscience*, 1(1), 1–22. <https://doi.org/10.3934/Neuroscience.2018.1.1>
- Verdone, P. (1965). Temporal reference of manifest dream content. *Perceptual and Motor Skills*, 20(3_suppl), 1253–1268. <https://doi.org/10.2466/pms.1965.20.3c.1253>
- Verga, L., D'Este, G., Cassani, S., Leitner, C., Kotz, S. A., Ferini-Strambi, L., & Galbiati, A. (2023). Sleeping with time in mind? A literature review and a proposal for a screening questionnaire on self-awakening. *PLOS ONE*, 18(3), e0283221. <https://doi.org/10.1371/journal.pone.0283221>
- Verkuil, B., Brosschot, J. F., Gebhardt, W. A., & Thayer, J. F. (2011). Perseverative cognition, psychopathology, and somatic health. In I. Nykliček, A. Vingerhoets, & M. Zeelenberg (Eds.), *Emotion Regulation and Well-Being* (pp. 85–100). Springer New York. https://doi.org/10.1007/978-1-4419-6953-8_6
- Vinothkumar, M., & George, A. (2022). Binge watching, sleep quality, and fatigue among emerging adults. *International Journal of Social Sciences Review*, 10(3).

- Vorster, A. P. A., & Born, J. (2015). Sleep and memory in mammals, birds and invertebrates. *Neuroscience & Biobehavioral Reviews*, 50, 103–119. <https://doi.org/10.1016/j.neubiorev.2014.09.020>
- Vorster, A. P. A., Van Someren, E. J. W., Pack, A. I., Huber, R., Schmidt, M. H., & Bassetti, C. L. A. (2024). Sleep health. *Clinical and Translational Neuroscience*, 8(1), 8. <https://doi.org/10.3390/ctn8010008>
- Vyazovskiy, V. V., & Delogu, A. (2014). NREM and REM Sleep: Complementary roles in recovery after wakefulness. *The Neuroscientist*, 20(3), 203–219. <https://doi.org/10.1177/1073858413518152>
- Wagner, U., Gais, S., & Born, J. (2001). Emotional memory formation is enhanced across sleep intervals with high amounts of rapid eye movement sleep. *Learning & Memory*, 8(2), 112–119. <https://doi.org/10.1101/lm.36801>
- Walker, M. P., Liston, C., Hobson, J. A., & Stickgold, R. (2002). Cognitive flexibility across the sleep–wake cycle: REM-sleep enhancement of anagram problem solving. *Cognitive Brain Research*, 14(3), 317–324. [https://doi.org/10.1016/S0926-6410\(02\)00134-9](https://doi.org/10.1016/S0926-6410(02)00134-9)
- Wallace, M., Coleman, T. S., Mentch, L. K., Buysse, D. J., Graves, J. L., Hagen, E. W., Hall, M. H., Stone, K. L., Redline, S., & Peppard, P. E. (2021). Physiological sleep measures predict time to 15-year mortality in community adults: Application of a novel machine learning framework. *Journal of Sleep Research*, 30(6), e13386. <https://doi.org/10.1111/jsr.13386>
- Wamsley, E. J. (2014). Dreaming and offline memory consolidation. *Current Neurology and Neuroscience Reports*, 14(3), 433. <https://doi.org/10.1007/s11910-013-0433-5>
- Wamsley, E. J. (2022). Constructive episodic simulation in dreams. *PLOS ONE*, 17(3), e0264574. <https://doi.org/10.1371/journal.pone.0264574>
- Wamsley, E. J., Hamilton, K., Graveline, Y., Manceor, S., & Parr, E. (2016). Test expectation enhances memory consolidation across both sleep and wake. *PLOS ONE*, 11(10), e0165141. <https://doi.org/10.1371/journal.pone.0165141>
- Wamsley, E. J., Hirota, Y., Tucker, M. A., Smith, M. R., & Antrobus, J. S. (2007). Circadian and ultradian influences on dreaming: A dual rhythm model. *Brain Research Bulletin*, 71(4), 347–354. <https://doi.org/10.1016/j.brainresbull.2006.09.021>
- Wamsley, E. J., Perry, K., Djonlagic, I., Reaven, L. B., & Stickgold, R. (2010). Cognitive replay of visuomotor learning at sleep onset: Temporal dynamics and relationship to task performance. *Sleep*, 33(1), 59–68. <https://doi.org/10.1093/sleep/33.1.59>
- Wamsley, E. J., & Stickgold, R. (2010). Dreaming and offline memory processing. *Current Biology*, 20(23), R1010–R1013. <https://doi.org/10.1016/j.cub.2010.10.045>
- Wamsley, E. J., & Stickgold, R. (2019). Dreaming of a learning task is associated with enhanced memory consolidation: Replication in an overnight sleep study. *Journal of Sleep Research*, 28(1), e12749. <https://doi.org/10.1111/jsr.12749>
- Wamsley, E. J., Trost, T., & Tucker, M. (2024). Memory updating in dreams. *SLEEP Advances*, 5(1), zpae096. <https://doi.org/10.1093/sleepadvances/zpae096>
- Wamsley, E. J., Tucker, M., Payne, J. D., Benavides, J. A., & Stickgold, R. (2010). Dreaming of a learning task is associated with enhanced sleep-dependent memory consolidation. *Current Biology*, 20(9), 850–855. <https://doi.org/10.1016/j.cub.2010.03.027>
- Wang, K., & Scherr, S. (2022). Dance the night away: How automatic TikTok use creates pre-sleep cognitive arousal and daytime fatigue. *Mobile Media & Communication*, 10(2), 316–336. <https://doi.org/10.1177/20501579211056116>
- Weaver, E., Gradisar, M., Dohnt, H., Lovato, N., & Douglas, P. (2010). The effect of presleep video-game playing on adolescent sleep. *Journal of Clinical Sleep Medicine*, 06(02), 184–189. <https://doi.org/10.5664/jcsm.27769>
- Webb, W. B., Agnew, H. W., & Sternthal, H. (1966). Sleep during the early morning. *Psychonomic Science*, 6(6), 277–278. <https://doi.org/10.3758/BF03328065>
- Weiher, G. M., Varol, Y. Z., & Horz, H. (2022). Being tired or having much left undone: The relationship between fatigue and unfinished tasks with affective rumination and vitality in beginning teachers. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.935775>
- Werner, G. G., Schabus, M., Blechert, J., Kolodyazhnyi, V., & Wilhelm, F. H. (2015). Pre- to postsleep change in psychophysiological reactivity to emotional films: Late-night REM sleep is associated

- with attenuated emotional processing. *Psychophysiology*, 52(6), 813–825. <https://doi.org/10.1111/psyp.12404>
- Werner, G. G., Schabus, M., Blechert, J., & Wilhelm, F. H. (2021). Differential effects of REM sleep on emotional processing: Initial evidence for increased short-term emotional responses and reduced long-term intrusive memories. *Behavioral Sleep Medicine*, 19(1), 83–98. <https://doi.org/10.1080/15402002.2020.1713134>
- Wick, A., & Rasch, B. (2023). Targeted memory reactivation during slow-wave sleep vs. sleep stage N2: No significant differences in a vocabulary task. *Learning & Memory*, 30(9), 192–200. <https://doi.org/10.1101/lm.053683.122>
- Wicklow, A., & Espie, C. A. (2000). Intrusive thoughts and their relationship to actigraphic measurement of sleep: Towards a cognitive model of insomnia. *Behaviour Research and Therapy*, 38(7), 679–693. [https://doi.org/10.1016/S0005-7967\(99\)00136-9](https://doi.org/10.1016/S0005-7967(99)00136-9)
- Wiesner, C. D., Pulst, J., Krause, F., Elsner, M., Baving, L., Pedersen, A., Prehn-Kristensen, A., & Göder, R. (2015). The effect of selective REM-sleep deprivation on the consolidation and affective evaluation of emotional memories. *Neurobiology of Learning and Memory*, 122, 131–141. <https://doi.org/10.1016/j.nlm.2015.02.008>
- Winbush, N. Y., Gross, C. R., & Kreitzer, M. J. (2007). The effects of mindfulness-based stress reduction on sleep disturbance: A systematic review. *EXPLORE*, 3(6), 585–591. <https://doi.org/10.1016/j.explore.2007.08.003>
- Wirz, D. S., Ort, A., Rasch, B., & Fahr, A. (2022). The role of cliffhangers in serial entertainment: An experiment on cliffhangers' effects on enjoyment, arousal, and intention to continue watching. *Psychology of Popular Media*, 12, 186. <https://doi.org/10.1037/ppm0000392>
- Wofford, N., Snyder, M., Corlett, C. E., & Elkins, G. R. (2023). Systematic review of hypnotherapy for sleep and sleep disturbance. *International Journal of Clinical and Experimental Hypnosis*, 71(3), 176–215. <https://doi.org/10.1080/00207144.2023.2226177>
- Wuyts, J., De Valck, E., Vandekerckhove, M., Pattyn, N., Bulckaert, A., Berckmans, D., Haex, B., Verbraecken, J., & Cluydts, R. (2012). The influence of pre-sleep cognitive arousal on sleep onset processes. *International Journal of Psychophysiology*, 83(1), 8–15. <https://doi.org/10.1016/j.ijpsycho.2011.09.016>
- Wuyts, J., De Valck, E., Vandekerckhove, M., Pattyn, N., Exadaktylos, V., Haex, B., Maes, J., Verbraecken, J., & Cluydts, R. (2012). Effects of pre-sleep simulated on-call instructions on subsequent sleep. *Biological Psychology*, 91(3), 383–388. <https://doi.org/10.1016/j.biopsycho.2012.09.003>
- Yeh, Z.-T., Wung, S.-K., & Lin, C.-M. (2015). Pre-sleep arousal as a mediator of relationships among worry, rumination, and sleep quality. *International Journal of Cognitive Therapy*, 8(1), 21–34. <https://doi.org/10.1521/ijct.2015.8.1.21>
- Yoo, S.-S., Gujar, N., Hu, P., Jolesz, F. A., & Walker, M. P. (2007). The human emotional brain without sleep – a prefrontal amygdala disconnect. *Current Biology*, 17(20), R877–R878. <https://doi.org/10.1016/j.cub.2007.08.007>
- Zadra, A., & Stickgold, R. (2021). *When brains dream*. WW Norton & Company.
- Ziebertz, C. M., Beckers, D. G. J., Van Hooff, M. L. M., Kompier, M. A. J., & Geurts, S. A. E. (2017). The effect on sleep of being on-call: An experimental field study. *Journal of Sleep Research*, 26(6), 809–815. <https://doi.org/10.1111/jsr.12519>