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The role of objective sleep in implicit and explicit affect regulation: A comprehensive review

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ABSTRACT

Impairments in sleep and affect regulation are evident across a wide range of mental disorders. Understanding the sleep factors that relate to affect regulatory difficulties will inform mechanistic understanding and aid in treatment. Despite rising interest, some research challenges in this area include integrating across different clinical and non-clinical literatures investigating the role of sleep architecture (measured with polysomnography) and experimentally manipulated sleep, as well as integrating more explicit versus implicit affect regulation processes. In this comprehensive review, we use a unifying framework to examine sleep's relationship with implicit-automatic regulation and explicit-controlled regulation, both of which are relevant to mental health (e.g., PTSD and depression). Many studies of implicit-automatic regulation (e.g., fear extinction and safety learning) demonstrate the importance of sleep, and REM sleep specifically. Studies of explicit-controlled regulation (e.g., cognitive reappraisal and expressive suppression) are less consistent in their findings, with results differing depending on the type of affect regulation and/or way that sleep was measured or manipulated. There is a clear relationship between objective sleep and affect regulation processes. However, there is a need for 1) more studies focusing on sleep and explicit-controlled affect regulation; 2) replication with the same types of regulation strategies; 3) more studies experimentally manipulating sleep to examine its impact on affect regulation and vice versa in order to infer cause and effect; and 4) more studies looking at sleep's impact on next-day affect regulation (not just overnight change in affect reactivity).

1. Introduction

Impairments in sleep and affect regulation are evident across a wide range of mental health disorders. Understanding relationships between such impairments is a high priority, offering the promise of better understanding of the mechanisms involved in mental disorders, as well as better-defined targets for interventions designed to prevent or treat mental health conditions.

Affect Regulation: According to the process model of affect regulation (Gross et al., 2019), affect is generated when an individual pays attention to an aspect of a situation (this could be an external or internal stimulus), evaluates it as good or bad, and has an affective reaction. Affect regulation refers to the processes responsible for identifying, evaluating, and modifying the trajectory of an affective response. Individuals can either up- or down-regulate negative (e.g., sadness, anxiety) or positive (e.g., joy, interest) affect, and the goal of affect regulation will necessarily depend on situation and context.

Individuals use a variety of different strategies to regulate their affect (see Gross, 2015). To organize these strategies at the broadest level, it is useful to employ a two-dimensional framework describing whether the

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goal of affect regulation is implicit or explicit as well as whether the process of regulation is automatic or controlled (Braunstein et al., 2017). Explicit-controlled affect regulation strategies involve consciously and deliberately changing one's affective states. These often entail the use of higher-order control processes, such as executive attention, working memory, and inhibition; for example, changing thoughts to feel less negative. By contrast, implicit-automatic strategies involve unconsciously changing one's affective states without an explicit goal and without the involvement of top-down control processes. For example, if an individual who is afraid of snakes were exposed to repeated presentation of a safe snake cue (e.g., a picture of a snake), their affect reactivity would decrease over time.

Both explicit-controlled and implicit-automatic regulatory strategies are relevant in mental health disorders. For example, in the explicit-controlled domain, difficulty challenging unhelpful thoughts (e.g., "Everything is my fault; " "The world is a dangerous place,") may lead to negative affect and symptoms of depressive and/or anxiety disorders. In the implicit-automatic realm, having an excessive hyperarousal response to objectively safe situations reflects a difficulty of internalizing safety cues, which is evident in PTSD and other anxiety disorders. Notably, gold-standard psychological treatments for these disorders explicitly teach regulatory strategies to patients to help them modify their affective experiences and reduce symptoms. For example, cognitive therapy for depression teaches cognitive reappraisal, which is an explicit and controlled affect regulation strategy (Clark and Beck, 2010). Exposure therapy, by contrast, aims to expose patients to feared but safe stimuli, which allows for extinction learning to occur (Craske and Mystkowski, 2006) – a more implicit regulation process. Understanding the factors that influence these affect regulatory processes will provide insight into the mechanisms relevant to these disorders and aid in treatment.

Sleep Disturbance: Sleep disturbance is one factor that is hypothesized to influence affect regulatory processes. Sleep is an active process which consists of multiple stages over the course of a night of sleep, including rapid eye movement (REM) sleep, the stage of sleep during which the most vivid dreaming takes place, and non-REM sleep. Sleep architecture refers to typical patterns of polysomnographic (PSG) activity that are characteristic of particular stages of, or arousals from, sleep. REM sleep is associated with several clinically relevant variables, including affective memory consolidation, generalization of learned patterns, and the exacerbation or alleviation of symptoms in mental health disorders like depression and PTSD (Payne and Kensinger, 2018; Kim and Dimsdale, 2007). Alterations in REM sleep patterns are often observed in these conditions, suggesting a potential therapeutic target for interventions (Walker and van der Helm, 2009; Germain, 2013). Non-REM sleep, which encompasses multiple stages including Stage 3 "deep" sleep, is crucial cognitive restoration and the consolidation of declarative memory (Walker and Stickgold, 2004). Disruptions in non-REM sleep are linked to a range of health issues, such as cognitive impairments, increased sensitivity to pain, and greater risk of developing chronic conditions like hypertension and diabetes (Buxton and Marcelli, 2010; Mander et al., 2013).

Sleep disturbance is a near-universal symptom in mental health disorders, including disorders related to trauma and stress such as PTSD, anxiety, and depression. As many as 90% of veterans with PTSD experience significant regular sleep disturbances, such as insomnia, nightmares, and obstructive sleep apnea (OSA) (Neylan et al., 1998; Colvonen et al., 2020), and sleep difficulty is one of the most common self-reported complaints (McLay et al., 2010). Similarly, over 80% of depressed patients have at least one insomnia symptom (Stewart et al., 2006). Reviews of the literature suggest that sleep disturbance is a core feature in PTSD and may contribute to other mental health conditions (Germain et al., 2008; Spoormaker and Montgomery, 2008; Nutt et al., 2022). In addition, sleep disorders independently contribute to problematic substance use (Nishith et al., 2001), suicidality (Malik et al., 2014), and poor quality of life (Krakow et al., 2002) in individuals with trauma histories. Sleep disorders such as insomnia, nightmare disorder, and OSA are associated with worse mental health symptoms and treatment trajectories (Colvonen et al., 2018).

Sleep disturbances common to mental health disorders are known to affect sleep architecture. As such, examining sleep architecture using objective measures like PSG provides detailed insights into specific sleep stages and disruptions, which can lead to more precise diagnoses and tailored treatment interventions for sleep disorders. By contrast, self-reported measures like the Insomnia Severity Index, while useful for initial assessments, can be influenced by subjective bias and do not capture the granular physiological details objective PSG offers. Similarly, sleep deprivation and restriction paradigms are considered an effective tool for examining sleep architecture because they allow researchers to observe the body's responses to lack of sleep, when compared to controls, providing insights into the essential functions of different sleep stages. By selectively depriving or restricting individuals' sleep, researchers can more accurately discern the specific physiological, affective, and cognitive roles sleep architecture plays in daytime processes. This approach helps in understanding the impact of sleep disruptions on health and behavior, revealing the critical processes that occur during distinct phases of sleep (Siegel, 2005; Durmer and Dinges, 2005).

Affect Regulation and Sleep Disturbance: A growing body of research implicates neural activity during particular stages of sleep, as characterized by sleep architecture, in affective processes. For example, fragmented sleep architecture impacts affective learning (Colvonen et al., 2019) and affect reactivity (Altena et al., 2016), albeit with mixed findings (ten Brink et al., 2022). Neural processes taking place during REM sleep appear to be especially critical in affective processes (Deliens et al., 2014; Tempesta et al., 2018). In the last decade, research has increasingly focused on understanding the role of REM sleep in adaptive affect regulation (Goldstein and Walker, 2014; Gruber and Cassoff, 2014; Guarana et al., 2021).

Despite a rapid increase in the research related to affect regulation and sleep and some attempts to evaluate this area of study (Palmer and Alfano, 2017; Vandekerckhove and Wang, 2018) several challenges remain. Notably, a) research investigating relationships between sleep and affective processes often fails to differentiate between affect reactivity (i.e., response to affective stimuli), and affect regulation (i.e., a goal-directed process targeted at modifying affective states or affect reactivity); b) many studies examining the impact of sleep on affect regulation have not experimentally manipulated sleep or objectively measured it via PSG, raising questions about causal relationships or whether different aspects of sleep architecture (e.g., REM/non-REM) are specifically important; and c) only recently have conceptual models integrated implicit-automatic forms of affect regulation with more explicit-controlled regulation (see Braunstein et al., 2017). Therefore, integrating these literatures will provide the opportunity to compare and contrast the role of sleep in explicit-controlled versus implicit-automatic affect regulatory processes.

Here, our goal is to provide a comprehensive review that addresses these gaps in the literature by organizing, describing, and summarizing the available literature that examines links between objective sleep (assessed via polysomnography and sleep manipulation) and implicit/explicit affect regulation processes. We begin this review by giving a brief overview of a conceptual model of affect regulation developed by Braunstein et al. (2017) which encompasses implicit versus explicit regulation goals and automatic versus controlled regulation processes, and we then summarize extant studies on sleep and affect regulation and their relevance to this framework. Next, we organize the available research with these categories in mind and detail relevant findings. We conclude with a summary of findings and suggestions for future research.

2. Model of affect regulation

Braunstein et al. (2017) posit that affect regulation strategies differ along two orthogonal dimensions: how explicit (versus implicit) the goal of regulation is, and how controlled (versus automatic) the process of regulation is. Based on this, they identify four classes of affect regulation: explicit-controlled, implicit-automatic, explicit-automatic, and implicit-controlled (see Fig. 1). The lion's share of research on affect regulation and sleep architecture falls into the first two classes.

Explicit-controlled affect regulation refers to using strategies with an explicit (i.e., conscious) goal to change one's affective states that entail the use of higher-order control processes, such as executive attention, working memory, and inhibition (e.g., exerting effort in trying to feel less negative). Cognitive reappraisal (i.e., trying to change how one thinks about a situation) and expressive suppression (i.e., trying to not show how one feels) constitute the clearest examples of this class of affect regulation strategies.

Implicit-automatic affect regulation refers to a class of strategies that are used to change one's affective states without an explicit goal and without the involvement of top-down control processes. According to Braunstein et al. (2017), implicit regulation can involve goals that are activated without conscious awareness in a particular instance but that can also be activated explicitly in other contexts (as in the case of priming). It can also involve goals active in the long term but operating in the background of awareness (such as a goal to accurately identify and respond to threatening stimuli (Schultz et al., 1997; Ledoux, 2012), or reflect the incidental effect of another explicit goal (Lieberman et al., 2007).

The clearest examples of strategies belonging to this class are fear conditioning, fear extinction, safety learning, and affective learning – all processes where changes in the environment or experience cause a person to update their prior valuation of, or response to, a stimulus. Importantly, these are processes that happen automatically, without conscious control, and can take time for incremental changes in affect to accumulate.

It should be noted that Braunstein et al. (2017) also included two other classes of affect regulation strategies in their conceptual framework: implicit-controlled and explicit-automatic. **Explicit-automatic** regulation involves an explicit goal to alter one's affect, but which relies on non-controlled processing, such as in placebo effects (for a review on the role of sleep on placebo effects, see Chouchou et al., 2018). **Implicit-controlled** affect regulation involves conscious, top-down control processing where individuals are not explicitly trying to regulate their affect, even though their affect does change. In Braunstein et al. (2017), two types of implicit-controlled regulation are distinguished. First, regulation that occurs incidentally while engaged in another primary control task, such as selective attention (e.g., Chuah et al., 2010) or forced choice (e.g., Venkatraman et al., 2007). Second, regulation that occurs when people engage in a controlled process for a goal that operates below conscious awareness, such as a primed goal (e.g., McNamara et al., 2010) or a goal to follow social norms (e.g., Ben Simon and Walker, 2018). **However, we limit the scope of this review to explicit-controlled and implicit-automatic affect regulation** because of the complexity of making comparisons between regulation strategies and the relatively small number of studies within the latter two classes (see below).

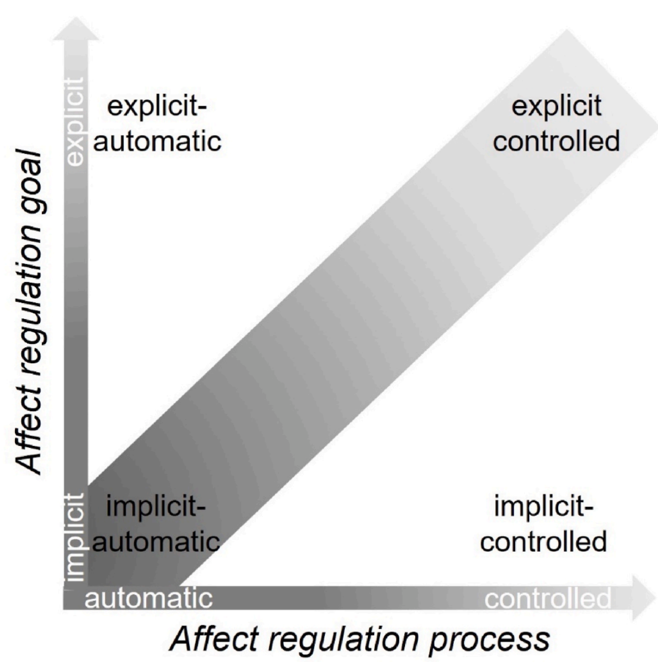

Fig. 1. Model of affect regulation by Braunstein et al. (2017) we used as the framework for this review. Since the majority of studies examined either implicit-automatic or explicit-controlled affect regulation, we focused on these domains for the current review (shaded region).

3. Study selection

In order to be included in the final review, studies met the following criteria: 1) written in English, 2) focused on an empirical study, either experimental or observational (i.e., review papers were excluded), 3) included human subjects, 4) focused on affect regulation (e.g., studies only focused on affective reactivity and not affect regulation were excluded), 4) measured sleep objectively via PSG or manipulated sleep via partial or total sleep deprivation, and 5) could be categorized as either explicit-controlled or implicit-automatic via the framework proposed by Braunstein et al. (2017); studies that could not be categorized as explicit-controlled or implicit-automatic were excluded due to the complexities involved in making comparisons between disparate regulation strategies. See Supplementary Table 1 for full inclusion/exclusion criteria.

See Fig. 2 for a flowchart depicting the process for selecting studies for this review. The database search and review process was done using Rayyan, an online literature review tool (Ouzzani et al., 2016). An extensive database search of Pubmed, PsychNet and Medline was conducted using the following search string: ((coping) OR ("affect regulation") OR ("emotion regulation") OR (extinction)) AND ((sleep AND polysomnography) OR (PSG) OR ("sleep restriction") OR ("sleep deprivation") OR (REM) OR (NREM)). Publication dates for the searches ranged from the beginning of each database to November 2023. The database search generated 1300 studies. 72 additional studies were added to this list because they were known to the authors and 9 studies were suggested by reviewers (see Fig. 2).

After removing duplicates (n = 549) and articles for which full text was not available (n = 127), 705 studies remained for screening. The title and abstract screening process involved a first pass of the studies based on the following exclusion criteria: non-human samples, language not English, and non-empirical papers. The second pass of the abstract screening involved exclusion of those abstracts which did not involve affect regulation, sleep architecture, or sleep manipulation. The abstract screening process was fully blinded. RS screened 100%, and MTB and PS each screened 50% of abstracts and titles. After the first screening process, 545 studies were excluded, whereas 160 studies remained for full text screening.

Next, one reader (either MTB, PS, or LS) carefully reviewed 138 eligible full text articles to determine eligibility based on the inclusion/exclusion criteria and gave each article a rating 1–5 on dimensions of implicit-explicit goals (with a clearly explicit regulation goal given a rating of 5) and automatic-controlled processes (with a clearly controlled regulation process given a rating of 5). After this, the readers discussed the categorization on as-needed basis with the other co-

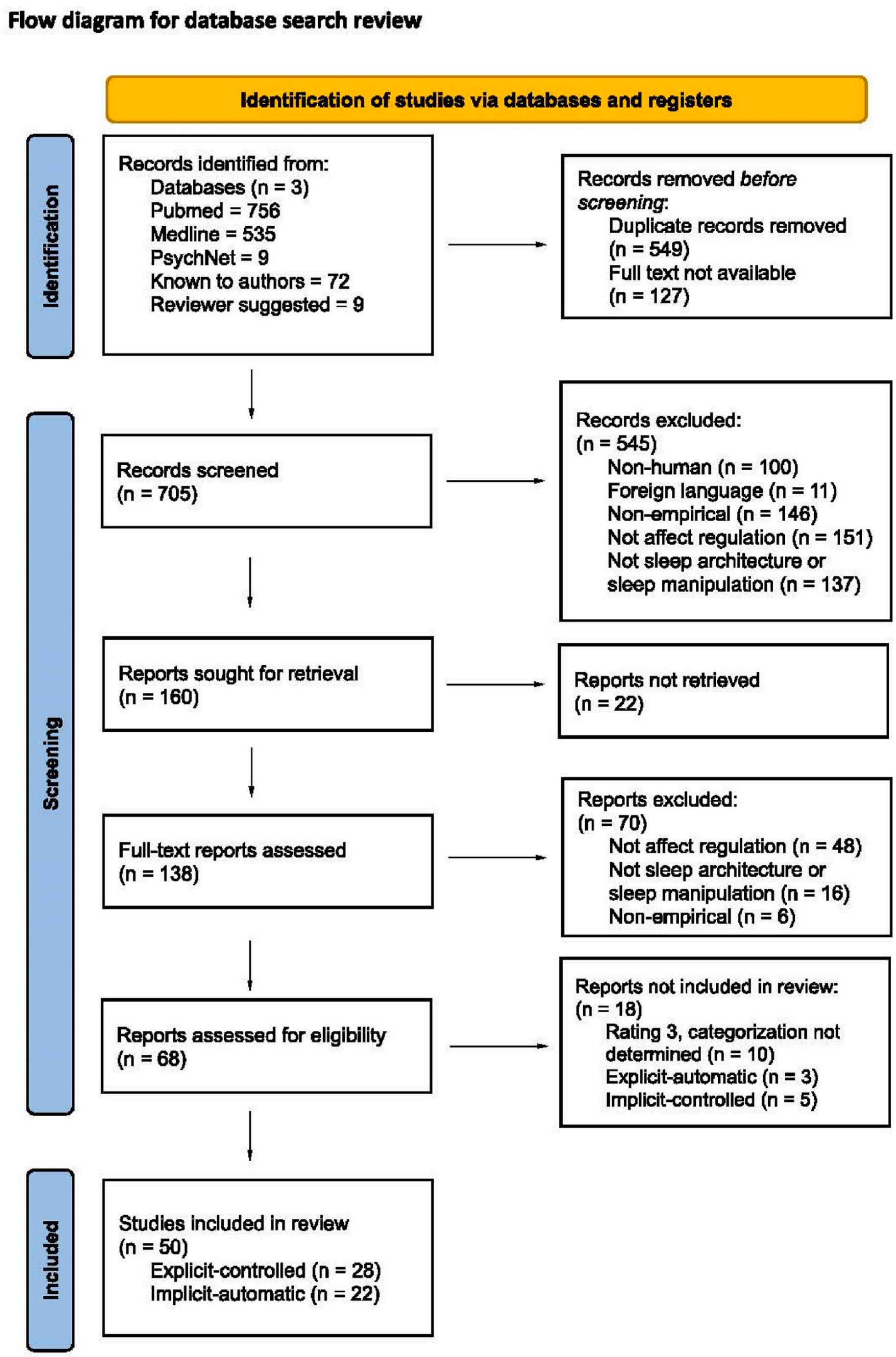

Fig. 2. Flow diagram for database search review.

authors and came to consensus. Based on the ratings, papers were categorized into one of the four classes of regulation: explicit-controlled, implicit-automatic, explicit-automatic, or implicit-controlled. Ten studies with ratings of "3," in which either the affect regulation goal or process dimensions were unclear/ambiguous, were excluded from the final set of articles. Seven studies were categorized as including explicit-automatic (n = 2) or implicit-controlled regulation (n = 5). Fifty studies categorized as explicit-controlled (n = 28) or implicit-automatic (n = 22) regulation were included in the final set of papers for this review.

4. Sleep and explicit-controlled affect regulation

Below, we summarize the extant research relevant to sleep and explicit-controlled affect regulation, which has grown significantly in the last 5 years (see Table 1 for a full list of included studies). We first discuss the relationship between sleep and cognitive reappraisal and expressive suppression specifically, given that these affect regulation strategies are the most well-studied in research involving objective sleep and due to their high relevance for mental health conditions. To investigate the question about how sleep disturbance and/or which aspects of sleep architecture might be most influential in explicit-controlled affect regulation, we then group the remaining identified studies in terms of study design, i.e., sleep architecture (measured with PSG) or sleep manipulation (either partial or total sleep deprivation).

Sleep and cognitive reappraisal: One of the most well-studied explicit-controlled affect regulation strategy is cognitive reappraisal,

Table 1
Explicit-controlled emotion regulation.

Authors/Year	Sleep Methods	Sample Size	Population
Germain et al. (2003).	PSG	63	Healthy adults
Galbiati et al. (2020).	PSG	46	Insomnia vs healthy adults
Jun et al. (2020).	PSG	94	REM behavior disorder vs healthy adults
Woud et al. (2018).	PSG	105	Healthy adults
Prados et al. (2020).	PSG	39	Fibromyalgia and insomnia
Vandekerckhove et al. (2012).	PSG	28	Healthy adults
Soehner et al. (2018).	PSG	43	Bipolar disorder vs healthy adults
Britton et al. (2012).	PSG	23	Antidepressant users with sleep complaints
Alfano et al. (2020)	PSG/Partial sleep deprivation	53	Healthy children
Zhang et al. (2019).	Total sleep deprivation	51	Healthy adults
Reddy et al. (2017).	Partial sleep deprivation	42	Healthy adolescents
Shermohammed et al. (2020).	Total sleep deprivation	34	Healthy adults
Baglioni et al. (2024)	Partial sleep deprivation	86	Healthy adults
Barnes et al. (2016)	Total sleep deprivation	88	Healthy adults
Britton and Bootzin (2004)	PSG	43	Near death experience vs healthy adults
Campbell et al. (2022)	Total sleep deprivation	69	Healthy adults
Glosemeyer et al. (2020)	Selective REM vs SWS deprivation	45	Healthy adults
Harrington et al. (2021)	Total sleep deprivation	60	Healthy adults
Killgore et al. (2008)	Total sleep deprivation (>50 h)	26	Healthy adults
Kollar et al. (1969)	Total sleep deprivation (>200 h)	4	Healthy adults
Li et al. (2023)	Total sleep deprivation	39	Healthy adults
McMakin et al. (2016)	Partial sleep deprivation	16	Healthy adolescents
Taylor et al. (2015)	PSG	60	Dementia caregivers
Wang et al. (2022)	PSG	43	Healthy adults
de Zambotti et al. (2019)	PSG	16	Insomnia
Saadat et al. (2017)	Total sleep deprivation	21	Anesthesiologists
Stenson et al. (2021)	Total sleep deprivation	60	Healthy adults

Note. PSG = polysomnography, REM = rapid eye movement, SWS = slow wave sleep.

which is when one consciously tries to reinterpret the situation that evoked an affective response to change affect (e.g., "My colleague is not angry with me but just tired"). This affect regulation strategy is particularly relevant in clinical contexts because cognitive distortions are common across mental health disorders (Yurica & DiTomasso, 2005) and because cognitive therapy is an intervention that deliberately teaches cognitive reappraisal to help address cognitive and affective symptoms of these disorders (Clark and Beck, 2010).

Of the studies that investigate objective sleep and cognitive reappraisal, most were experiments that manipulated sleep via either partial or total sleep deprivation and tested subsequent performance during cognitive reappraisal tasks. Findings are highly discrepant. For example, in a study by Shermohammed et al. (2020), healthy adults were instructed to use cognitive reappraisal in response to negative images while well-rested or after one night of total sleep deprivation. The investigators found that sleep deprivation did not affect the ability to implement cognitive reappraisal. Similarly, Reddy et al. (2017) examined sleep restriction in adolescents (13–17 years). They found that one night of sleep restriction (4 h of sleep) led to enhanced affect reactivity to negative images but did not impact individuals' ability to use cognitive reappraisal to regulate negative affect. These specific results have been replicated in some studies—healthy adults who underwent one night of REM sleep suppression showed enhanced negative affect without impact on cognitive reappraisal (Glosemeyer et al., 2020). By contrast, some studies have shown that sleep disturbance did negatively impact cognitive reappraisal. For example, Zhang et al. (2019) found that, in young adults, one night of total sleep deprivation impaired the ability to use of cognitive reappraisal (and distraction). Similar results have been replicated in other studies using total sleep deprivation in healthy adults (Stenson et al., 2021; Li et al., 2023). Such contradictory findings indicate that more research is needed to determine if the impact of sleep disruption on cognitive reappraisal depends on the group being studied (e.g., children versus adolescents versus adults), the type of sleep disturbance (e.g., total sleep deprivation versus partial sleep deprivation), or other relevant factors.

In addition to these studies, we also identified three more studies examining sleep and cognitive reappraisal which used designs other than testing cognitive reappraisal in sleep-deprived individuals. One was cross-sectional (Jun et al., 2020), and three implemented cognitive reappraisal training and then objectively measured subsequent sleep via PSG (Prados et al., 2020; Wang et al., 2022; Woud et al., 2018). Interestingly, Woud et al. (2018) used a cognitive bias modification intervention focused on cognitive reappraisal and found that sleep did not enhance the effect of the intervention, but participants who took a 90-min nap (compared to participants who watched a neutral film) experienced fewer intrusive memories of a stressful film shown during the study. These results suggest a protective effect of sleep on subsequent stress symptoms, but perhaps via a different mechanism than cognitive reappraisal.

Sleep and expressive suppression: Another commonly studied affect regulation strategy is expressive suppression, when one consciously tries not to outwardly show one's emotions to others (Gross and John, 2003). Suppression is highly relevant in mental health contexts, as it has been linked to numerous mental health disorders including PTSD (Khan et al., 2021) and social anxiety (Dryman and Heimberg, 2018), as well as lower positive affect in non-clinical populations (Fernandes and Tone, 2021).

To date, several studies manipulating sleep via total or partial sleep deprivation have consistently shown that sleep deprivation impacts suppression in ways that would amplify negative affect and/or reduce positive affect. For example, an ecological momentary assessment study suggested that sleep-restricted adults demonstrated increased frequency of maladaptive affective regulation strategies, including expressive suppression (Baglioni et al., 2024). Not only does sleep loss impact choice to use expressive suppression, it also appears to influence the effectiveness of expressive suppression when individuals are specifically instructed to use this strategy—a study in healthy young adults indicated that, following a night of total sleep deprivation, expressive suppression was ineffective at reducing negative affect (Zhang et al., 2018). Interestingly, Alfano et al. (2020), restricted sleep in children aged 7–11 and showed that the children subsequently were *more* able to suppress *positive* emotions. In each case, sleep deprivation influenced expressive suppression in ways that would increase the likelihood of negative affect, which raises the possibility that this mechanism is relevant for mental health symptoms.

Sleep architecture and explicit-controlled affect regulation: We identified ten studies that used PSG to explore relationships between sleep architecture and a diverse array of affect regulation strategies beyond cognitive reappraisal or suppression. These studies tended to fall into two broad categories: 1) studies comparing questionnaire assessments of affect regulation in clinical groups, and 2) studies that trained participants to use specific affect regulation strategies in tasks and then measured the effect on subsequent sleep architecture.

To our knowledge, five studies have explored relationships between objective sleep and affect regulation by comparing clinically significant groups. These studies used self-report questionnaires assessing use of a heterogenous set of coping and affect regulation strategies involving explicit goals and controlled processes. For example, one study demonstrated that, among dementia caregivers, avoidant coping (e.g., denial, mental disengagement, behavioral disengagement) heightened the likelihood that these individuals would be classified as having low sleep efficiency as confirmed by PSG (Taylor et al., 2015). Other cross-sectional studies have implicated REM specifically. For example, in a study by Jun et al. (2020), polysomnographically-confirmed sleep disorder patients (with idiopathic REM sleep behavior disorder) reported lesser use of adaptive regulation strategies (specifically, positive refocusing, refocusing on planning, and positive reappraisal) compared to a control group. Galbiati et al. (2020) had insomnia patients complete a questionnaire measuring difficulties in affect regulation and undergo PSG recording overnight. Several REM sleep parameters, including REM latency and an author-derived REM arousal index, were positively associated with more difficulties in affect regulation. Britton and Bootzin (2004) compared individuals who had experienced Near Death Experience (NDEs) to matched controls. Compared to the controls, individuals who had experienced NDEs scored higher on a measure of active problem-focused coping, and also demonstrated longer REM latencies and fewer REM episodes. Notably, high REM latency and fewer REM episodes are often proxies for consolidated REM sleep (see Marshall et al., 2014). Although these investigators did not report directly measuring associations between positive coping and REM consolidation, this may be of interest to explore in future studies. With one study as an exception (Germain et al., 2003), taken together, these results provide evidence that REM sleep is uniquely related to explicit-controlled affect regulation assessed by questionnaires.

In addition to the studies noted above, several (n = 5) have explored the impact of training participants to use an explicit-controlled affect regulation strategy in a task and its subsequent impact on sleep architecture. These studies are currently fewer in number and more varied in their conclusions. For example, Soehner et al. (2018), observed more REM sleep in individuals who were trained to up-regulate sad affect in response to musical cues. Vandekerckhove et al. (2012) induced a failure experience in healthy adults shortly before bed and trained them to use either experiential (i.e., acknowledging, understanding, and expressing actual affective experience about a situation) or analytical (i.e., analyzing the causes, meanings, and consequences of the affective situation) affect regulation strategies. They found that the use of experiential (vs. analytical) affect regulation resulted in several changes to sleep macrostructure including a longer sleep time, fewer awakenings, and higher sleep efficiency. The authors did not find significant differences in the percentage of REM or NREM sleep either compared to baseline or between the two affect regulation conditions. Wang et al. (2022) also experimentally induced a failure experience and did not demonstrate that a technique based on body focus impacted subsequent sleep parameters, whereas other investigators have trained individuals to use mindfulness strategies (Britton et al., 2012) or paced-breathing biofeedback (de Zambotti et al., 2019) and showed improved objective sleep consolidation, such as reduced wake time and increased sleep efficiency, post-intervention. These studies suggest that direct manipulation of explicit-controlled affect regulation may impact objective sleep parameters, including sleep consolidation. However, in contrast to the group comparison studies using questionnaire assessments, REM architecture variables were less likely to be affected.

Sleep deprivation and explicit-controlled affect regulation: In addition to the studies using PSG, we identified eight studies that manipulated sleep via partial or total sleep deprivation and then measured the impact on subsequent explicit-controlled affect regulation. These studies focused on a broad array of different explicit-controlled affect regulation strategies and reported heterogenous results, though different patterns may be observed when considering the impact of sleep deprivation on primarily internal affect regulation strategies (e.g., thought suppression) versus affect regulation that involves a behavioral component (e.g., approaching versus avoiding specific emotional stimuli).

The studies examining explicit-controlled affect regulation on primarily internal strategies almost universally noted a deleterious effect of sleep loss. For example, an experiment in healthy adults showed that individuals were less able to suppress intrusive unwanted thoughts after a night of total sleep deprivation (Harrington et al., 2021). Similarly, total sleep deprivation impacted healthy adults' ability to reduce negative affect in response to pictures (Stenson et al., 2021), and reduced individuals' confidence in their capacity to understand one's own and others' emotions more generally (Killgore et al., 2008). Given that challenges modulating unwanted thoughts or affect internally is a specific feature of mental health conditions, these studies provide evidence that sleep loss might play a role in exacerbating or maintaining symptoms.

Results from the studies on sleep deprivation and explicit-controlled affect regulation were more complex when considering affect regulation strategies with a behavioral component. Some studies showed a deleterious impact of sleep loss on specific affect regulatory behaviors, such as the ability to inhibit displays of negative affect during a conversation about peer conflict (McMakin et al., 2016). However, other studies showed that sleep deprivation heightened negative affective reactivity to distressing stimuli without noting a specific change in behavior. For example, one study using prolonged sleep deprivation described heightened physiological reactivity to a cold pressor task (Kollar et al., 1969) without noting specific changes to the amount of time participants could withstand the task. Similarly, an experiment where healthy adults were instructed to approach disgust-provoking stimuli reported that participants experienced heightened negative affect during the task but did not display changes in their actual approach versus avoidance behavior (Campbell et al., 2022). Several studies suggested that some regulatory techniques were more resilient to sleep loss than others. In one study measuring reaction time in anesthesiologists after a night call, self-reported use of avoidance as a coping technique negatively impacted reaction time, whereas engaging in problem-solving or support seeking did not (Saadat et al., 2017). In another experiment focused on charismatic leadership (Barnes et al., 2016), use of "deep acting" (i.e., trying to feel the emotions needed to show to others) was also resistant to total sleep deprivation. These mixed results suggest that sleep deprivation might differentially impact some explicit-controlled affect regulatory strategies more than others, which indicates more research is needed to determine implications for mental health treatments that include a behavioral component (e.g., cognitive behavioral therapy, behavioral activation). Moreover, differing durations of sleep deprivation protocols and the chronic (compared to acute) nature of the deprivation may contribute to the varied findings.

5. Sleep and implicit-automatic affect regulation

To our knowledge, all available research examining sleep and implicit-automatic affect regulation focuses on fear learning, fear extinction, and safety signal learning. Research on this area has been of robust interest for several decades and employs relatively homogenous methods, compared to the newer focus on and heterogenous methods explored by studies of explicit-controlled regulation and sleep. We therefore organize this section to summarize findings relevant to sleep and extinction processes and safety signal learning processes in turn. See Table 2 for a full list of studies related to implicit-automatic affect regulation.

Sleep and fear extinction learning and memory: Research in this category often makes use of Pavlovian fear conditioning paradigms to

Table 2
Implicit-automatic emotion regulation.

Authors/Year	Sleep Methods	Sample Size	Population
Bottary et al. (2020).	PSG	48	Insomnia vs healthy controls
Lerner et al. (2017).	PSG	17	Healthy controls
Marshall et al. (2014).	PSG	42	Healthy controls
Pace-Schott et al. (2014).	PSG, comparison between sleep versus wakefulness periods	28	Healthy controls
Richards et al. (2022).	PSG	46	Trauma-exposed
Spoormaker et al. (2010).	PSG	16	Healthy controls
Spoormaker et al. (2014).	PSG	17	Healthy controls
Spoormaker et al. (2012).	REM versus NREM sleep deprivation	18	Healthy controls
Straus et al. (2017).	Total sleep deprivation	71	Healthy controls
Straus et al. (2018).	PSG	13	Veterans with PTSD
Sturm et al. (2013).	PSG	24	Healthy controls
Seo et al. (2021).	PSG/Partial sleep deprivation	154	Healthy controls
Yuksel et al. (2024)	PSG	113	Trauma exposed
Kuriyama et al. (2010)	TSD	28	Healthy controls
Menz et al. (2016)	Partial sleep deprivation	80	Healthy controls
Rihm et al. (2016)	PSG	60	Spider phobia
Seo et al. (2018)	PSG	46	Insomnia vs healthy controls
Seo et al. (2022)	PSG	133	PTSD vs trauma exposed controls

Note. PSG = polysomnography, REM = rapid eye movement, NREM = non rapid eye movement, PTSD = posttraumatic stress disorder.

examine the factors related to extinction processes. For example, someone with a snake phobia who is in the presence of a safe snake for 30 min will have an implicit reduction of their fear response (extinction). Those with successful recall of fear extinction will not show an enhanced fear response to similar stimuli in the future. With only one exception (Kuriyama et al., 2010), research studies in this area consistently link disrupted sleep with impaired extinction, including extinction learning (Sturm et al., 2013; Lerner et al., 2017), recall (Straus et al., 2017; Bottary et al., 2020), and generalization (Pace-Schott et al., 2009). Additionally, sleep deprivation has been shown to interfere with the neural correlates of extinction processes (Seo et al., 2021). REM sleep seems especially critical—individuals with more duration or consolidation of REM sleep consistently show better extinction recall (Spoormaker et al., 2010; Menz et al., 2016; Yuksel et al., 2024), and one study showed that selectively depriving individuals of REM sleep interfered with extinction recall (Spoormaker et al., 2014). While most experiments to date have focused on healthy adults, a growing number have recruited individuals from clinically important groups such as individuals with insomnia (Bottary et al., 2020; Seo et al., 2018), trauma exposure and PTSD symptoms (Yuksel et al., 2024; Seo et al., 2022), and spider phobia (Rihm et al., 2016) Taken together, these findings demonstrate how disrupted sleep, especially REM sleep, impairs these implicit-automatic affect regulatory processes and thus may influence clinical symptoms, especially fear-related symptoms.

Sleep and safety signal learning and memory: In addition to extinction processes, safety learning is another critical implicit-automatic regulatory strategy involving the ability to differentiate cues that predict threat versus safety. For example, a combat veteran with PTSD may experience a heightened fear response to a cue that had previously signaled threat (e.g., helicopter sound), even in the presence of many safety cues (e.g., far away from deployment location). In laboratory studies, safety signal learning is operationalized by examining response to neutral cues (e.g., yellow circles) that are never presented along with a threat stimulus (e.g., shock). Relatively fewer studies have examined the role of sleep in safety signal learning. However, one study in healthy control participants (Marshall et al., 2014) showed safety signal learning was associated with more consolidated subsequent REM sleep, which in turn was linked to better discrimination between threat and safety signals the following day. Richards et al. (2022) recently replicated these findings using a nap paradigm in individuals with trauma histories. In a small pilot study, Straus et al. (2018) showed relationships between increased REM sleep consolidation and better safety learning in veterans with PTSD. Though to our knowledge these are the only three studies examining relationships between sleep architecture and safety learning, they provide strong evidence of the importance of REM sleep for this aspect of implicit-automatic affect regulation.

6. Discussion

In this review, we examine the relationship between objective sleep (either manipulated via sleep deprivation or measured via polysomnography) and affect regulation. Given that explicit-controlled and implicit-automatic affect regulation are both clinically relevant for mental health stress sequelae (e.g., PTSD and depression), we use a unifying framework (Braunstein et al., 2017) to examine the role of sleep in both these domains. One benefit to examining explicit-controlled and implicit-automatic affect regulation together in one review is that it provides the opportunity to compare and contrast the findings in these domains. Doing so will help elucidate patterns as well as identify gaps to be filled by future research. Below, we summarize the relevant research in each category, then compare the findings from both. We then discuss clinical relevance of our findings for mental health disorders and treatment, then discuss methodological considerations, limitations, and suggestions for future research.

Sleep and explicit-controlled affect regulation: In relation to objective sleep, the most well-studied explicit-controlled affect regulation strategies include cognitive reappraisal and expressive suppression. Studies examining expressive suppression suggest sleep loss affects this strategy in a way that might promote or maintain negative affect (Zhang et al., 2018; Alfano et al., 2020), while results from cognitive reappraisal were more mixed (Shermohammed et al., 2020; Zhang et al., 2019a,b). Among other explicit-controlled affect regulation strategies, cross-sectional studies comparing salient clinical groups suggests REM sleep may be linked with affect regulation assessed via questionnaires (Jun et al., 2020; Taylor et al., 2015; Galbiati et al., 2020), though training individuals to explicitly use an explicit-controlled strategy in task paradigms may not influence sleep architecture (Wang et al., 2022). Sleep deprivation appears to have a deleterious impact on affect regulation strategies focused on internal processes (Harrington et al., 2021; Stenson et al., 2021) but might not make a difference in regulating behavioral responses (Campbell et al., 2022). Overall, these varied results suggest that more studies in this area, particularly multiple studies within specific sub-types of affect regulation strategies using consistent operationalizations, are needed to identify relevant factors that might influence results (e.g., children versus adults, clinical populations versus controls, regulating internal processes versus behavioral responses, using PSG versus sleep deprivation).

Sleep and implicit-automatic affect regulation: Findings are more consistent when examining implicit-automatic affect regulation. While the only specific processes in this category that have been examined so far involve fear extinction and safety learning, many of these studies demonstrate the importance of sleep, and REM sleep consolidation specifically, on fear extinction learning and retention as well as safety signal learning.

Comparison/contrast between explicit-controlled and implicit-automatic domains: Research on implicit-automatic affect regulation nearly universally suggests that disrupted sleep (e.g., total sleep deprivation or REM sleep fragmentation) significantly impairs fear extinction and safety processes. The findings regarding explicit-controlled regulation are more mixed. In this review, the category showing the most inconsistency of findings was the impact of sleep disruption on cognitive reappraisal—for example, some studies showed that sleep deprivation impaired cognitive reappraisal (Alfano et al., 2020), but others did not (Shermohammed et al. 2020; Reddy et al., 2017). However, it must be noted that the earliest study in this category was published in 2017 (Reddy et al., 2017), underscoring how this area of study is still in its infancy. Additionally, the studies in the explicit-controlled domain cover many disparate affect regulation strategies (such as cognitive reappraisal versus expressive suppression versus other techniques), have used different methodologies (e.g., laboratory versus intervention studies) and have focused on different populations (e.g., children versus adolescents versus adults, controls versus clinical populations). This is in contrast with the literature on implicit-automatic regulation, which was more homogeneous given that all studies focused on processes related to fear conditioning, all studies were conducted in adults, and most studies were in healthy controls. More focused research is needed to elucidate patterns in the role of sleep generally and sleep architecture features specifically when it comes to explicit-controlled affect regulation.

Clinical relevance: Taken together, these findings largely fit into the growing body of research suggesting sleep, and particularly REM sleep, plays a critical role in affective processes (Goldstein and Walker, 2014; Gruber and Cassoff, 2014; Guarana et al., 2021; Palmer and Alfano, 2017). This is of special importance clinically given the near ubiquity of sleep symptoms in mental health conditions (Germain et al., 2008; Spoormaker and Montgomery, 2008; Nutt et al., 2022). These findings also have clinical implications for mental health treatment. For example, given that individuals who generally have a difficult time regulating affect via explicit-controlled strategies also have difficulties with sleep consolidation, using sleep-specific interventions to consolidate sleep (e.g., cognitive behavioral therapy for insomnia) may aid with affect regulation. Additionally, two studies using cognitive-behavioral therapy (Prados et al., 2020) and mindfulness (Britton et al., 2012) to teach explicit-controlled affect regulation showed downstream benefits to objective sleep consolidation—clinicians may expect to see sleep benefits more generally when using such interventions. A growing number of studies have shown that sleep deprivation or REM fragmentation negatively impact implicit-automatic affect regulation, so future clinicians could consider treating patients' insomnia prior to initiating interventions that make use of this type of affect regulation (e.g., prolonged exposure for PTSD).

Methodology considerations and recommendations for future research: Studies investigating the relationship between sleep and affect regulation often consider a change in affect (e.g., self-reported affect levels or physiological reactivity to a stimulus) as evidence for affect regulatory processes having taken place. However, a change in affect from before sleep to after sleep does not necessarily provide evidence that affect regulation *per se* is operating. For instance, decreases in reactivity could simply be due to habituation, time passing, context shifts, or other factors. Only when the goal is to change affect trajectory can we be certain that affect regulation processes are taking place. We therefore did not include studies of affect change pre- and post-sleep in this review. Although it is possible that studies examining affect change could indeed represent implicit affect regulation, it is much easier to investigate explicit affect regulation because individuals have conscious access to the regulatory goal. As was apparent in the present review, relatively few studies ($n = 28$) have focused on explicit-controlled affect regulation in relation to sleep. Therefore, more experimental research examining how sleep is associated with affect regulation itself, not just change in affect levels or affect reactivity, is needed. One approach would be to induce affect (e.g., with affective stimuli) and then instruct participants to use specific affect regulation strategies. Comparing affective responses (e.g., self-reports or physiological reactivity) between affect regulation and no regulation conditions (i.e., reacting naturally), or the effectiveness of using affect regulation strategies before and after sleep, will help clarify the role of sleep in affect regulation and vice-versa (e.g., see Vandekerckhove et al., 2012; Zhang et al., 2019; Zhang et al., 2021). We also note that most studies that manipulated sleep did so via sleep deprivation. Thus, it is important to consider how these findings might be more relevant to some real-world contexts than others—for example, it may be more normal for first responders, medical and military personnel to experience total sleep deprivation, whereas sleep disturbance looks different among individuals with sleep disorders such as sleep apnea and insomnia.

There are some additional limitations and future directions to consider. While we have taken care to the extent possible to explicate the various affect regulation processes relevant here, we also acknowledge that sleep architecture refers to an enormous, heterogenous set of phenomena. Given the state of the literature, we still are in an observational, exploratory phase of understanding which aspects of neural activity during sleep relate to affect regulation, and further research in this area will elucidate how sleep may be a mechanistic factor in mental health and/or whether shared biological substrates account for both sleep and affect regulation difficulties. Additionally, it is notable that we needed to collapse together explicit-controlled versus implicit-automatic given that most studies fell into one of these two categories, whereas explicit-automatic and implicit-controlled affect regulation remain unexplored. We are also very interested in many potential moderators that may be at play (demographic characteristics, clinical patients versus healthy controls, etc.), though with this body of research still in its infancy, it is not possible at present to characterize how they may operate.

Based on our investigation here, we suggest several avenues for future research. There is a need for 1) more studies focusing on sleep architecture and explicit-controlled affect regulation with consistent operationalizations; 2) replication with the same types of regulation strategies; 3) more studies experimentally manipulating sleep, including selectively disrupting specific sleep stages, to examine its impact on affect regulation and vice versa in order to infer cause and effect; 4) more studies looking at sleep's impact on next-day affect regulation (not just overnight change in affect reactivity) and 5) broadening the examination to include self-reported measures of sleep parameters (e.g., sleep diary sleep efficiency or insomnia symptoms). Future research will be invaluable for understanding the relationship between sleep and affect regulation and will inform interventions targeted toward improving sleep quality, improving quality of life, and reducing suffering in individuals with mental health difficulties.

CRediT authorship contribution statement

Laura D. Straus: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Maia ten Brink:** Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing. **Pilleriin Sikka:** Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing. **Radhika Srivastava:** Data curation. **James J. Gross:** Conceptualization, Writing – original draft. **Peter J. Colvonen:** Conceptualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

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Appendix A. Supplementary data

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References

Alfano, C.A., Bower, J.L., Harvey, A.G., Beidel, D.C., Sharp, C., Palmer, C.A., 2020. Sleep restriction alters children's positive emotional responses, but effects are moderated by anxiety. JCPP (J. Child Psychol. Psychiatry) 61 (10), 1150–1159. https://doi.org/10.1111/jcpp.13287.

Altena, E., Micoulaud-Franchi, J.A., Geoffroy, P.A., Sanz-Arigita, E., Bioulac, S., Philip, P., 2016. The bidirectional relation between emotional reactivity and sleep: from disruption to recovery. Behav. Neurosci. 130 (3), 336. https://doi.org/10.1037/bne0000128.

Baglioni, C., Johann, A.F., Benz, F., Steinmetz, L., Meneo, D., Frase, L., et al., 2024. Interactions between insomnia, sleep duration and emotional processes: an ecological momentary assessment of longitudinal influences combining self-report and physiological measures. J. Sleep Res. 33 (2), e14001 https://doi.org/10.1111/jsr.14001.

Barnes, C.M., Guarana, C.L., Nauman, S., Kong, D.T., 2016. Too tired to inspire or be inspired: sleep deprivation and charismatic leadership. J. Appl. Psychol. 101 (8), 1191–1199. https://doi.org/10.1037/apl0000123.

Ben Simon, E., Walker, M.P., 2018. Sleep loss causes social withdrawal and loneliness. Nat. Commun. 9 (1), 1–9. https://doi.org/10.1038/s41467-018-05377-0.

Bottary, R., Seo, J., Daffre, C., Gazecki, S., Moore, K.N., Kopotiyenko, K., et al., 2020. Fear extinction memory is negatively associated with REM sleep in insomnia disorder. Sleep 43 (7). https://doi.org/10.1093/sleep/zsaa007.

Braunstein, L.M., Gross, J.J., Ochsner, K.N., 2017. Explicit and implicit emotion regulation: a multi-level framework. Soc. Cognit. Affect Neurosci. 12 (10), 1545–1557. https://doi.org/10.1093/scan/nsx096.

Britton, W.B., Bootzin, R.R., 2004. Near-death experiences and the temporal lobe. Psychol. Sci. 15 (4), 254–258. https://doi.org/10.1111/j.0956-7976.2004.00661.x.

Britton, W.B., Haynes, P.L., Fridel, K.W., Bootzin, R.R., 2012. Mindfulness-based cognitive therapy improves polysomnographic and subjective sleep profiles in antidepressant users with sleep complaints. Psychother. Psychosom. 81 (5), 296–304. https://doi.org/10.1159/000332755.

Buxton, O.M., Marcelli, E., 2010. Short and long sleep are positively associated with obesity, diabetes, hypertension, and cardiovascular disease among adults in the United States. Soc. Sci. Med. 71 (5), 1027–1036.

Campbell, R.L., Feldner, M.T., Leen-Feldner, E.W., 2022. An experimental test of the effects of acute sleep deprivation on affect and avoidance. J. Behav. Ther. Exp. Psychiatr. 77, 101770 https://doi.org/10.1016/j.jbtep.2022.101770.

Chouchou, F., Dang-Vu, T.T., Rainville, P., Lavigne, G., 2018. The role of sleep in learning placebo effects. Int. Rev. Neurobiol. 139, 321–355. https://doi.org/10.1016/bs.irn.2018.07.013.

Chuah, L.Y., Dolcos, F., Chen, A.K., Zheng, H., Parimal, S., Chee, M.W., 2010. Sleep deprivation and interference by emotional distracters. Sleep 33 (10), 1305–1313. https://doi.org/10.1093/sleep/33.10.1305.

Clark, D.A., Beck, A.T., 2010. Cognitive theory and therapy of anxiety and depression: convergence with neurobiological findings. Trends Cognit. Sci. 14 (9), 418–424. https://doi.org/10.1016/j.tics.2010.06.007.

Colvonen, P.J., Almklov, E., Tripp, J.C., Ulmer, C.S., Pittman, J.O., Afari, N., 2020. Prevalence rates and correlates of insomnia disorder in post-9/11 veterans enrolling in VA healthcare. Sleep 43 (12), zsaa119. https://doi.org/10.1093/sleep/zsaa119.

Colvonen, P.J., Straus, L.D., Acheson, D., Gehrman, P., 2019. A review of the relationship between emotional learning and memory, sleep, and PTSD. Curr. Psychiatr. Rep. 21 (1), 1–11. https://doi.org/10.1007/s11920-019-0987-2.

Colvonen, P.J., Straus, L.D., Stepnowsky, C., McCarthy, M.J., Goldstein, L.A., Norman, S. B., 2018. Recent advancements in treating sleep disorders in co-occurring PTSD. Curr. Psychiatr. Rep. 20 (7), 1–13. https://doi.org/10.1007/s11920-018-0916-9.

Craske, M.G., Mystkowski, J.L., 2006. Exposure therapy and extinction: clinical studies. https://doi.org/10.1037/11474-011.

de Zambotti, M., Sizintsev, M., Claudatos, S., Barresi, G., Colrain, I.M., Baker, F.C., 2019. Reducing bedtime physiological arousal levels using immersive audio-visual respiratory bio-feedback: a pilot study in women with insomnia symptoms. J. Behav. Med. 42, 973–983. https://doi.org/10.1007/s10865-019-00020-9.

Deliens, G., Gilson, M., Peigneux, P., 2014. Sleep and the processing of emotions. Exp. Brain Res. 232 (5), 1403–1414. https://doi.org/10.1007/s00221-014-3832-1.

Durmer, J.S., Dinges, D.F., 2005. Neurocognitive consequences of sleep deprivation. In: Seminars in Neurology, 25. Thieme Medical Publishers, Inc., pp. 117–129, 333 Seventh Avenue, New York, NY 10001, USA.

Dryman, M.T., Heimberg, R.G., 2018. Emotion regulation in social anxiety and depression: a systematic review of expressive suppression and cognitive reappraisal. Clin. Psychol. Rev. 65, 17–42. https://doi.org/10.1016/j.cpr.2018.07.004.

Fernandes, M.A., Tone, E.B., 2021. A systematic review and meta-analysis of the association between expressive suppression and positive affect. Clin. Psychol. Rev. 88, 102068 https://doi.org/10.1016/j.cpr.2021.102068.

Galbiati, A., Sforza, M., Fasiello, E., Casoni, F., Marrella, N., Leitner, C., et al., 2020. The association between emotional dysregulation and REM sleep features in insomnia disorder. Brain Cognit. 146, 105642 https://doi.org/10.1016/j.bandc.2020.105642.

Germain, A., 2013. Sleep disturbances as the hallmark of PTSD: where are we now? Am. J. Psychiatr. 170 (4), 372–382. https://doi.org/10.1176/appi.ajp.2012.12040432.

Germain, A., Buysse, D.J., Nofzinger, E., 2008. Sleep-specific mechanisms underlying posttraumatic stress disorder: integrative review and neurobiological hypotheses. Sleep Med. Rev. 12 (3), 185–195. https://doi.org/10.1016/j.smrv.2007.09.003.

Germain, A., Buysse, D.J., Ombao, H., Kupfer, D.J., Hall, M., 2003. Psychophysiological reactivity and coping styles influence the effects of acute stress exposure on rapid eye movement sleep. Psychosom. Med. 65 (5), 857–864. https://doi.org/10.1097/01.PSY.0000079376.87711.B0.

Glosemeyer, R.W., Diekelmann, S., Cassel, W., Kesper, K., Koehler, U., Westermann, S., et al., 2020. Selective suppression of rapid eye movement sleep increases next-day negative affect and amygdala responses to social exclusion. Sci. Rep. 10 (1), 17325 https://doi.org/10.1038/s41598-020-74169-8.

Goldstein, A.N., Walker, M.P., 2014. The role of sleep in emotional brain function. Annu. Rev. Clin. Psychol. 10, 679. https://doi.org/10.1146/annurev-clinpsy-032813-153716.

Gross, J.J., 2015. Emotion regulation: current status and future prospects. Psychol. Inq. 26 (1), 1–26. https://doi.org/10.1080/1047840X.2014.940781.

Gross, J.J., John, O.P., 2003. Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. J. Pers. Soc. Psychol. 85 (2), 348. https://doi.org/10.1037/0022-3514.85.2.348.

Gross, J.J., Uusberg, H., Uusberg, A., 2019. Mental illness and well-being: an affect regulation perspective. World Psychiatr. 18 (2), 130–139.

Gruber, R., Cassoff, J., 2014. The interplay between sleep and emotion regulation: conceptual framework empirical evidence and future directions. Curr. Psychiatr. Rep. 16 (11), 1–9. https://doi.org/10.1007/s11920-014-0500-x.

Guarana, C.L., Ryu, J.W., O'Boyle Jr, E.H., Lee, J., Barnes, C.M., 2021. Sleep and self-control: a systematic review and meta-analysis. Sleep Med. Rev. 59, 101514 https://doi.org/10.1016/j.smrv.2021.101514.

Harrington, M.O., Ashton, J.E., Sankarasubramanian, S., Anderson, M.C., Cairney, S.A., 2021. Losing control: sleep deprivation impairs the suppression of unwanted thoughts. Clin. Psychol. Sci. 9 (1), 97–113. https://doi.org/10.1177/2167702620951511.

Jun, J.S., Kim, R., Jung, H.M., Byun, J.I., Seok, J.M., Kim, T.J., et al., 2020. Emotion dysregulation in idiopathic rapid eye movement sleep behavior disorder. Sleep 43 (2). https://doi.org/10.1093/sleep/zsz224.

Khan, A.J., Maguen, S., Straus, L.D., Nelyan, T.C., Gross, J.J., Cohen, B.E., 2021. Expressive suppression and cognitive reappraisal in veterans with PTSD: results from the mind your heart study. J. Affect. Disord. 283, 278–284. https://doi.org/10.1016/j.jad.2021.02.015.

Kim, E.J., Dimsdale, J.E., 2007. The effect of psychosocial stress on sleep: a review of polysomnographic evidence. Behav. Sleep Med. 5 (4), 256–278. https://doi.org/10.1080/15402000701557383.

Kollar, Edward J., Pasnau, R.O., Rubin, R.T., Naitoh, Paul, Slater, Grant G., Anthony, K. A.L.E.S., 1969. Psychological, psychophysiological, and biochemical correlates of prolonged sleep deprivation. Am. J. Psychiatr. 126 (4), 488–497.

Krakow, B., Melendrez, D., Johnston, L., Warner, T.D., Clark, J.O., Pacheco, M., et al., 2002. Sleep-disordered breathing, psychiatric distress, and quality of life impairment in sexual assault survivors. J. Nerv. Ment. Dis. 190 (7), 442–452.

Killgore, W.D., Kahn-Greene, E.T., Lipizzi, E.L., Newman, R.A., Kamimori, G.H., Balkin, T.J., 2008. Sleep deprivation reduces perceived emotional intelligence and constructive thinking skills. Sleep Med. 9 (5), 517–526. https://doi.org/10.1016/j.sleep.2007.07.003.

Kuriyama, K., Soshi, T., Kim, Y., 2010. Sleep deprivation facilitates extinction of implicit fear generalization and physiological response to fear. Biol. Psychiatr. 68 (11), 991–998. https://doi.org/10.1016/j.biopsych.2010.08.015.

LeDoux, J.E., 2012. Evolution of human emotion: a view through fear. Prog. Brain Res. 195, 431–442. https://doi.org/10.1016/B978-0-444-53860-4.00021-0.

Lerner, I., Lupkin, S.M., Sinha, N., Tsai, A., Gluck, M.A., 2017. Baseline levels of rapid eye movement sleep may protect against excessive activity in fear-related neural circuitry. J. Neurosci. 37 (46), 11233–11244. https://doi.org/10.1523/JNEUROSCI.0578-17.2017.

Li, Z.Q., Qin, Y., Cai, W.P., Deng, S.Q., Mao, X.F., Zhang, J.G., et al., 2023. Sleep deprivation impairs human cognitive reappraisal ability: a randomized controlled trial. Nat. Sci. Sleep 729–736. https://doi.org/10.2147/NSS.S414962.

Lieberman, M.D., Eisenberger, N.I., Crockett, M.J., Tom, S.M., Pfeifer, J.H., Way, B.M., 2007. Putting feelings into words. Psychol. Sci. 18 (5), 421–428. https://doi.org/10.1111/j.1467-9280.2007.01916.x.

Malik, S., Kanwar, A., Sim, L.A., Prokop, L.J., Wang, Z., Benkhadra, K., Murad, M.H., 2014. The association between sleep disturbances and suicidal behaviors in patients with psychiatric diagnoses: a systematic review and meta-analysis. Syst. Rev. 3 (1), 1–9. https://doi.org/10.1186/2046-4053-3-18.

Mander, B.A., Rao, V., Lu, B., Saletin, J.M., Lindquist, J.R., Ancoli-Israel, S., et al., 2013. Prefrontal atrophy, disrupted NREM slow waves and impaired hippocampal-dependent memory in aging. Nat. Neurosci. 16 (3), 357–364. https://doi.org/10.1038/nn.3324.

Marshall, A.J., Acheson, D.T., Risbrough, V.B., Straus, L.D., Drummond, S.P., 2014. Fear conditioning, safety learning, and sleep in humans. J. Neurosci. 34 (35), 11754–11760. https://doi.org/10.1523/JNEUROSCI.0478-14.2014.

McLay, R.N., Klam, W.P., Volkert, S.L., 2010. Insomnia is the most commonly reported symptom and predicts other symptoms of post-traumatic stress disorder in US service members returning from military deployments. Mil. Med. 175 (10), 759–762. https://doi.org/10.7205/MILMED-D-10-00193.

McMakin, D.L., Dahl, R.E., Buysse, D.J., Cousins, J.C., Forbes, E.E., Silk, J.S., et al., 2016. The impact of experimental sleep restriction on affective functioning in social and nonsocial contexts among adolescents. JCPP (J. Child Psychol. Psychiatry) 57 (9), 1027–1037. https://doi.org/10.1111/jcpp.12568.

McNamara, P., Auerbach, S., Johnson, P., Harris, E., Doros, G., 2010. Impact of REM sleep on distortions of self-concept, mood and memory in depressed/anxious participants. J. Affect. Disord. 122 (3), 198–207. https://doi.org/10.1016/j.jad.2009.06.030.

Menz, M.M., Rihm, J.S., Büchel, C., 2016. REM sleep is causal to successful consolidation of dangerous and safety stimuli and reduces return of fear after extinction. J. Neurosci. 36 (7), 2148–2160. https://doi.org/10.1523/JNEUROSCI.3083-15.2016.

Neylan, T.C., Marmar, C.R., Metzler, T.J., Weiss, D.S., Zatzick, D.F., Delucchi, K.L., et al., 1998. Sleep disturbances in the Vietnam generation: findings from a nationally representative sample of male Vietnam veterans. Am. J. Psychiatr. 155 (7), 929–933. https://doi.org/10.1176/ajp.155.7.929.

Nishith, P., Resick, P.A., Mueser, K.T., 2001. Sleep difficulties and alcohol use motives in female rape victims with posttraumatic stress disorder. J. Trauma Stress 14 (3), 469–479. https://doi.org/10.1023/A:1011152405048.

Nutt, D., Wilson, S., Paterson, L., 2022. Sleep disorders as core symptoms of depression. Dialogues Clin. Neurosci. https://doi.org/10.31887/DCNS.2008.10.3/dnutt.

Ouzzani, M., Hammady, H., Fedorowicz, Z., Elmagarmid, A., 2016. Rayyan—a web and mobile app for systematic reviews. Syst. Rev. 5, 1–10. https://doi.org/10.1186/s13643-016-0384-4.

Pace-Schott, E.F., Milad, M.R., Orr, S.P., Rauch, S.L., Stickgold, R., Pitman, R.K., 2009. Sleep promotes generalization of extinction of conditioned fear. Sleep 32 (1), 19–26. https://doi.org/10.5665/sleep/32.1.19.

Palmer, C.A., Alfano, C.A., 2017. Sleep and emotion regulation: an organizing, integrative review. Sleep Med. Rev. 31, 6–16.

Payne, J.D., Kensinger, E.A., 2018. Stress, sleep, and the selective consolidation of emotional memories. Curr. Opin. Behav. Sci. 19, 36–43. https://doi.org/10.1016/j.cobeha.2017.09.006.

Prados, G., Miró, E., Martínez, M.P., Sánchez, A.I., Lami, M.J., Cáliz, R., 2020. Combined cognitive-behavioral therapy for fibromyalgia: effects on polysomnographic parameters and perceived sleep quality. Int. J. Clin. Health Psychol. 20 (3), 232–242. https://doi.org/10.1016/j.ijchp.2020.04.002.

Reddy, R., Palmer, C.A., Jackson, C., Farris, S.G., Alfano, C.A., 2017. Impact of sleep restriction versus idealized sleep on emotional experience, reactivity and regulation in healthy adolescents. J. Sleep Res. 26 (4), 516–525. https://doi.org/10.1111/jsr.12484.

Richards, A., Inslicht, S.S., Yack, L.M., Metzler, T.J., Russell Huie, J., Straus, L.D., et al., 2022. The relationship of fear-potentiated startle and polysomnography-measured sleep in trauma-exposed men and women with and without PTSD: testing REM sleep effects and exploring the roles of an integrative measure of sleep, PTSD symptoms, and biological sex. Sleep 45 (1). https://doi.org/10.1093/sleep/zsab271.

Rihm, J.S., Sollberger, S.B., Soravia, L.M., Rasch, B., 2016. Re-presentation of olfactory exposure therapy success cues during non-rapid eye movement sleep did not increase therapy outcome but increased sleep spindles. Front. Hum. Neurosci. 10, 340. https://doi.org/10.3389/fnhum.2016.00340.

Saadat, H., Bissonnette, B., Tumin, D., Raman, V., Rice, J., Barry, N.D., Tobias, J., 2017. Effects of partial sleep deprivation on reaction time in anesthesiologists. Pediatr. Anesth. 27 (4), 358–362. https://doi.org/10.1111/pan.13035.

Schultz, W., Dayan, P., Montague, P.R., 1997. A neural substrate of prediction and reward. Science (New York, N.Y.) 275 (5306), 1593–1599. https://doi.org/10.1126/science.275.5306.1593.

Seo, J., Moore, K.N., Gazecki, S., Bottary, R.M., Milad, M.R., Song, H., Pace-Schott, E.F., 2018. Delayed fear extinction in individuals with insomnia disorder. Sleep 41 (8), zsy095. https://doi.org/10.1093/sleep/zsy095.

Seo, J., Oliver, K.I., Daffre, C., Moore, K.N., Gazecki, S., Lasko, N.B., et al., 2022. Associations of sleep measures with neural activations accompanying fear conditioning and extinction learning and memory in trauma-exposed individuals. Sleep 45 (3), zsab261. https://doi.org/10.1093/sleep/zsab261.

Seo, J., Pace-Schott, E.F., Milad, M.R., Song, H., Germain, A., 2021. Partial and total sleep deprivation interferes with neural correlates of consolidation of fear extinction memory. Biol. Psychiatr.: Cognit. Neurosci. Neuroimag. 6 (3), 299–309. https://doi.org/10.1016/j.bpsc.2020.09.013.

Shermohammed, M., Kordyban, L.E., Somerville, L.H., 2020. Examining the causal effects of sleep deprivation on emotion regulation and its neural mechanisms. J. Cognit. Neurosci. 32 (7), 1289–1300. https://doi.org/10.1162/jocn_a_01555.

Siegel, J.M., 2005. Clues to the functions of mammalian sleep. Nature 437 (7063), 1264–1271. https://doi.org/10.1038/nature04285.

Soehner, A.M., Kaplan, K.A., Saletin, J.M., Talbot, L.S., Hairston, I.S., Gruber, J., et al., 2018. You`ll feel better in the morning: slow wave activity and overnight mood regulation in interepisode bipolar disorder. Psychol. Med. 48 (2), 249–260. https://doi.org/10.1017/S0033291717001581.

Spoormaker, V.I., Gvozdanovic, G.A., Sämann, P.G., Czisch, M., 2014. Ventromedial prefrontal cortex activity and rapid eye movement sleep are associated with subsequent fear expression in human subjects. Exp. Brain Res. 232 (5), 1547–1554. https://doi.org/10.1007/s00221-014-3831-2.

Spoormaker, V.I., Montgomery, P., 2008. Disturbed sleep in post-traumatic stress disorder: secondary symptom or core feature? Sleep Med. Rev. 12 (3), 169–184. https://doi.org/10.1016/j.smrv.2007.08.008.

Spoormaker, V.I., Schröter, M.S., Andrade, K.C., Dresler, M., Kiem, S.A., Goya-Maldonado, R., Wetter, T.C., Holsboer, F., Sämann, P.G., Czisch, M., 2012. Effects of rapid eye movement sleep deprivation on fear extinction recall and prediction error signaling. Hum. Brain Mapp. 33 (10), 2362–2376. https://doi.org/10.1002/hbm.21369.

Spoormaker, V.I., Sturm, A., Andrade, K.C., Schröter, M.S., Goya-Maldonado, R., Holsboer, F., et al., 2010. The neural correlates and temporal sequence of the relationship between shock exposure, disturbed sleep and impaired consolidation of fear extinction. J. Psychiatr. Res. 44 (16), 1121–1128. https://doi.org/10.1016/j.jpsychires.2010.04.017.

Stenson, A.R., Kurinec, C.A., Hinson, J.M., Whitney, P., Van Dongen, H.P., 2021. Total sleep deprivation reduces top-down regulation of emotion without altering bottom-up affective processing. PLoS One 16 (9), e0256983. https://doi.org/10.1371/journal.pone.0256983.

Stewart, R., Besset, A., Bebbington, P., Brugha, T., Lindesay, J., Jenkins, R., et al., 2006. Insomnia comorbidity and impact and hypnotic use by age group in a national survey population aged 16 to 74 years. Sleep 29 (11), 1391–1397. https://doi.org/10.1093/sleep/29.11.1391.

Straus, L.D., Acheson, D.T., Risbrough, V.B., Drummond, S.P., 2017. Sleep deprivation disrupts recall of conditioned fear extinction. Biol. Psychiatr.: Cognit. Neurosci. Neuroimag. 2 (2), 123–129. https://doi.org/10.1016/j.bpsc.2016.05.004.

Straus, L.D., Norman, S.B., Risbrough, V.B., Acheson, D.T., Drummond, S.P., 2018. REM sleep and safety signal learning in posttraumatic stress disorder: a preliminary study in military veterans. Neurobiol. Stress 9, 22–28. https://doi.org/10.1016/j.ynstr.2018.07.001.

Sturm, A., Czisch, M., Spoormaker, V.I., 2013. Effects of unconditioned stimulus intensity and fear extinction on subsequent sleep architecture in an afternoon nap. J. Sleep Res. 22 (6), 648–655. https://doi.org/10.1111/jsr.12074.

Taylor, B.J., Irish, L.A., Martire, L.M., Siegle, G.J., Krafty, R.T., Schulz, R., Hall, M.H., 2015. Avoidant coping and poor sleep efficiency in dementia caregivers. Psychosom. Med. 77 (9), 1050–1057. https://doi.org/10.1097/PSY.0000000000000237.

Ten Brink, M., Dietch, J.R., Tutek, J., Suh, S.A., Gross, J.J., Manber, R., 2022. Sleep and affect: a conceptual review. Sleep Med. Rev. 101670 https://doi.org/10.1016/j.smrv.2022.101670.

Tempesta, D., Socci, V., De Gennaro, L., Ferrara, M., 2018. Sleep and emotional processing. Sleep Med. Rev. 40, 183–195. https://doi.org/10.1016/j.smrv.2017.12.005.

Vandekerckhove, M., Kestemont, J., Weiss, R., Schotte, C., Exadaktylos, V., Haex, B., et al., 2012. Experiential versus analytical emotion regulation and sleep: breaking the link between negative events and sleep disturbance. Emotion 12 (6), 1415. https://doi.org/10.1037/a0028501.

Vandekerckhove, M., Wang, Y.L., 2018. Emotion, emotion regulation and sleep: an intimate relationship. AIMS Neurosci. 5 (1), 1. https://doi.org/10.3934/Neuroscience.2018.1.1.

Venkatraman, V., Chuah, Y.L., Huettel, S.A., Chee, M.W., 2007. Sleep deprivation elevates expectation of gains and attenuates response to losses following risky decisions. Sleep 30 (5), 603–609.

Walker, M.P., Stickgold, R., 2004. Sleep-dependent learning and memory consolidation. Neuron 44 (1), 121–133. https://doi.org/10.1016/j.neuron.2004.08.031.

Walker, M.P., van der Helm, E., 2009. Overnight therapy? The role of sleep in emotional brain processing. Psychol. Bull. 135 (5), 731–748. https://doi.org/10.1037/a0016570.

Wang, Y., Vlemincx, E., Vantieghem, I., Dhar, M., Dong, D., Vandekerckhove, M., 2022. Bottom-up and cognitive top-down emotion regulation: experiential emotion regulation and cognitive reappraisal on stress relief and follow-up sleep physiology. Int. J. Environ. Res. Publ. Health 19 (13), 7621. https://doi.org/10.3390/ijerph19137621.

Woud, M.L., Cwik, J.C., Blackwell, S.E., Kleim, B., Holmes, E.A., Adolph, D., et al., 2018. Does napping enhance the effects of cognitive bias modification-appraisal training? An experimental study. PLoS One 13 (2), e0192837. https://doi.org/10.1371/journal.pone.0192837.

Yuksel, C., Watford, L., Muranaka, M., McCoy, E., Lax, H., Mendelsohn, A.K., Oliver, K.I., Daffre, C., Acosta, A., Vidrin, A., Martinez, U., Lasko, N., Orr, S., Pace-Schott, E.F., 2024. REM disruption and REM vagal activity predict extinction recall in trauma-exposed individuals. bioRxiv : the preprint server for biology 9 (28), 560007. https://doi.org/10.1101/2023.09.28.560007, 2023.

Yurica, C.L., DiTomasso, R.A., 2005. Cognitive distortions. Encyclopedia of Cognitive Behavior Therapy, pp. 117–122.

Zhang, C., Bengio, S., Hardt, M., Recht, B., Vinyals, O., 2021. Understanding deep learning (still) requires rethinking generalization. Commun. ACM 64 (3), 107–115. https://doi.org/10.1145/3446776.

Zhang, J., Lau, E.Y.Y., Hsiao, J.H., 2019a. Sleep deprivation compromises resting-state emotional regulatory processes: an EEG study. J. Sleep Res. 28 (3), e12671 https://doi.org/10.1111/jsr.12671.

Zhang, J., Lau, E.Y.Y., Hsiao, J.H.W., 2019b. Using emotion regulation strategies after sleep deprivation: ERP and behavioral findings. Cognit. Affect Behav. Neurosci. 19 (2), 283–295. https://doi.org/10.3758/s13415.