Journal of Sleep Research

REVIEW ARTICLE OPEN ACCESS

Sleep & Cognition

How Mental Concepts Shape Sleep: Introducing the Mental Concept Reactivation Hypothesis of Sleep

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Received: 1 December 2025 | **Revised:** 11 May 2026 | **Accepted:** 21 May 2026

ABSTRACT

Sleep problems affect a substantial proportion of individuals, and negative thoughts, rumination, and worry are considered key factors underlying persistence and severity. While extensive research has examined how these states disrupt sleep before falling asleep, much less is known about how mental concepts, including thoughts, expectations, intentions, and emotions, continue to influence sleep during sleep itself. Likewise, the potential benefits of sleep-promoting mental concepts during sleep remain underexplored. Here, we propose the Mental Concept Reactivation (MCR)-Hypothesis of Sleep, suggesting that mental concepts activated before sleep continue to influence sleep by spontaneous reactivations during sleep. Drawing on appraisal theories of emotion and evidence for endogenous memory reactivation, the hypothesis rests on three core premises. First, mental concepts relevant to sleep are activated during the day and particularly before bedtime. Second, these pre-sleep appraisals undergo spontaneous reactivations during sleep, with the intensity depending on their self-relevance. Third, these reactivations affect subjective restoration and objective sleep parameters. We present research supporting our hypothesis, particularly focusing on studies from our lab that began to systematically test key aspects of the MCR-Hypothesis and discuss limitations, alternative explanations, and open questions. Overall, the MCR-Hypothesis offers a testable framework for understanding how cognitive and emotional mental concepts influence sleep during this state. It may help to explain interindividual differences in sleep reactivity to stress, worry, and pre-sleep expectations. It offers a theoretical basis for developing non-pharmacological interventions aimed at reducing maladaptive mental concepts and strengthening beneficial ones, enhancing sleep quality in both clinical and non-clinical populations.

1 | Introduction

Sleep is essential for our health and well-being, and disturbances in sleep can severely impact physiological and cognitive functioning (Cricco et al. 2001; Irish et al. 2015; Jackson et al. 2011). In modern societies, sleep problems are increasingly prevalent and closely associated with a wide range of physical and psychiatric conditions. Sleep disturbances may occur as comorbidities, as consequences of physiological processes or substance use, or as a result of hyperarousal, for example, insomnia (Riemann et al. 2010).

Although sleep-inducing medications are widely used to treat poor sleep, they often deteriorate sleep quality, lose effectiveness over time, and carry a high risk of dependency (Riemann and Perlis 2009). Cognitive Behavioural Therapy for Insomnia (CBT-I) is currently the first-line treatment for insomnia-like sleep disturbances, as its efficacy has been demonstrated in numerous clinical trials and meta-analyses (Riemann et al. 2023). In addition to behavioural changes to improve sleep (e.g., sleep restriction), CBT-I encompasses several cognitive techniques targeting dysfunctional, sleep-hindering thoughts and practicing relaxation procedures.

Several insomnia models highlight the important role of cognitive processes, such as negative thoughts, worry, and rumination, in explaining insomnia (see Tang et al. 2023 for an overview). Moreover, many sleep problems are associated with stress, worry, and anxiety beyond clinically diagnosed insomnia. However, most models focus exclusively on cognitive processes during wake times before sleep onset or after awakening during the night (exception see Perlis et al. 2011). Implicitly or explicitly, most accounts assume that negative thoughts, worry, anxiety, and stress (i.e., "cognitive arousal") lead to increased physiological arousal during wakefulness. This results in increased sympathetic activity, which is associated with, for example, cortisol secretion, increases in heart rate, blood pressure, etc. Indeed, increased physiological arousal inhibits sleep initiation processes and extends sleep onset (Akerstedt 2006; Meneo and Baglioni 2025).

However, most people with sleep problems will fall asleep at some point, sometimes even rather quickly, due to their build-up sleep pressure (Borbély 1982). After sleep onset, our sympathetic activation decreases enough to allow sleep as well as entry into the profound stage of slow-wave sleep (SWS). Thus, in spite of worries, ruminations, and negative thoughts, physiological arousal is decreased during sleep compared to wakefulness (Buckley and Schatzberg 2005). But how do negative thoughts lead to increased awakenings from sleep after we have successfully fallen asleep? How do negative thoughts, worries, and rumination affect our sleep quality while we are actually sleeping? How does our intention to wake up early in the morning to catch an early flight disturb our sleep? Why does being "on-call" disturb our sleep even when there are no sounds presented during the night? In our view, the long-lasting effects of intentions, worry, and negative thoughts on ongoing sleep processes cannot be fully explained by increases in sympathetic activity at sleep onset. Here, we propose that our thoughts, evaluations, and intentions present at sleep onset activate a specific mental concept and are spontaneously reactivated during sleep. Importantly, the valence of these mental concepts may play a secondary role, whereas we consider the level of salience and arousal to be more critical. This continuous reactivation could explain ongoing effects of our thoughts, evaluations, and intentions (i.e., our mental concepts) on ongoing sleep processes, despite the reduction in sympathetic activity associated with sleep onset and deep sleep stages (i.e., SWS).

We will begin with a brief overview of sleep, its regulatory mechanisms, and common sleep problems, followed by introducing the Mental Concept Reactivation (MCR)-Hypothesis of Sleep. After outlining its core premises and conceptual foundations, we will discuss empirical findings that support the MCR-Hypothesis, with particular emphasis on studies conducted in our laboratory. Building on this scientific foundation, we will position the hypothesis within a broader context, discuss its strengths and limitations, and highlight potential avenues for future research.

2 | Physiology of Sleep and Sleep Disturbances

The principles of the MCR-Hypothesis of Sleep discussed here are framed by the general biological and regulatory mechanisms of sleep. Sleep is defined as a "natural and reversible state of reduced responsiveness to external stimuli and relative inactivity, accompanied by a loss of consciousness" (Rasch and Born 2013, 681). It is homeostatically regulated by a circadian rhythm (Process C) and the build-up of sleep pressure (Process S) (Borbély 1982; see Figure 1a). Moreover, it follows a characteristic architecture throughout the night (see Figure 1b). Sleep cycles alternate between two main stages: rapid eye movement (REM) sleep and non-REM (NREM) sleep. NREM sleep can be further divided into three stages of increasing depth (N1, N2, and slow-wave sleep, SWS), with SWS representing the deepest stage and being particularly associated with recovery and restoration (Dijk and Archer 2009; Iber et al. 2007). Moreover, all sleep stages are characterized by specific physiological and electrophysiological markers and frequencies. N2 sleep is marked by sleep spindles and K-Complexes whereas SWS is characterized by slow oscillating delta waves (1–4.5 Hz). REM sleep is defined by rapid eye movements, mixed low-amplitude, high frequency brain waves (beta, alpha and theta), and reduced muscle tone (Iber et al. 2007).

Falling asleep results from the coordinated downregulation of arousal across neurobiological, physiological, cognitive, motivational, and emotional levels. According to Meneo and Baglioni (2025), this transition can be supported by specific pre-sleep behaviours and routines that may help reduce arousal levels and facilitate the transition from wakefulness to sleep.

3 | Disturbances of Sleep

Sleep disturbances may arise from substance-related factors (e.g., alcohol, caffeine, and stimulants), physiological disruptions (e.g., jet lag and shift work), medical conditions (e.g., cardiovascular disease and sleep apnea), or genetic predispositions (Möller et al. 2008; Shaw et al. 2013). The most common sleep disorder is insomnia (Riemann et al. 2010). It is characterized by problems initiating sleep, maintaining sleep and/or early awakenings. Rumination, worry, and negative thoughts are key factors in explaining insomnia, leading to "hyperarousal" on cognitive, emotional, and physiological levels both during the day and before bedtime, accompanied by specific maladaptive behavioural factors. Sleep problems, such as insomnia, frequently co-occur with psychiatric conditions such as depression and anxiety (Riemann et al. 2001) and may also arise primarily from stress, major life events, or distressing thoughts (Lichstein and Rosenthal 1980; Möller et al. 2008). Cognitive behavioural therapy (CBT) has been shown to be highly effective in treating insomnia (Riemann et al. 2023; Williams et al. 2013). The most effective treatment component of CBT-I is sleep restriction, which increases sleep pressure according to the mechanisms proposed by the two-process model of sleep regulation (Borbély 1982; see above; Steinmetz et al. 2024). Thus, increases in sleep pressure can overcome the sleep-hindering influences of negative thoughts, worry, and intentions. However, sleep restriction is also the most challenging CBT-I intervention, and many patients do not successfully complete it. Thus, it is highly important to advance our understanding of the mechanisms of how negative thoughts and worry influence our sleep quality, to provide the basis for new clinical interventions.

Beyond insomnia, many sleep problems share similar cognitive and emotional mechanisms that interfere with restorative sleep, contributing to their persistence and severity. These sleep problems affect more than one-third of our population and further increase with age (BFS 2024; Brewster et al. 2019). Therefore,

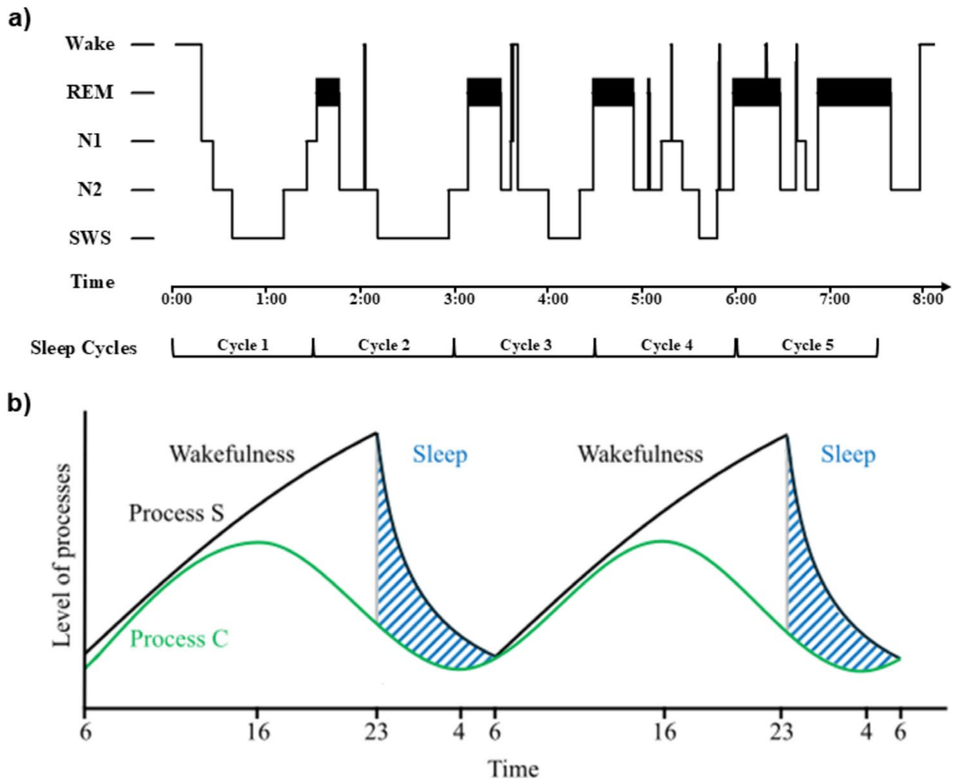

FIGURE 1 | Hypnogram of a nocturnal sleep period of a healthy young adult and the two process model of sleep homeostasis. (a) The hypnogram, a visual representation of the sleep architecture, shows the sequence and distribution of all sleep stages: Non-Rapid Eye Movement (NREM), stages N1, N2 and N3 (SWS), and Rapid Eye Movement (REM), as well as the time awake after sleep onset. The x-axis shows the time spent in bed and the y-axis shows the different sleep stages. Following the sleep onset latency, sleep is characterized by a repetitive cyclical alternation between NREM sleep stages and REM sleep. Noteworthy, SWS predominates the first night half, whereas REM sleep is predominant in the second half of the night (Carskadon and Dement 2011; Rasch and Born 2013). The 90-min sleep cycles are visualized with brackets. (b) The two-process model of sleep homeostasis of Borbély's (1982). According to this model, there are two processes that underlie changes in sleep and wakefulness. Process C (green line; plotted as a negative function) and process S (black line). Process C represents the circadian process and fluctuates during the day. Process S represents the individual built-up sleep pressure, which accumulates during the day and reaches its maximum before sleep onset at around 23:00. Process S then decreases with sleep and is at a minimum during sleep offset. Process S is associated with the amount of slow-wave sleep. This model promotes sleep especially at night. The x-axis represents the time of day, while the y-axis shows the level of processes C and S (adapted from Borbély 1982 and published in Wick 2025).

also for such sub-clinical sleep problems, a better understanding of how our cognitive and emotional mental concepts influence sleep is highly warranted. Finally, most theories and concepts exclusively focus on the sleep-disturbing effects of negative thoughts and emotions. However, it remains unclear whether and how positive thoughts and emotions might also have a beneficial effect on sleep quality (Meneo et al. 2023). Although general positive affect or mood has been shown to have only weak effects on sleep (Krizan et al. 2024; Ong et al. 2017), it may still be possible that specific sleep-related or relaxation-related thoughts, suggestions, intentions, and emotions could enhance sleep quality.

Taken together, the current state of sleep research reveals a central gap: while the influence of negative cognitive and emotional processes on sleep has been extensively examined during the day and before sleep (Meneo et al. 2023; Tang et al. 2023), the potential influence of cognitive and emotional mental concepts activated during the sleep state itself is still unknown. Addressing this gap is the central motivation of our present review. In the following, we introduce the Mental Concept Reactivation (MCR)-Hypothesis of Sleep, which aims to provide a conceptual framework for how activated cognitive and emotional concepts before sleep remain active during subsequent sleep, influencing sleep architecture and its quality.

4 | Mental Concept Reactivation Hypothesis of Sleep

The Mental Concept Reactivation (MCR)-Hypothesis of Sleep (see Figure 2) aims to explain how mental concepts influence ongoing sleep processes. Concretely, we define mental concepts very generally as multimodal cognitive-emotional representations that include thoughts, expectations, intentions, imagery, and associated affective states. If these mental concepts are salient, personally meaningful, and sleep-relevant, they induce a certain level of cognitive, emotional, and/or physiological arousal (or relaxation) and will have an impact on subsequent sleep. Importantly, these mental concepts can be either positively or negatively valenced and may involve both conscious and non-conscious processes. Purely

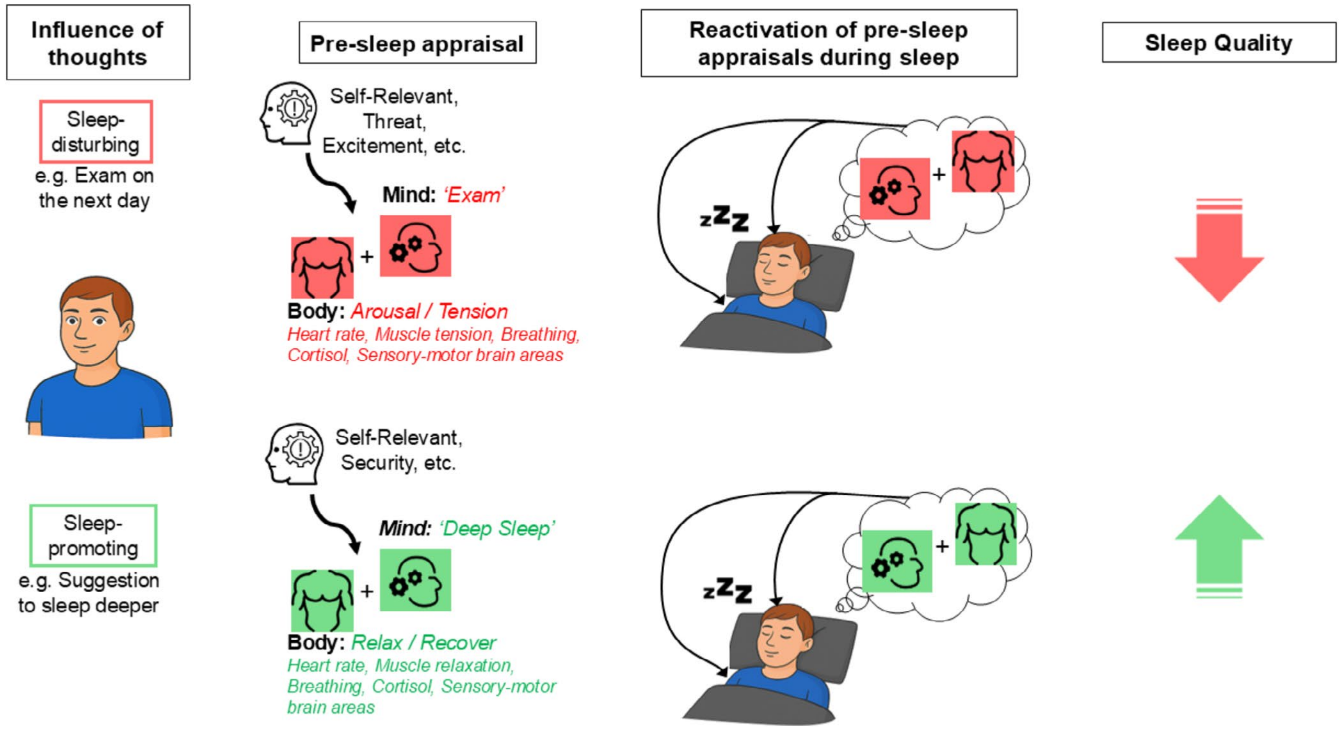

FIGURE 2 | The Mental Concept Reactivation (TMCR)-Hypothesis of Sleep. Throughout the day, and especially during the period immediately before sleep, specific cognitive or emotional representations (i.e., mental concepts) related to the impending sleep or arousal state become activated. These representations are referred to as pre-sleep appraisals. A central example of a sleep-disturbing pre-sleep appraisal involves interpreting the sleep environment as "unsafe" or detecting potential threats, whether imagined or real. In contrast, a key sleep-promoting pre-sleep appraisal consists of perceiving "relaxation" or an "appropriate state for sleep." During subsequent sleep, these pre-sleep appraisals are spontaneously reactivated, much like previously encoded memories. The extent of these reactivations depends on the intensity of their activation and their personal relevance during the pre-sleep period. When such spontaneous reactivations arise during sleep, they (a) activate mental concepts which bias predominant thoughts, emotions, and other cognitive processes during sleep, and (b) influence physiological and neural arousal responses. In turn, this affects both (a) subjective feelings of restoration and (b) objective indicators of sleep quality (e.g., frequency of awakenings or arousals, depth of sleep).

physiological states without any cognitive or emotional mental representations are not considered mental concepts within this framework.

The MCR Hypothesis mainly draws on two sources of evidence and theoretical concepts: appraisal theories of emotion (Ellsworth and Scherer 2002; Smith and Ellsworth 1985) and evidence that memories undergo endogenous reactivation during sleep (Rasch and Born 2013). The hypothesis rests on three core premises, which will be explained in more detail in the next section.

1. During the day and especially during the pre-sleep period, certain salient, arousing or relaxing mental concepts, relevant to one's subsequent sleep or arousal state are activated. These mental concepts are termed pre-sleep appraisals. A core example of a sleep-disturbing pre-sleep appraisal is evaluating the sleep environment as "unsafe", perceiving any potential (imagined or real) threat ("e.g. I have to wake up early") or having any arousing anticipation (e.g., "Tomorrow I will get an important reward for my career") An example of a sleep-promoting pre-sleep appraisal is "safety", "relaxation" or "appropriate state for sleeping".
2. During subsequent sleep, pre-sleep appraisals will be spontaneously reactivated during sleep, similar to previously encoded memories. The degree of these reactivations during sleep depends on two aspects: (a) the strength of activation during the pre-sleep period and (b) the strength of salience and self-relevance of pre-sleep appraisals.
3. The reactivation of pre-sleep appraisals during sleep will activate (a) related mental concepts, thereby biasing our predominant thoughts and emotions present during the sleep state and (b) also influence (to a weaker degree, depending on the amount of sleep pressure, etc.) associated physiological responses and neural circuits in arousal and sleep regulation brain regions. This will affect (a) the subjective feelings of recovery after sleep (less recovery due to a more alert, awake-like, stressful mental state during sleep or more recovery due to a more relaxed mental state during sleep) and (b) the objective sleep quality (e.g., number of awakenings/arousals, sleep depth, etc.).

5 | Central Pillars of the MCR-Hypothesis of Sleep

The core premises of the MCR-Hypothesis of Sleep draw upon key psychological theories, including appraisal theories of emotion and the repetitive reactivations of memories. These central pillars will be explained in the following sections.

5.1 | Appraisal Theories of Emotion

A central pillar of the MCR-Hypothesis is the cognitive appraisal of emotions theory. Cognitive appraisal is defined as the process by which individuals evaluate and interpret stimuli, situations, or events thereby generating emotions (Roseman and Smith 2001). In this process, potential stressors are assessed in terms of whether they pose a threat or represent a challenge, in fast, automatic and mostly subconscious manner. These appraisals play a pivotal role in shaping emotional, behavioural, and physiological responses (Ellsworth and Scherer 2002; Gaab et al. 2005; Lazarus and Folkman 1984). Importantly, appraisal theories explicitly or implicitly assume a strong interconnection between cognitive and physiological processes. Negative appraisal can induce physiological stress responses; therefore, stress arises from the individual's evaluation of a situation (Gaab et al. 2005). More generally, we assume that cognitions and emotions are not abstract or detached, but rather, are rooted in multimodal neural representations that are continuously shaped by the dynamic interaction between the body and the environment (i.e., they are embodied) (Barsalou 2008; Niedenthal 2007; Shapiro and Spaulding 2024). Empirical evidence consistently demonstrates that bodily sensations, postures, and physiological signals both influence and are influenced by cognitive processes (Critchley and Garfinkel 2018; Niedenthal 2007; Niedenthal et al. 2005). Neuroimaging studies support these findings by showing that abstract and concrete verbal concepts activate sensory, limbic, and sensorimotor regions associated with those concepts. For example, hearing words such as “leg” or “arm” triggers activity in corresponding sensorimotor areas (Boulenger et al. 2012). This would explain how cognitive appraisal can influence physiological parameters. In addition, since cognitive appraisals of the same stimulus or situation differ between individuals, appraisal theories of emotion can explain why the same situation induces highly different stress responses in different individuals. Empirical evidence suggests that the particular appraisals of stressful situations account for a substantial proportion of the variance in physiological stress responses, such as cortisol secretion, that cannot be explained by stable personality traits or retrospective evaluations (Gaab et al. 2005; Pulopulos et al. 2020; Schlotz et al. 2011). Specifically, individuals with high coping abilities tend to exhibit attenuated cortisol responses during stress exposure, reflecting more effective anticipatory stress regulation. Improved anticipatory regulation, in turn, is consistently associated with lower overall physiological reactivity to stress (Pulopulos et al. 2020; Schlotz et al. 2011). The MCR-Hypothesis applies the concepts of the appraisal theories of emotions to sleep.

Similar to stress, we assume that our ability to relax and fall asleep strongly depends on how we evaluate the situation in a fast, automatic and mostly subconscious manner. If we judge our sleeping situation as insecure and potentially dangerous, it makes a lot of sense to either not fall asleep, or to fall asleep but remain vigilant and attentive to cues signalling danger. This results in less deep and more disrupted sleep. From an evolutionary perspective, the ability to regulate our sleep depth and awakening probability, depending on the degree of danger present in our surrounding, might have benefited our ancestors' survival. In turn, pre-sleep appraisals of safety and security should result in fewer awakenings and a more stable, continuous, and deeper sleep. Of course, in modern societies, the probability of an existential threat is rather low due to mostly secure bedroom conditions. However, similar to stress responses, the same “old” mechanisms may underlie sleep disturbances in modern societies, for example, when we sleep in unfamiliar environments (e.g., First- Night Effects (FNEs); Agnew et al. 1966; Tamaki et al. 2016; see below), unsafe neighbourhoods (Hill et al. 2016), when we hear auditory cues that are associated with subjective feelings of disturbances (e.g., traffic noise, church bells, etc.; Brink et al. 2011; Ouis 1999), or a behaviorally relevant situation (e.g., baby cries, on-call situations; Hall et al. 2017; Poitras et al. 1973). Furthermore, in addition to external environmental factors such as noise and sounds, internal mental states such as stress, fear, and anxiety can also result in a sleep-disrupting pre-sleep appraisal. Stressful and potentially “dangerous” events (e.g., a relevant exam or presentation the next day, fear of missing an early flight, or an unresolved conflict with another person etc.), as well as positive arousing emotions (a promotion the next day) might be judged as relevant and sleep-disturbing, especially if they are anticipated for the next day. In contrast, certain relaxation strategies (e.g., specific hypnotic suggestions), habits, and routines (e.g., explicitly stopping our daily activities and tasks, writing a diary, convincing oneself that one has accomplished enough for the day, allowing oneself a break and sleeping, etc.) might induce a sleep-promoting pre-sleep appraisal, which should benefit sleep quality.

Additionally, the MCR-Hypothesis incorporates the distinction between valence and arousal as conceptualized in Russell's affective circumplex model (Russell 1980). Within this framework, emotions are located along two continuous dimensions: valence and arousal. Crucially, we emphasize that only mental concepts that elicit a sufficient level of arousal/relaxation and are appraised as salient and self-relevant prior to sleep are likely to influence subsequent sleep processes. In contrast, content lacking self-relevance or arousal/relaxation is expected to exert little or no influence on sleep.

Importantly, sleep-disturbing concepts are not limited to negatively valenced content. Both negative and positive valenced mental concepts may disrupt sleep if they are highly arousing and self-relevant. For example, intense excitement when expecting to receive a reward the next day (e.g., the night before a major award ceremony) may interfere with sleep in a manner similar to negatively valenced stress-related thoughts.

5.2 | Memory Reactivation During Sleep

Another pillar of the MCR-Hypothesis is the well-established role of memory reactivation during sleep. Extensive research has demonstrated that sleep facilitates memory consolidation, and the reactivation of memory traces during sleep has been identified as the principal factor contributing to these benefits (Diekelmann and Born 2010; Klinzing et al. 2019; Rasch and Born 2013). Particularly during NREM sleep, memories acquired before sleep are repeatedly and spontaneously reactivated, which facilitates the gradual integration of memories from hippocampal into neocortical long-term memory networks. This reactivation process relies on a precise coordination and interplay of neuronal patterns, including neocortical slow oscillations (SO) upstates (<1 Hz), fast spindles (13–15 Hz), and hippocampal sharp-wave ripple (SW-R) activity (Lutz et al. 2026). Numerous studies have provided empirical evidence for hippocampal replay activity in rodents (see O'Neill et al. 2010 for a review), as well as in humans (Peigneux et al. 2004; Zhang et al. 2025). Importantly, while signs of reactivations during sleep are typically most prominent during the first hour of sleep, some studies have provided evidence for a more long-lasting, novelty-induced reactivation during sleep up to 24 h (Ribeiro et al. 2004).

Over the past decades, studies have shown that consolidation processes can be externally manipulated through the presentation of memory cues during sleep that were previously associated with learned material (Hu et al. 2020). This targeted memory reactivation (TMR) makes use of the fact that the brain continues to process sensory input, albeit at a reduced level (Tononi et al. 2024). Effective cues include words, odours, and tones, which can enhance the reactivation of memory traces and thereby allow consolidation processes to be systematically examined (Carbone and Diekelmann 2024; Oudiette and Paller 2013). Taken together, both the functional role of endogenous memory reactivation during sleep and the experimental enhancement of this process through TMR are now firmly established (Denis and Cairney 2023; Hu et al. 2020).

In the framework of the MCR-Hypothesis, we propose that memory representations share certain properties similar to those of general mental concepts including pre-sleep appraisal judgements. Both are perceived and encoded during the day, particularly encoded or activated during the pre-sleep period. They induce the same stable representation, particularly if they are self-relevant, relevant for the future, and sufficiently arousing (or relaxing). Since memory representations encoded from memory tasks are spontaneously reactivated during sleep, we can also assume that other representations encoded during the day are similarly reactivated, even if they were not learned in a memory task. Notably, scientific research describes repetitive cognitive processes, such as rumination and worry, as the repeated activation of certain thought patterns. These processes occur in both healthy individuals and patients alike (Matthews and Wells 2003; McEvoy et al. 2013). Noteworthy, the assumption that cognitive concepts can be reactivated during sleep is not new. Brosschot et al. (2007, 2010) also examined the impact of stressors on sleep and proposed that worries and stress-related thoughts remain active and are unconsciously reactivated during sleep.

Therefore, the MCR-Hypothesis assumes that the pre-sleep appraisal of "potential danger" or "unsafe sleeping environment" encoded before sleep onset is spontaneously and repeatedly reactivated during sleep. As these appraisals are stored in multimodal representations closely associated with the brain's arousal and sleep regulatory centers, the reactivation of appraisals of "danger" or "unsafety" will both affect the internal mental state during sleep, the probability of arousals or awakenings, and possibly even the depth of sleep itself. In turn, sleep-promoting pre-sleep appraisals of "safety" or "relaxation" might lead to a mental state during sleep that is optimal for recovery. This may also lead to fewer arousals and awakenings, as well as deeper and more consolidated sleep. From an evolutionary perspective, such reactivations may serve as a protective mechanism to sleep less deeply and prepare the organism emotionally for relevant situations in the future.

Additionally, dreaming raises an important question regarding how the proposed reactivation of mental concepts during sleep relates to ongoing cognitive activity. When dreaming is defined broadly as any mental activity during sleep (e.g., "What went through your mind?"), such reports may serve as a relevant outcome measure to assess the reactivation of mental concepts during sleep.

With respect to memory consolidation, some studies suggest that reactivated memories can be reflected in dreams, others report weak or inconsistent evidence of memory reactivation during dreams (Hudachek and Wamsley 2023). This indicates that the reactivation of mental concepts and dreaming may be at least partially independent processes. Consistent with this, when dreaming is defined more strictly as structured dream experiences (e.g., "What did you dream about?"), it remains unclear to what extent reactivated concepts are systematically incorporated into dream content.

Additionally, the ongoing reactivation of concepts associated with wakefulness or stress may bias subjective evaluations upon awakening. This reactivation could create altered dream experiences and the sensation of being awake, even though one is objectively asleep, and may therefore contribute to sleep misperception, which is frequently reported especially in individuals suffering from insomnia (Benz et al. 2020; Feige et al. 2023). In line with this idea, we hypothesize that a mental state characterized by wake-like or sleep-disruptive content may exacerbate sleep misperception and reduce the subjective feeling of rest (see Figure 2).

How does the MCR-Hypothesis differ from existing frameworks of memory consolidation, such as the active systems consolidation account (e.g., Diekelmann and Born 2010)? While the MCR-Hypothesis builds on the assumption that mental content is reactivated during sleep, it does not aim to specify whether such reactivation leads to the consolidation or strengthening of memories. Questions regarding whether specific mental concepts are better remembered the next day or whether salient or emotional memories are preferentially consolidated during sleep or not are therefore not central to the MCR-framework. Instead, the MCR-Hypothesis shifts the focus away from memory outcomes (e.g., retrieval or consolidation) toward the functional consequences of reactivation for sleep itself. Specifically, it proposes that the reactivation of salient, arousing/relaxing, and self-relevant mental concepts influences sleep quality, sleep continuity, and the subjective experience of sleep, including processes such as restoration and sleep misperception.

In this sense, the MCR-Hypothesis generalizes beyond memory consolidation accounts by reframing reactivation as a mechanism that can either disrupt or facilitate sleep, depending on the nature of the activated content. By integrating insights from memory research with theories of emotion and arousal, the model aims to provide a theoretically grounded framework with direct clinical relevance for understanding and treating sleep disturbances such as insomnia.

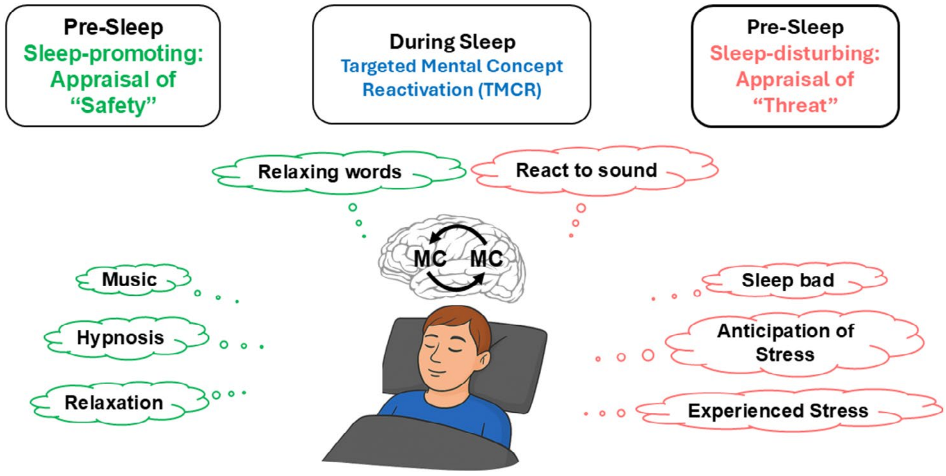

FIGURE 3 | Overview of studies directly testing the MCR-Hypothesis. Green: Studies that successfully induced sleep-promoting pre-sleep appraisals of safety, typically using relaxation techniques, music, or hypnosis. Red: Studies examining sleep-disturbing pre-sleep appraisals of threat, including instructions to expect poor sleep as well as comparisons between anticipated and experienced stress. Blue: Studies that actively, externally intervened in the reactivation process with targeted mental concept reactivation (TMCR) played relaxing words and tones that participants had to respond to.

In summary, the MCR-Hypothesis suggests that the mind–body mechanisms underlying stress and memory consolidation also shape sleep. The way we appraise our external and internal state, particularly during the pre-sleep period, is stored and then reactivated during sleep. If the appraisal is sleep-disturbing-like, the content of the repetitive reactivation and its associated mental concepts will be more arousing. We will be more attentive to external cues, and our sleep will be more disrupted and less deep. Conversely, when our pre-sleep appraisal is sleep-promoting, the reactivation during sleep ensures optimal mental recovery, resulting in deeper, more consolidated sleep, with fewer awakenings. This hypothesis explains why negative thoughts and worries continue to affect our sleep even after falling asleep and after sympathetic activation has decreased. It can also explain why the effects of stress, negative thoughts, and rumination on sleep vary so much from person to person. Finally, this hypothesis offers a theoretical foundation for testing and developing interventions that increase sleep quality, both before but also during sleep.

After outlining the foundational evidence underlying the MCR-Hypothesis, we next present behavioural support organized in different areas, with a particular emphasis on studies conducted in our own laboratory (for an overview see Figure 3). In general, research testing the MCR-Hypothesis is still in its infancy, although many existing lines of research indirectly support its core assumptions. As we have been trying to test the MCR-Hypothesis more directly in our laboratory for the past 8 years, this review reflects a research-based perspective with an inherent bias toward our work.

6 | Empirical Evidence of the MCR-Hypothesis

6.1 | Stress-Related Concepts and Their Impact on Sleep

A very well-known example supporting the conceptual framework of the MCR-Hypothesis is the First-Night Effect (FNE), which describes deteriorated sleep quality during the first night in a new environment (Agnew et al. 1966). According to the MCR-Hypothesis, sleeping in a foreign environment is associated with unfamiliarity or insecurity, leading to sleep-disturbing pre-sleep appraisals. During subsequent sleep, these pre-sleep appraisals of novelty and insecurity are reactivated, leading to changes in sleep architecture and reduced sleep quality, which are typical features of an FNE. In sleep research, an adaptation night is typically included to counteract this effect (Ding et al. 2022). However, FNEs are typically examined only in subsequent experimental night designs, whereas adaptation nights in experimental sleep research can occur several days or weeks earlier. In support of this practice, Wick et al. (2024) showed that FNEs also persist in nights spaced 1 week apart, particularly affecting wake after sleep onset (WASO), sleep onset latency (SOL), and total sleep time (TST). Thus, even after 1 week, the new environment is already appraised as safer than during the very first night, resulting in better sleep quality. In addition, sleeping in a familiar environment (at home) prior to sleeping in the unfamiliar environment attenuated (but did not eliminate) the FNE on subsequent nights in the unfamiliar setting (in the sleep laboratory). Thus, the recording equipment also appears to be appraised as unsafe or at least unfamiliar, which affects sleep architecture and quality. This may also explain why FNEs were also detected in the familiar home environment.

Another example is the well-established impairment of stress on sleep, which results in changes in sleep architecture and heart rate after an acute stress exposure (Feng et al. 2023; Hall et al. 2004). For example, psychosocial stress before a daytime nap led to delayed sleep onset and a slight reduction of early SWS but only marginally affected the overall sleep architecture (Ackermann et al. 2019). While most studies examined the effects of (completed) stress before sleep onset on later sleep, a number of studies have also assessed the anticipation of stress and its impact on sleep. A review by Akerstedt (2006) summarizes that anticipating stress, which also includes cognitive arousal, contributes to sleep impairments.

Work from our research group by Beck et al. (2023) directly compared experienced stress before sleep versus anticipated stress after sleep. Both forms significantly impaired sleep quality, as reflected by reduced SWS, lower spindle activity, and diminished sleep depth. However, there was an important distinction between the two conditions: When stress occurred before sleep (and was completed), then it impaired sleep mainly in the first part of the subsequent nap. The duration of the impairment was consistent with the well-known physiological response duration after stress (e.g., approximately 40 min). After that time, sleep depth and spindle activity re-emerged to a normal level or even exceeded the control condition. In the framework of the MCR-Hypothesis, this shows that completed stress before sleep (which is not relevant or threatening for the future) does not induce sleep-disturbing pre-sleep appraisals. However, in the anticipated stress condition, when stress is expected to occur after sleep, impairments in SWS and spindles activity were most prominent at the end of the nap, in close proximity to the stressor. This time course cannot be explained by an increased sympathetic response that starts in the pre-sleep period and continues throughout. Instead, the MCR-Hypothesis proposes that the anticipation of stress after the nap activates a self-relevant pre-sleep appraisal of potential future threats. This pre-sleep appraisal is then spontaneously reactivated during sleep, becoming increasingly dominant and relevant across the sleep period. Therefore, sleep impairments mostly occur in the later part of the nap period, as the actual stress approaches. Notably, a comparable pattern (although not very strong) regarding the influence of the temporal proximity of stressors on the emotionality of dream content was recently reported: In a study by Baselgia and Rasch (2025), pre-sleep stress intensified the perceived threat in dream content during the early part of the night, whereas anticipatory stress occurring after sleep onset increased the feeling of threat during the second half of the night.

Interestingly, these findings align with recent theoretical frameworks emphasizing predictive aspects of sleep and dreaming, such as the concept of predictive homeostasis. According to this perspective, sleep not only serves restorative functions but also supports the anticipation of future demands (Arnulf et al. 2014; Simor et al. 2023). In this context, the reactivation of anticipated, future-relevant mental concepts during sleep, as proposed by the MCR-Hypothesis, may reflect predictive processing of upcoming events.

6.2 | Intentional Influence on Sleep

In a next study, we further examined premises of the MCR-Hypothesis and investigated whether a deliberate intention to influence sleep is powerful enough to measurably affect sleep architecture and its quality. If so, this would demonstrate a powerful intervention for voluntarily regulating sleep quality and corroborate the premises of the MCR-Hypothesis. One important example is the ability of individuals to intentionally plan their wake-up time intrinsically without external time feedback (Hayashi et al. 2010). Experimental studies (e.g., Born et al. 1999; Hayashi et al. 2010) show that this process involves both cognitive intention and physiological mechanisms, such as anticipatory rises in stress hormones (e.g., ACTH) before the planned wake time, leading to subtle changes in sleep architecture (Ikeda and Hayashi 2010).

To test also the effects of intentions on sleep itself in our lab, participants were instructed to consciously form the intentions immediately before falling asleep, to either sleep as optimally or as poorly as possible. Interestingly, negative intentions impaired objectively measured sleep: SOL increased, WASO was prolonged, and subjective misperception of sleep increased. In contrast, the intention to sleep optimally did not improve sleep quality compared to a control condition. The result pattern indicates a stronger impact or even self-relevance of sleep-disturbing compared to sleep-promoting intentions toward sleep. Although a ceiling effect may account for this pattern because only healthy, good sleepers were studied, it is also possible that it is inherently easier to voluntarily impair sleep than to improve it (Combertaldi and Rasch 2020).

6.3 | Reactions to Stimuli During Sleep

This rather negative direction of the first study on the power of internally generated intentions on subsequent sleep was followed by investigations examining whether instructions directed toward a stimulus presented during the night could produce measurable changes in sleep architecture and quality. Several studies have already shown that the sleeping brain continues to selectively process information that is personally or emotionally meaningful. Studies using auditory paradigms have demonstrated that salient stimuli, such as one's own name, familiar voices, or emotionally charged words, evoke distinct event-related potentials (ERPs) even during sleep, leading to more awakenings (Ameen et al. 2022; Blume et al. 2017, 2018; Legendre et al. 2019; Perrin et al. 1999; Portas et al. 2000). Consistent with these findings, both our study and that of Wuyts et al. (2012) indicate that an instruction can increase the personal relevance of a neutral stimulus, thereby activating specific concepts before sleep. This enhances the sleeping brain's selective sensitivity to meaningful cues and maintains somehow active during sleep, supporting the premises of the MCR-Hypothesis.

In Combertaldi et al. (2022), participants were instructed to respond to a neutral acoustic stimulus (a repeatedly presented one-second tone) during the night, mimicking the demands of on-call duty. Remarkably, the instruction alone was sufficient to impair objective sleep even without any actual tone presentation. Sleep efficiency (SE) was reduced, WASO increased, and slow-wave activity (SWA) diminished. These findings align with earlier results by Wuyts et al. (2012), who also reported impaired subjective sleep quality, prolonged WASO, and reduced SE under simulated on-call conditions. Moreover, Combertaldi et al. (2022) demonstrated through more refined ERP analyses that pre-sleep instructions modulate neurophysiological responses to tones. These results provide evidence that a simple instruction toward a neutral stimulus can increase its relevance and cognitive expectations during sleep, as well as objectively shape the processing of sensory stimuli. This shows that a simple instruction can enhance the relevance of a given stimulus.

Other lines of evidence also show and corroborate the importance of personal relevance and individual attitudes toward stressors. Several studies on noise and its effects on sleep have shown that attitudes regarding noise, perceived annoyance, and noise sensitivity significantly influence the likelihood and severity of sleep disturbances caused by noise. Individuals who perceive noise as more annoying or harmful, or who exhibit greater noise sensitivity, tend to report poorer sleep quality and more frequent sleep problems, even when exposed to similar noise levels as less sensitive individuals (Beutel et al. 2020; Chen et al. 2016; Lee and Chung 2024; Onakpoya et al. 2015; Peer et al. 2025).

6.4 | Pre-Sleep Activities and Their Influence on Sleep: Media Use

Beyond the pre-sleep appraisal of situational and environmental factors during the first night, we further examined how specific pre-sleep activities influence sleep, thereby expanding the framework of the MCR-Hypothesis. In our investigation of Baselgia et al. (2023), 50 healthy young adults watched a suspenseful TV show with cliffhangers before bedtime. Objective sleep parameters remained largely unchanged, showing only a trend toward prolonged SOL. However, EEG analyses revealed an increased slow-wave–beta ratio, which is indicative of reduced sleep quality. Additionally, ECG measurements showed an elevated heart rate during the first sleep cycle. These findings suggest that although cliffhangers minimally affect sleep architecture, the reported oscillatory and subtle autonomic changes may reflect continued cognitive processing during sleep.

Another study (Combertaldi et al. 2021) compared the effects of 30 min of social media use and a relaxation condition before bedtime on 32 healthy young adults' sleep. While social media did not significantly affect objective sleep parameters, relaxation improved SE, shortened SOL transition into SWS, and reduced heart rate. Subjective sleep quality remained unchanged after social media use but improved after relaxation.

Together, the results of the two studies show that neither social media use nor watching TV series before sleep can be generally classified as sleep-disruptive. Once again, the individual relevance and evaluation play a central role. Future research should focus on personally relevant content, for example highly suspenseful shows that create strong emotional involvement and impatience to find out what happens next. Such studies could reveal clearer effects on sleep. In the second study on media use before sleep, participants communicated with friends via a messaging app, which may have induced feelings of social connectedness rather than stress. Indeed, the common assumption in popular media that nighttime media use disrupts sleep appears to be overly generalized since the empirical evidence is inconclusive (see Meneo and Baglioni 2025). Rather, the individual appraisal and relevance of the stimulus and its situational meaning seem crucial in determining its subsequent impact on sleep architecture and sleep quality.

By combining the different results listed above, a next step would be to examine whether maintaining social contact with friends or family during the first night in a sleep laboratory could reduce the FNE by increasing feelings of situational familiarity and security.

6.5 | Body Posture and Semantic Processing

The foundational assumption of appraisal theories of emotion is that cognitions are embodied and stored in multimodal networks. Support for this notion comes from previous reports on the embodiment of action words, which show that reading sentences describing a specific movement significantly increases movement times (Glenberg 2010; Zwaan et al. 2012) and that pre-activation of motor networks facilitates the activation of compatible semantic networks (Mollo et al. 2016). In another study (Chen and Bargh 1999), participants were asked to rate the valence of presented words (e.g., “hate” or “love”) by pulling or pushing a lever toward or away from themself. Interestingly, they responded faster to positive words when pulling the lever toward themselves, and faster to negative words when pushing it away. These results further suggest that categorizing a word's valence is facilitated by a bodily movement that matches its meaning (Niedenthal et al. 2009).

We tested this assumption also in the context of sleep and conducted a first wakestudy (Hülsemann and Rasch 2021). We presented participants with sleep- or activity-related words while either standing or lying down. Semantic processing was facilitated when body posture and word meaning were congruent (e.g., sleep words while lying down and activity words while standing). This was reflected in enhanced ERP components (N180, P280, and N400), indicating both facilitated semantic integration and improved acoustic processing. However, no behavioural effects were observed. Nevertheless, these findings suggest that body posture activates multimodal semantic networks and facilitates access to congruent word meanings.

All these results support the fundament of the MCR-Hypothesis and underline a close link between bodily states and cognitions. Whether physiological factors, such as sleep deprivation, might modulate these word processing mechanisms remains an open question.

6.6 | Sleep-Promoting Concepts: Relaxation and Hypnosis

So far, the studies listed above suggest that the explicit activation of specific mental concepts before sleep is mainly effective for stress-related, sleep-disruptive concepts. Sleep-promoting, neutral, weakly relevant concepts appear insufficient to influence sleep meaningfully. A more optimistic perspective emerges from relaxation-based and hypnotic interventions before sleep. The relax condition in Combertaldi et al. (2021) demonstrated that sleep can indeed be improved through physiological relaxation. According to the MCR-Hypothesis, relaxation induces embodied concepts of calmness, which lowers pre-sleep arousal which becomes reactivated during sleep and promotes restorative sleep. These results align with the winding-down process described by Meneo and Baglioni (2025), which emphasizes multi-level de-arousal as a key mechanism facilitating the successful transition from wakefulness to sleep.

Strong evidence that sleep can be positively influenced emerges from studies that activate sleep-related concepts not through conscious, deliberate intentions (e.g., "I want to sleep better"; Combertaldi and Rasch 2020), but rather on a subconscious level. A series of investigations by Cordi et al. (2014), Cordi et al. (2015), Cordi et al. (2020), for example, presented highly hypnotizable young adults with hypnotic suggestions to "sleep deeper" immediately before sleep. Across multiple studies, these suggestions produced measurable improvements in objective sleep parameters: SWS and SWA significantly increased following the hypnotic intervention (Cordi et al. 2014). Similar effects were replicated in nighttime sleep and in adults over age 65 (Cordi et al. 2015, 2020). Beck, Cordi, and Rasch (2021); Beck, Loretz, and Rasch (2021) further corroborated these findings in both nap and nighttime settings, showing that hypnosis increased SWS and improved subjective sleep quality, although it slightly reduced slow-wave–spindle coupling. In contrast, Friesen et al. (2023), using a fear-conditioning paradigm, reported improvements only in subjective sleep quality, with no corresponding increase in SWS duration.

Additional support comes from Besedovsky et al. (2022), who replicated the SWS and SWA increases during naps and additionally observed a substantial rise in growth hormone levels after participants listened to deep-sleep hypnotic suggestions, which is an endocrine response typically associated with nocturnal SWS. These results indicate that hypnotic suggestions can intensify both neural and hormonal markers of deep sleep, potentially enhancing sleep's restorative functions.

Importantly, these enhancements in SWS cannot be attributed to the general relaxation elicited by listening to an audio recording; rather, the improvements depend specifically on the content of the hypnotic suggestions. Within the framework of the MCR-Hypothesis, the subconscious encouragement to "sleep deeper" is proposed to activate the pre-sleep appraisal of deep sleep, which then is spontaneously reactivated during sleep and facilitates deeper sleep. It is also noteworthy that individuals with low to medium hypnotizability do not appear to benefit from these suggestions, even when the audio is described merely as an "imagery exercise" rather than labeled as hypnosis (Cordi and Rasch 2021).

6.7 | Reactivation of Sleep-Promoting Mental Concepts During Sleep

The positive effects of pre-sleep hypnotic suggestions on sleep may be explained by the assumption that specific mental concepts (i.e., pre-sleep appraisals) are activated before sleep and reactivated during sleep, thereby influencing ongoing psychophysiological sleep processes. Assuming that our mental concepts can indeed be reactivated during sleep, one could make use of TMR to deliberately trigger the reactivation of the mental concept during sleep. We conducted a first study to test this idea. Following a pre-sleep hypnosis session, Beck, Cordi, and Rasch (2021) and Beck, Loretz, and Rasch (2021) repeatedly presented relaxing words during the second and third sleep cycles of nighttime sleep, using a TMR-like procedure. We termed this procedure targeted mental concept reactivation (TMCR). In this within-subject design with 55 young healthy participants, presenting relaxing words during sleep extended SWS, increased event-related SWA, and improved subjective sleep quality and an increase in subjective alertness. Complementing these findings, Koroma et al. (2024) reported that relaxing words elicited event-related heart-rate slowing and enhanced cardiac modulation relative to control words. Together, these results suggest that re-exposing individuals with TMCR procedure to relaxation-related words during sleep can reactivate corresponding mental content of deep sleep, thereby positively biasing sleep depth at both neural and physiological levels.

So far, pre-sleep interventions, such as hypnosis and relaxation, have been shown to improve sleep quality. Listening to relaxing music before sleep can also have positive effects (Dickson and Schubert 2020; Jespersen 2022). Cordi et al. (2019) reported that relaxing music before a nap reduced N1 sleep, tended to increase SWS, and improved subjective sleep quality, with particularly strong effects in individuals with low hypnotic suggestibility. Such interventions may activate rest- and sleep-related mental concepts that influence sleep through the masking of disturbing sounds, the distraction from stress, and the enjoyment of preferred music (Dickson and Schubert 2019, 2020). Yet, it remains unresolved whether music can be employed during sleep, rather than solely before sleep, within a TMCR-framework to shape and enhance sleep processes. We have recently initiated work in this research direction.

As a first step, we investigated whether the sleeping brain is even capable of perceiving basic musical elements. Wick and Rasch (2025) presented participants with major, minor, and dissonant chords. These chords elicit during wakefulness distinct neural responses and emotional reactions, with major chords generally inducing positive affect and minor chords negative affect (Bakker and Martin 2014; Maslennikova et al. 2013). In a proof-of-concept study, 47 healthy participants were presented with these chords during nocturnal sleep. ERPs recorded during NREM sleep revealed significant differences between chord types. Major chords elicited the strongest negative amplitude, minor chords produced intermediate amplitudes, and dissonant chords elicited the lowest amplitudes. Differences were also observed in several frequency bands in the time-frequency analysis. These findings are quite promising and indicate that the sleeping brain differentially processes single musical chords consistent with Western musical conventions. Moreover, these results provide a foundation for future research to examine whether more complex harmonic structures, such as chord sequences, or individual preferred musical stimuli, are processed differentially during sleep.

Overall, these findings demonstrate that not only stress- and threat-related concepts negatively affect sleep, but that rest- and relaxation-related concepts can be actively leveraged to deepen sleep and promote restorative processes.

7 | Open Questions and Limitations

The Mental Concept Reactivation (MCR)-Hypothesis of Sleep seeks to explain how thoughts, expectations, beliefs, and cognitions influence sleep, and how the individual relevance of these mental concepts may account for the substantial variability in sleep-related responses across individuals.

It is important to emphasize again, however, that the MCR-Hypothesis remains subordinate to the regulatory forces described in the two-process model of sleep regulation (Borbély 1982): Sleep is fundamentally governed by the interaction of circadian timing and homeostatic sleep pressure, and any cognitive or conceptual modulation operates within these biologically determined constraints. Whether sleep can still be experienced as restorative when sleep-disturbing mental concepts are active, but sleep pressure is too high, is an open question that requires empirical investigations.

Moreover, future research should disentangle the relative contributions of circadian, built-up sleep pressure, and targeted activation of mental concepts, and examine whether interventions such as relaxing words or musical stimulation during sleep produce different effects across varying circadian phases or levels of sleep pressure.

Still, the MCR-Hypothesis may help to explain phenomena such as sleep misperception or paradoxical insomnia. The reactivation of highly salient or negatively valenced mental content during sleep may create a subjective experience of wakefulness or unrest, even when objective sleep is present. This may contribute to the perception of non-restorative sleep despite sufficient sleep duration and depth.

Furthermore, the temporal proximity of mental concept activation to sleep onset is still unclear and requires further investigation. While the pre-sleep period may increase the likelihood that sleep-relevant content, whether externally or internally generated, becomes dominant, it is unclear to what extent temporal proximity, as opposed to salience, arousal, and sleep-related relevance, determines whether such content influences subsequent sleep quality.

Moreover, several aspects of the MCR-Hypothesis remain unresolved: For example, the exact underlying mechanisms through which these mental concepts influence sleep are still unclear. We propose that this influence is due to a multimodal representation of the mental concept associated with sleep and arousal regulatory brain networks. However, the strength of these associations and the circumstances in which they are stronger or weaker remain to be tested.

In addition, it is not yet clear whether the activated mental concepts during sleep remain continuously active from the pre-sleep period, or if they are truly "reactivated" (i.e., if activation after the pre-sleep period is reduced or gone and then reappears in a later sleep stage). While some evidence supports the notion of "reactivation" (e.g., dynamic changes in sleep architecture during anticipated stress in the morning or self-awakenings, see above), one could alternatively assume the existence of a continuous vigilance system active during sleep, rather than assuming reactivated mental concepts. Possibly studies investigating the neural or brain oscillatory level may be necessary to distinguish between these two alternatives. Moreover, the exact timing, localization in the brain, and reactivation frequency require further clarification. Additionally, it is also unclear what type of content is being reactivated and whether abstract intentions or specific semantic-emotional associations with the physiological arousal are involved and reactivated during sleep. Likewise, possible interactions or influences on mental activity present in dreams also remain to be determined as well as the influence of sleep misperception.

Since our studies have predominantly shown that the MCR-Hypothesis operates in a sleep disturbing direction, future studies should focus more on the possibility to activate sleep-promoting mental concepts and test whether they can indeed improve sleep quality. This would further test the sleep-improving effects of hypnotic suggestions or the TMCR through relaxing words, sounds, or music. Additionally, the MCR-Hypothesis currently faces several important limitations that restrict its broader application and generalizability. Primarily, much of the supporting empirical evidence derives from our research group. This means that independent replications in other laboratories are strongly needed, to the robustness of key findings outside our group. Furthermore, nearly all studies to date have involved samples of healthy young adults, which limits the generalizability to other populations, such as older adults, individuals with insomnia, or patients with relevant medical comorbidities. This lack of diversity currently restricts the translational potential of the MCR-Hypothesis, as its approaches cannot be reliably extended to clinical or high-risk groups without further research. Further, existing research has primarily focused on behavioural and electrophysiological measurements.

An important avenue for future research concerns the neurobiological mechanisms underlying the MCR hypothesis. While the present framework focuses on a conceptual level, future studies should aim to identify the activated areas, neuronal circuits, and neurotransmitter systems through which the reactivation of salient mental concepts interacts with arousal and sleep-regulatory processes. Sophisticated neuroimaging techniques, such as high-density EEG or functional magnetic resonance imaging, have yet to be employed to study the neural basis of MCR-related phenomena. Consequently, a critical question about the specific brain mechanisms involved remains to be addressed. To advance the field, rigorous, independent replication studies are needed, as well as more stringent control of cognitive and sensory stimuli in experiments. Moreover, more varied and clinically relevant samples must be included, and multimodal neuroimaging methods must be implemented to better establish the mechanistic pathways at work before any firm, practical or clinical recommendations can be made.

8 | How to Falsify the MCR-Hypothesis

The primary aim of this section is to outline the conditions under which the MCR-Hypothesis could be falsified. To accomplish this, it should be demonstrated that cognitive or intentional states prior to sleep do not measurably influence neural or behavioural sleep parameters once sleep begins. Specifically, the hypothesis would be rejected if manipulating mental content before sleep (e.g., anticipating stress, directing thoughts, or forming intentions) did not alter sleep architecture, oscillatory dynamics, or subjective sleep quality. Strong evidence against the hypothesis would be provided if both subjective restoration and physiological parameters remained entirely unaffected by pre-sleep mental content manipulations.

Furthermore, alternative explanations must be ruled out. One important alternative is that the presumed persistence or reactivation of cognitive processes during sleep may simply reflect brief micro-awakenings. During these micro-awakenings, individuals temporarily regain awareness and reengage with their pre-sleep appraisals and mental concepts. In this case, any observed effects would not indicate genuine MCR during sleep, but rather the transient reactivation associated with brief wakefulness. Therefore, it is essential to demonstrate that the neural or behavioural effects attributed to the MCR-Hypothesis occur during the sleep state itself, and not after awakening from sleep.

Also listed as an open question, the hypothesis could be disproved by drawing on underlying neural mechanisms. If pre-sleep appraisals truly influence sleep, then we would also expect identifiable neural markers of these cognitive states during sleep. Similar to insomnia research, where increased beta activity or signatures of cognitive hyperarousal can be observed (Perlis et al. 1997), there should be detectable correlates of appraisal-related mental processing during sleep. Possible candidates include increased high-frequency activity, transient intrusions of waking thought patterns, or other EEG signatures indicating the continued presence of pre-sleep mental content. If no such neural markers can be reliably detected, or if the observed patterns can be fully explained by wake-like intrusions, this would further weaken support for the MCR-Hypothesis.

9 | Conclusion

With the MCR-Hypothesis of Sleep, we propose a framework that explains how thoughts, expectations, emotions, and other cognitive states can influence sleep not only during wakefulness and sleep onset period, but sleep itself. We suggest that certain mental concepts may persist or become reactivated during sleep, thereby shaping subjective sleep quality, arousal levels, and sleep architecture. By extending the influence of cognition and emotion beyond the wake–sleep transition, as well as by introducing the concepts of individual appraisal and sleep relevance, our approach offers an explanation for why individuals differ substantially in their reactivity of sleep to stress, pre-sleep worry, and pre-sleep expectations, and why these differences may manifest in both subjective and objective sleep measures.

Advancing our understanding of these mechanisms could support the development of interventions that interrupt maladaptive cognitive and emotional processes and reduce arousal both before but also during sleep. At the same time, this framework highlights the potential of leveraging sleep-promoting mental concepts to improve sleep quality. Such insights would enable the design of non-pharmacological, low-cost, and side-effect-free strategies with high relevance for both clinical and non-clinical populations. These approaches could provide new effective treatment options for individuals with insomnia and help healthy sleepers maintain sleep quality and prevent sleep difficulties from escalating into chronic insomnia or other sleep disorders. This could also explain sleep disturbances caused by anxiety because individuals are more likely to perceive situations as threatening. Following traumatic experiences, there is a greater likelihood that trauma-related images will resurface, which can result in nightmares. In cases of depression, negative emotions that are chronically reactivated during sleep could impair sleep recovery. One might even speculate that our hypothesis is relevant to explaining other sleep disorders, such as certain forms of parasomnia.

By integrating a combined perspective of cognitive, emotional, and physiological factors, the MCR-Hypothesis provides a testable and theoretically grounded framework for exploring how the sleeping brain engages with mental content and its effects on sleep parameters. Ultimately, our MCR-Hypothesis may substantially broaden our understanding of the dynamic interplay between mental concepts and sleep, opening new avenues for targeted sleep interventions to improve this important state of consciousness.

Author Contributions

Björn Rasch: supervision, funding acquisition, conceptualization, writing – review and editing, project administration, validation. **Anna Zoé Wick:** writing – original draft, conceptualization, validation, visualization, methodology, writing – review and editing.

Acknowledgements

We thank Sandrine Baselgia, Jonas Beck, Selina Combertaldi, Maren Cordi, Mareike Hülsemann, and all additional team members who contributed to this ERC-funded project for their valuable work, constructive discussions on the MCR-Hypothesis of Sleep, and continuous involvement throughout all research stages. Open access publishing facilitated by Universite de Fribourg, as part of the Wiley - Universite de Fribourg agreement via the Consortium of Swiss Academic Libraries.

Funding

All studies conducted at the University of Fribourg, Department of Psychology, Division of Cognitive Biopsychology and Methods were supported by a grant of the European Research Council under the European Union's Horizon 2020 research and innovation program (grant agreement number 667875), the Swiss National Science Foundation (project number 10.002.483), and the University of Fribourg.

Disclosure

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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