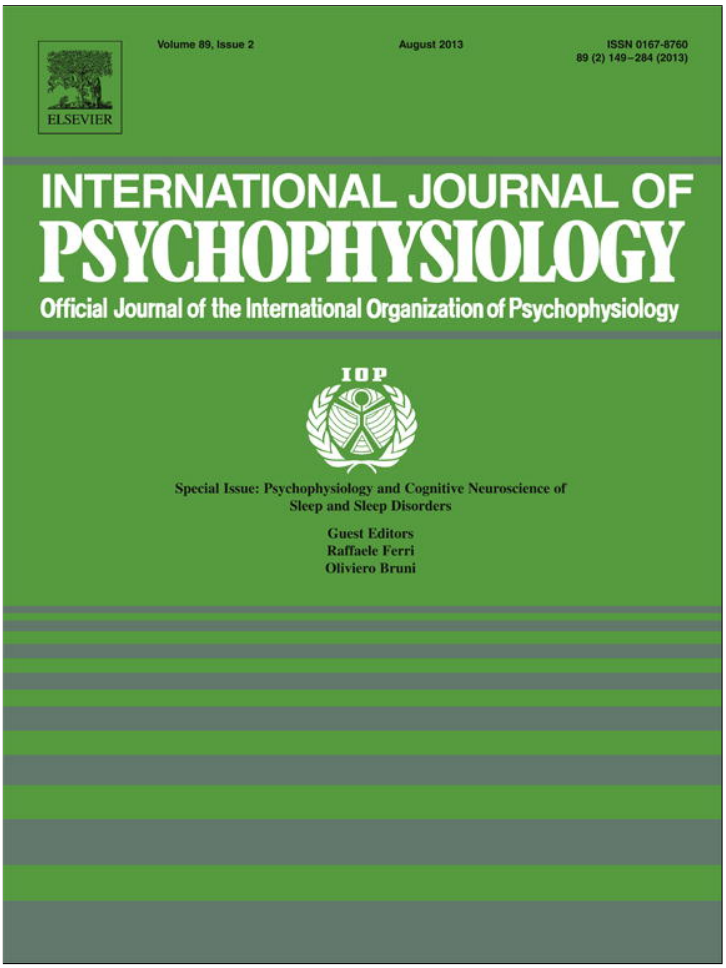

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Review

Sleep and emotions: Bidirectional links and underlying mechanisms

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ABSTRACT

A growing body of literature suggests that sleep and emotions are closely linked, and that the relationship between these two domains is complex and bidirectional. This review synthesizes some of the most current empirical findings with regard to the effects of sleep (with an emphasis on sleep deprivation) on subsequent emotional state, and the effects of emotions on subsequent sleep. Furthermore, we review a selection of possible mechanisms underlying some of these associations. Finally, suggestions are made for future research as part of the effort to develop a more comprehensive theory for this emerging field.

1. Introduction

"Sleep is that golden chain that ties health and our bodies together" wrote English poet Thomas Dekker in the 17th century (The Gull's Hornbook, 1609), indicating the close connections between sleep and various aspects of health and psychological functioning (Banks and Dinges, 2007; Roth, 2007). The strong links between sleep and behavior, as well as cognitive functioning have long been recognized (see Banks and Dinges, 2007 for review). Surprisingly, the bi-directional links between sleep and emotions have only recently received increased attention.

The importance of understanding the links between sleep and affect is apparent in light of several key findings. First, there is ample scientific evidence demonstrating associations between sleep and psychopathology (Dahl and Harvey, 2007; Gregory and Sadeh, 2012). For instance, insomnia is a common symptom in most psychiatric disorders and in affective disorders in particular (Baglioni et al., 2010). Second, over the past decades research has shown a gradual increase in the prevalence of psychiatric disorders (Costello et al., 2003; Kessler et al., 2005). At the same time, there is cumulative data suggesting a gradual reduction in sleep time of children and adults around the world (Bixler, 2009; Matricciani et al., 2012; Mindell et al., 2009). The potential links between these global tendencies suggest that a growing proportion of the population may be at risk for compromised mental health. Understanding the relationship between emotion and sleep in healthy populations, as well as identifying the mechanisms which underlie these links may provide valuable insights to the research in psychopathology and general well-being.

Existing evidence suggests that the associations between emotion and sleep are complex and bidirectional. That is, poor sleep may adversely affect emotional well-being, and conversely, certain emotions may lead to compromised sleep. In this review the links between sleep and emotions will be addressed separately via each potential causal direction, focusing mainly on existing experimental data. We begin with a presentation of findings concerning the effects of sleep, and particularly sleep deprivation on emotions in healthy adults. We then proceed to describe the role of emotions as potential predictors of sleep-related problems, including the possible underlying mechanisms of these connections. A model summarizing these potential links is presented in Fig. 1. This review continues the important work done by Vandekerckhove and Cluydts (2010) and Baglioni et al. (2010) in reviewing corresponding aspects of this topic, to include the most recent findings in this rapidly evolving field.

2. The effects of sleep on emotions

Sleep serves for recuperation and as a "restart" at many neurophysiological levels. Does sleep also serve as a "restart" function for networks responsible for maintaining emotional regulation? In the following section, we begin by presenting the main findings regarding the emotional consequences of sleep deprivation, and then we present possible mechanisms that underlie these consequences.

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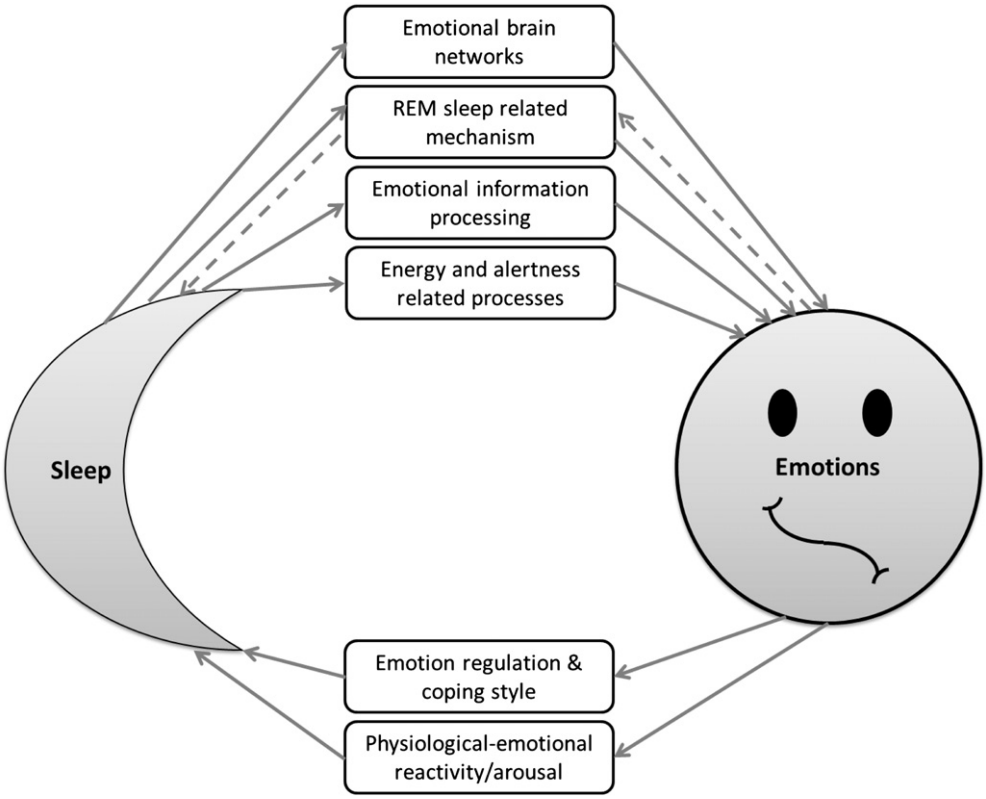

Fig. 1. An overview of empirically established bidirectional links between sleep and emotions, and their proposed underlying mechanisms. The arrows reflect the direction of the effects derived from studies addressed in this review. Gray arrows reflect effects that have been more established by experimental data, while dashed gray arrows reflect less established effects. However, effects in other directions are certainly possible.

2.1. The effects of sleep deprivation on emotions

2.1.1. Effects on subjective emotions and mood

The common use of the term sleep deprivation refers to extended sleepless periods that can range from hours to days. Sleep restriction (partial sleep deprivation) refers to periods during which sleep is restricted to a limited time that is considered insufficient sleep. However, in the literature the terms are often used indiscriminately.

The negative impact of sleep deprivation on different levels of functioning has been extensively described particularly on cognitive, behavioral and psychomotor performance (Astill et al., 2012; Dinges, 2006; Lim and Dinges, 2010). However, the emotional consequences of sleep loss have not received as much attention in the literature. Still, they are considered severe, to the extent that prolonged sleep deprivation is regarded as torture when used in imprisonment contexts, and is prohibited by the UN human rights convention (Physicians for Human Rights, 2008). In a comprehensive meta-analytic review conducted by Pilcher and Huffcutt (1996), mood was found to be negatively affected by sleep deprivation more intensely than either cognitive or motor performance.

One of the main general findings in the experimental literature concerning sleep deprivation is an increase in negative affect. Relatively early experimental studies in this domain have tended to focus on negative emotions. Dinges et al. (1997) demonstrated increases in tension–anxiety, confusion, fatigue and total mood disturbance across a week of sleep restriction (of roughly 5 h per night). Several studies have reported an increase in depressive symptoms as a result of sleep deprivation in non-clinical adult and adolescent samples (Caldwell et al., 2004; Campos-Morales et al., 2005; Cutler and Cohen, 1979; Forbes et al., 2006; Fredriksen et al., 2004). Correspondingly, there is evidence for an increase in anxiety symptoms following sleep deprivation in healthy adults and adolescents (Kahn-Greene et al., 2007; Sagaspe et al., 2006). These results are consistent with correlative data associating compromised sleep with depression and anxiety (Alfano et al., 2007; Ford and Kamerow, 1989; Lee and Douglass, 2010; Roth et al., 2006). Recently, Babson et al. (2010) tested the effects of acute sleep deprivation on state anxiety, depressive symptoms and general distress among a non-clinical sample of adults. After 24 h without sleep, increases in all three domains were reported, indicating that sleep loss tends to elevate negative emotions.

Contemporary studies expanded the research on affective consequences of sleep deprivation by assessing positive as well as negative affect. Paterson et al. (2011) recently tested the effects of acute sleep deprivation on the frequency and intensity with which positive and negative mood were experienced. Sleep deprived subjects exhibited less intense and less frequent positive mood (happiness and activation), in addition to more intense negative mood (anger, depression, fear and fatigue). Positive affect was also subjectively reported to lessen in an experimental test of one night of sleep deprivation compared to regular sleep (Franzen et al., 2008). These data are in line with findings regarding the associations between sleep quality and emotions, which demonstrate that poor sleep quality is associated with increased negative and decreased positive affective states (Berry and Webb, 1983; Norlander et al., 2005; Scott and Judge, 2006).

Comparably, in an experimental investigation by Talbot et al. (2010) two nights of partial sleep deprivation resulted in decreased reports of various positive emotions, along with increased anxiety as a result of catastrophizing, and higher appraisals of catastrophe likelihood compared to the rested condition in adults and adolescents. Unlike adults and mid-adolescents (ages 13–16), sleep deprived early adolescents (ages 10–13) appraised their most threatening worry as more threatening compared to rested controls. Thus, this group exceeded the threat appraisal levels of mid-adolescents and adults when sleep deprived. It was suggested that these findings were due to

poorer affective decision-making, characteristic of the earlier stage of development of the prefrontal cortex (Hooper et al., 2004).

Evidence as to the detrimental effects of sleep deprivation on emotion in adolescence was also found in a recent study by Dagys et al. (2012). Sleep deprived adolescents reported less positive affect, and exhibited lower positivity ratios (using the Positive and Negative Affective Schedule for children; PANAS-C), compared to when rested. It has been postulated that positivity ratio (i.e. the balance between positive and negative emotion) may be more indicative of individuals' healthy emotional functioning than positive or negative emotion examined independently (Diener, 2000; Fredrickson and Losada, 2005), and to date this is the only study to have investigated positivity ratios in the context of sleep-affect connections.

2.1.2. Effects on objective correlates of emotions

Given the limitations of self-reported measures, a few recent studies have also attempted to explore these links using more objective means to assess affective states. Minkel et al. (2011) found a decrease in emotional expressiveness following sleep loss using judgments of facial expression, whereas no subjective differences in emotion were found between sleep deprived and rested participants. Applying pupillography as a measure of emotional information processing, Franzen et al. (2009) found that sleep deprived individuals displayed larger pupil diameter while viewing negative pictures compared to positive or neutral pictures. The sleep-deprived group also demonstrated anticipatory pupillary reactivity during warning cues in blocks of negative pictures. These outcomes were not found in the normal sleep control condition, indicating that sleep deprivation alters emotional responses to unpleasant picture stimuli. Contrary to Franzen et al. (2009) results obtained using pupillography, a study conducted by the same group using a self-report instrument to assess emotional states (the PANAS) yielded no difference in negative emotion between the sleep deprived and rested participants (Franzen et al., 2008). The authors proposed that these discrepancies may be due to greater sensitivity of physiological measures, and asserted that objective and subjective measures should be regarded as separate entities.

Using three different methods of assessment, McGlinchey et al. (2011) measured vocal expression of emotions in adults and adolescents before and after a night of sleep restriction. Sleep restriction resulted in a decrease in positive emotion expression and an increase in negative emotion expression. Also, after sleep loss a computerized acoustic property measure showed significant changes in pitch, energy and vocal sharpness, which have previously been associated with sadness, low activation and stress (Fuller et al., 1992; Juslin and Scherer, 2005). Moreover, using the computerized acoustic analysis, it was found that sleep deprived adolescents displayed significantly less positive emotion relative to sleep deprived adults (McGlinchey et al., 2011). Together with the previously described findings by Talbot et al. (2010), these data suggest that adolescents may be particularly vulnerable to insufficient sleep in terms of emotion regulation and functioning. Still, further investigations are warranted regarding the links between sleep and emotions in this age group.

2.2. Proposed underlying mechanisms of the effects of sleep on emotions

A number of underlying mechanisms have been proposed to explain the links between sleep deprivation and emotion. Evidence concerning these mechanisms is preliminary, and it seems that theoretical conceptualization in this field is still in its infancy. In the following section we present four distinct levels of analysis that constitute prominent directions of this inquiry; Emotional brain networks that may play a significant role in sleep's influence on affect, REM sleep related mechanisms, emotional information processing and the cognitive-energy model.

2.2.1. Emotional brain networks

A promising theoretical framework proposed to clarify how sleep and emotion are intertwined focuses on emotional brain networks. It has been postulated that sleep loss leads to a diminished ability to implement inhibitory control over negative emotion, by means of disrupting prefrontal cortex functions (Dahl and Lewin, 2002). Imaging studies exploring the role of sleep on emotional brain networks are scarce. Thus far, two studies have examined the effects of sleep loss on emotion using functional magnetic resonance imaging (fMRI). In the earlier study, sleep deprived individuals exhibited significantly increased amygdala activation (60% greater magnitude) in response to negative emotional stimuli compared to the rested control group (Yoo et al., 2007). Moreover, results showed decreased connectivity between the amygdala and the medial prefrontal cortex (an area that has been found to be involved in inhibitory control with strong inhibitory projections to the amygdala) in the sleep deprived relative to the control (normal sleep) group. The contrary was found between the amygdala and the autonomic-activating centers of the locus coeruleus, i.e. there was greater connectivity between these regions in the sleep deprived group. These results indicate that sleep deprivation may disrupt emotion regulation by degrading top-down inhibitory processes of emotional reactions. With that said, experiential affective reactions were not reported in this study; thus the expression of these neural differences remains unclear.

In the second study that used fMRI to investigate the manifestation of these links in emotional brain networks, reactions to positive stimuli were examined (Gujar et al., 2011b). It was found that sleep deprivation amplified reactivity throughout mesolimbic reward brain networks in response to positive emotional pictures. Moreover, this increase was associated with a reduction in connectivity in medial and orbitofrontal cortex, yet an enhanced coupling in early primary visual processing pathways and extended limbic regions. These neuroanatomical changes were expressed behaviorally, by an increase in the number of stimuli rated as pleasant in the sleep-deprived group. This bias was correlated with activity in mesolimbic regions. These findings complement data regarding neurochemical increases in dopamine activity within relevant brain reward networks following acute sleep loss (Volkow et al., 2009). The findings are also consistent with research concerning the possible emotional benefit of sleep loss in patients suffering from major depression (Gillin et al., 2001). Taken together, fMRI data provide preliminary evidence as to the critical role of sleep in regulating emotional brain function. Sleep deprivation appears to be associated not only with amplified reactivity towards negative stimuli, but also with enhanced reward-relevant reactivity towards pleasure-evoking stimuli, as has been demonstrated both on the behavioral and neurophysiological levels.

2.2.2. REM sleep related mechanisms

In examining the role of underlying affective brain networks REM sleep has received special attention. Neuro-imaging studies have demonstrated significant elevations in activity in these brain networks during REM sleep (Walker and van der Helm, 2009). Research has shown that REM sleep alterations and abnormalities are associated with daytime affective states (Vandekerckhove and Cluydts, 2010). Furthermore, clinical evidence implies that nearly all affective psychiatric and neurological mood disorders are associated with alterations in REM sleep (Baglioni et al., 2010; Benca et al., 1992; Lee and Douglass, 2010).

On the basis of this empirical and clinical literature, several models have been proposed, suggesting that REM sleep serves as a modulator of affective brain processes. Due to its neuroanatomical, neurophysiological, and neurochemical characteristics, REM sleep has been hypothesized to offer an optimal biological milieu, in which negative emotional experiences are ameliorated, resulting in favorable “therapeutic” outcomes (Levin and Nielsen, 2009; Walker, 2009; Walker and van der Helm, 2009). A recent study provides

support for these theoretical frameworks. It was found that REM sleep during a daytime nap, as opposed to a nap without REM sleep, may reverse progressive enhancement in experiences of fear throughout the day, and at the same time enhance ratings of positive stimuli (Gujar et al., 2011a). Despite the fact that sleep deprivation was not used in this study, its results shed light on the possible remodulation of emotions attained during REM sleep.

Nevertheless, some studies have yielded contrasting results concerning the emotional consequences of REM sleep. For example, McNamara et al. (2010), found that upon awakening from REM sleep compared to non-REM sleep, depressed/anxious participants showed an increase in negative self-ratings and a reduction in positive self-ratings. Furthermore, a greater production of emotionally negative memories with neutral cues was found after REM compared to non-REM sleep awakenings for both healthy and depressed/anxious individuals. Correspondingly, Wagner et al. (2002) reported an enhancement in negative ratings of familiar affective picture stimuli following late-night sleep, compared to early sleep and wake periods. As REM sleep is more prevalent in the second-half of the night, the authors suggested that periods rich in REM sleep actually enhance "aversive reactivity" to negative stimuli. Findings reported by Lara-Carrasco et al. (2009) also associate REM sleep with higher reactivity toward negative stimuli. Higher percentages of REM sleep deprivation in this study resulted in better adaptation to negative stimuli relative to lower REM sleep deprivation percentages.

These findings are in accord with clinical observations and experimental data regarding affective disorders. Patients suffering from depression often exhibit abnormalities in REM sleep, such as reduced REM sleep latency and increased REM density and REM time (Cartwright et al., 2003). In addition, most antidepressant drugs reduce REM sleep (Nicholson et al., 1989; Thase, 1998). Accordingly, selective restriction of REM sleep has been shown to temporarily alleviate depressive symptoms in clinical samples, with deterioration towards depression after subsequent sleep (Berger and Riemann, 2009; Giedke and Schwärzler, 2002). There is also data to show that following sleep deprivation a compensating "rebound" effect tends to occur, with increased REM sleep, suggesting that the incidence of this sleep stage is essential (Andreassi, 2007; Vandekerckhove and Cluydts, 2010). These links suggest that REM sleep is highly associated with emotional functioning, though it seems that the relationship is neither straightforward nor unidirectional.

The role of REM sleep has also been investigated in the context of post-traumatic stress disorder (PTSD). Evidence has suggested that this sleep stage contributes to the psychogenesis and maintenance of PTSD (Mellman et al., 2002; Ross et al., 1989). Germain et al. (2008) have postulated that REM sleep amplifies abnormal amygdala and medial frontal cortex activation seen in PTSD patients, making these patients prone to posttraumatic nightmares.

Interestingly, Riemann et al. (2012) have recently hypothesized that REM sleep "instability" underlies the subjective experience of disrupted sleep in insomnia patients, which is often unexplained by objective alterations in sleep parameters. It has been suggested that the increased fragmentation of REM sleep, characteristic of these patients, may render wake-like negative cognitions more accessible to conscious perception and memory, thus creating an experience of non-restorative sleep. Moreover, the fragmentation of REM sleep may disrupt the functioning of emotional brain networks during this sleep stage, possibly contributing to further emotional and cognitive disturbances.

2.2.3. Emotional information processing

Literature relating to emotional information processing provides further insight about the imperative role sleep plays in emotion regulation processes. Studies have repeatedly shown that emotionally arousing stimuli are remembered better than neutral ones, both in the laboratory and in real life (Walker, 2009). Recent evidence has emerged, demonstrating that during sleep memories are altered in ways that are emotionally adaptive. Data from a series of studies examining sleep's role in the consolidation of emotional episodic memories suggest that the sleeping brain "unbinds" objects from their background to consolidate only the emotionally salient and perhaps adaptive emotional element (see Payne and Kensinger, 2010 for review). Evidence has also been yielded regarding a positive association between REM sleep and a consolidation bias towards negative features of complex scenes. Furthermore, the magnitude of this consolidation bias seems to be determined by the timing of sleep, and is maximized when sleep follows soon after learning (Payne et al., 2012).

Hence, lack of sleep may negatively affect the individual's emotional state. Moreover, sleep appears to selectively influence the encoding of new memories, thus shaping the profile of emotional memories (Walker and van der Helm, 2009). For example, sleep deprivation was found to impair the encoding of neutral and especially positive emotional memories, whereas negative emotional stimuli were not significantly affected by lack of sleep (Walker and Tharani, 2009). These findings suggest a selective alteration in memory, by which sleep deprived individuals tend to remember negative experiences, but forget, or take less notice of positive ones. This imbalance provides a possible explanation for the widespread co-occurrence of sleep disturbance and depression (Mayers and Baldwin, 2006), since insufficient sleep may impose a negative remembering bias, which does not permit the remaining of many positive emotional experiences in the aware mind.

The influence of sleep on the emotional state may also be moderated by other features of emotional information processing. Several studies have associated sleep disruptions with compromised facial expression recognition. Sleep deprivation has been found to impair facial emotional expression recognition in adult women (van der Helm et al., 2010). Pallesen et al. (2004) demonstrated a decrease in speed and accuracy of facial emotion recognition following sleep deprivation. Similar findings were recently demonstrated in children and early adolescents, indicating that poor sleep quality predicted lower performance in a face-emotion information processing task, but not in a neutral facial information processing task over time (Soffer-Dudek et al., 2011). Correspondingly, Killgore et al. (2008) showed a detrimental effect of sleep deprivation on adults' reported capacity to understand emotions both in oneself and in others. Thus, it appears that compromised sleep may have detrimental effects on the perception and processing of emotional stimuli, and consequently on the emotional experience.

2.2.4. The cognitive-energy model and the emotional context

In an attempt to explain the negative emotional consequences of sleep loss, Zohar et al. (2005) stressed the potential deficit in energetic supplies and noted that it is imperative to take into account the context in which emotions arise. In a well-designed longitudinal field study, rather than using random sampling of emotional states, these researchers used an experience-sampling methodology. Medical residents received phone calls at random times during their working days, cueing them to report the recent changing circumstances, and to rate their consequent emotional response. Results showed that subsequent to disruptive events, sleep loss enhanced negative emotions. However, a similar effect was not found when such events weren't reported prior to emotion evaluations. The effect of sleep loss on positive affect was reversed, with a null effect in the context of goal-enhancing events, as opposed to elevated positive affect in the absence of such events. The authors stressed the importance of context-dependent analysis in the field of emotional assessment, and interpreted these findings on the basis of the cognitive-energy model, suggesting that sleep induced changes in energetic supplies required for self-regulation influence emotional reactions (Zohar et al., 2003). Namely, when sleep deprived and facing a gratifying situation, low energy levels may not suffice to reach optimal satisfaction, whereas facing

a challenging situation when fatigued may lead to inflated levels of negative affect (Zohar et al., 2005).

Correspondingly, a recent study by Minkel et al. (2012) found no differences in subjective stress, anger or anxiety between sleep deprived and rested participants following exposure to a high stressor condition. Contrary to expectations, sleep deprivation did lead to greater negative mood in response to a mild stressor condition. It was postulated that sleep loss may lower the psychological threshold at which an individual experiences an event as stressful. Taken together, it seems that the conditions under which emotions arise should be taken into account as possible modulators in the sleep–emotion relationship.

3. The effects of emotions on sleep

Affective states may influence sleep patterns in different manners, as emotional trouble can lead to difficulty falling asleep in addition to further sleep disruptions (e.g. Vandekerckhove et al., 2011). Examining emotional functioning as a factor that may underlie sleep problems may be highly informative, in the attempt to broaden the understanding of these prevalent phenomena (National Sleep Foundation, 2008). The following section will review the possible consequences of various relevant emotions on sleep, including pathways that may underlie these relationships, focusing predominantly on stress, as it has received the most research attention.

3.1. The effects of stress and anxiety on sleep

One of the most studied emotional states in this context is stress. Data has shown stress to be associated with sleep disturbances (Åkerstedt et al., 2007; Galambos et al., 2010; Lundh and Broman, 2000; Roberts et al., 2011; Sadeh, 1996; Van Reeth et al., 2000). These disturbances include reduced sleep quantity and poor sleep quality, as measured by self-reports, actigraphy and polysomnography (PSG). Recently, LeBlanc et al. (2009) have identified anxiety symptoms as a major risk factor for insomnia. Correspondingly, stress is the main etiological factor of primary insomnia according to the diagnostic classification of sleep disorders (ICSD-2; American Academy of Sleep Medicine, 2005).

Several studies have shown that experimentally induced stress may result in sleep disruptions. For example, an early study by Gross and Borkovec (1982) found that good sleepers who were told they would have to give a speech upon awakening required more time to fall asleep and obtained less sleep relative to controls. In a study by Germain et al. (2003) a similar paradigm was used, whereby the subjects were told that they would be required to present a speech in the morning, and that their performance would be evaluated. An increase in REM sleep density across REM periods, and a decrease in REM counts during the late-night sleep period were exhibited via PSG. These were seen to reflect functional regulation of waking emotional stress during sleep. In a recent study, pre-sleep negative emotion resulted in longer sleep onset latency, more time awake after sleep onset, an increase in awakenings from REM sleep and decreases in total sleep time, sleep efficiency, percentage of REM sleep and percentage of slow wave sleep (SWS; Vandekerckhove et al., 2011). Additional studies using PSG have also indicated that certain sleep stages are particularly responsive to the effect of psychological stress exposure (Cui et al., 2008; Vein et al., 2002). In a review of PSG findings by Kim and Dimsdale (2007) it was concluded that experimentally induced stress seemed to result in decreased REM sleep, as well as decreases in SWS and sleep efficiency, and increases in the frequency of night awakenings.

Studies which examined other types of stress have also reported consequential disruptions in sleep architecture. Daily life stress has been associated with compromised sleep in several studies (Kim and Dimsdale, 2007). For example, apprehension of a difficult next working day resulted in decreased SWS and subjectively poor sleep (Kecklund and Åkerstedt, 2004). Also, negative family life events and academic stress were both found to predict symptoms of insomnia (Bernert et al., 2007). Furthermore, as discussed earlier, sleep disturbances in the context of traumatic stress have drawn considerable research attention (Babson and Feldner, 2010). A meta-analysis of PSG data comparing sleep in individuals with and without PTSD yielded three general findings typical of PTSD patients (a) less SWS (b) more stage 1 sleep, and (c) greater REM sleep density (Kobayashi et al., 2007).

Hence, research regarding the detrimental consequences of stress on sleep has been substantial, and yet many inconsistencies seem to exist. Some studies have failed to demonstrate such disturbances, or have documented more resilient sleep in association with stressful conditions or posttraumatic stress disorder (Breslau et al., 2004; Dagan et al., 1997; Lauer et al., 1987). Examining the processes that lie beneath and moderate these links may create a broader understanding of the ways emotions effect sleep, as discussed hereinafter.

3.2. Underlying mechanisms of the effects of stress on sleep

3.2.1. Emotion regulation and coping style

From a theoretical standpoint, Sadeh (1996) has offered some rationale for the varied findings presented above, by identifying two opposite modes of relevant response of the sleep–wake system: (a) the emotional "turn on" response, compatible with the hyperarousal characteristic of the "alarm stage" which is associated with the activation of the hypothalamic–pituitary–adrenal axis (Selye, 1976; Van Reeth et al., 2000), which results in difficulty initiating and maintaining sleep and (b) the "shut off" response, a systematic withdrawal from external and internal stimuli, which may promote sleep. The "Shut off" mode is compatible with the stage of exhaustion (Selye, 1976) and with the conservation-withdrawal hypothesis (Engel and Schmale, 1972), which refers to the organism's tendency to preserve energy in response to uncontrollable stress.

These distinct response modes appear to relate to specific strategies of emotionally processing stressful experiences. It has been postulated that an individual's coping style and emotion regulation strategy may moderate the effects of emotional stress on sleep. A study by Sadeh et al. (2004) for instance, demonstrated that dispositional emotion-focused coping (EFC; i.e., coping aimed at regulating emotional responses to a problematic situation) predicted a reduction in total sleep time (as assessed using actigraphy) and in perceived sleep quality during high compared with low stress periods. The authors suggested that EFC may compromise sleep by increasing alertness during stressful situations, as in the "turn on" response mode (Sadeh et al., 2004; Selye, 1976). In accordance with these findings, Morin et al. (2003) found that insomnia patients relied more on EFC strategies, and reported higher levels of bedtime arousal compared to good sleepers. In an earlier study, short sleepers were found to use more EFC than long sleepers (Hicks et al., 1991). More recently, EFC was found to be associated with vulnerability to insomnia (Fernández-Mendoza et al., 2010). Insomnia patients have also been shown to resort rigidly to monitoring (vigilant information-seeking) when coping with stressful situations (Voss et al., 2006). Still in this study, blunting on the other hand appeared to predict high sleep quality. This finding is consistent with the hypothesis suggesting that a predisposition to disengage in response to stress would likely be associated with a tendency to "escape" to sleep, enhancing sleep quality (Sadeh and Gruber, 2002).

Contrary to these findings, several studies have demonstrated that a tendency to disengage and detach oneself from a stressor may in fact disrupt sleep, whereas a more emotion-focused coping style may in some cases promote sleep. Thomas et al. (2009) compared the effects of avoidance coping (behavioral disengagement, denial and distraction) with approach coping (active coping, planning, acceptance, support seeking, emotional expression and emotional

processing) on sleep in prostate and breast cancer patients undergoing radiation therapy. Results indicated that avoidance coping was associated with more self-reported sleep problems in both groups of patients. In contrast, approach coping actually predicted better sleep, but only in prostate cancer patients. In another study by this group, avoidant coping had a detrimental effect on the reported severity of several sleep parameters in cancer patients (Hoyt et al., 2009). However, approach coping was unrelated to indicators of sleep quality in this study.

These inconsistencies may be partially explained by the need to consider coping flexibility when dealing with different types of stressors, rather than the absolute use of a particular coping type across stressful situations. Using converging methodologies, Cheng (2001, 2003) highlighted the importance of properly adjusting one's coping strategy according to the perceived controllability of a stressor. Specifically, problem-focused coping appears to be more beneficial than problem-focused coping in dealing with controlled stressors (e.g., the stress from an upcoming exam), whereas EFC appears to be more beneficial than problem-focused coping in situations where the stressor is uncontrollable (e.g., the stress when waiting for the grade of the exam).

Zooming in further, it seems that lumping together different coping strategies to form a unified coping category (e.g., EFC) is likely to result in oversimplified conclusions. In the last two decades the study of emotion regulation has made it clear that emotion focused regulation strategies have different outcomes in different situations (Gross, 1998; Koole, 2009; Sheppes and Gross, 2011 for reviews). To give one example, recent findings show that directing attention away from emotional situations via distraction can be very effective in providing short term relief from intense emotional events, relative to changing the meaning of emotional situations via cognitive reappraisal (e.g., Sheppes and Meiran, 2007, 2008). However, reappraisal offers long term emotional adaptation relative to distraction (e.g., Thiruchselvam et al., 2011). These differential consequences also strongly influence how individuals flexibly choose between regulation strategies in different emotional situations (Kashdan and Rottenberg, 2010; Sheppes et al., 2011, in press).

The moderating role of coping and emotional regulation was further explored in two studies by Vandekerckhove et al. (2010, 2012). In the earlier study, individuals with a high dispositional experiential emotional approach (defined as a tendency to affectively "face", identify and express the emotional experience surrounding stressors; Stanton et al., 2000) were found to be less negatively affected by a failure induction on objectively measured sleep patterns, relative to individuals "low" in experiential emotional approach (Vandekerckhove et al., 2010). In the later study, the moderating function of an experiential emotional approach was explored in comparison to a cognitive analytical approach (defined as a tendency to analyze the causes, meanings and consequences of the stressful situation; Vandekerckhove et al., 2012). After induction of a stressor, participants were instructed to apply one of either approach before commencing sleep. Individuals who applied an experiential approach showed fewer awakenings, longer total sleep time and higher sleep efficiency as assessed by PSG, compared to participants who were instructed to apply an analytical approach. Interestingly, the former group also exhibited longer sleep onset latency, which was interpreted as a sign that regulating their emotions took a longer period of time. The authors concluded that in the context of sleep physiology, an experiential approach may be more effective than an analytical approach in the recovery from an emotional negative event.

Rumination has also been examined in several recent studies as a moderator of the effects of psychological stress on sleep. Rumination is defined as a cognitive process in which repetitive thoughts arise, focusing on problematic situations or events as well as the emotions and symptoms these evoke and their potential consequences (Thomsen et al., 2003). Guastella and Moulds (2007) examined individual differences in high vs. low trait ruminators, and found that high-trait ruminators experienced more pre-sleep intrusive thoughts and reported poorer sleep quality relative to low-trait ruminators on the night following an examination. Furthermore, rumination was manipulated in a way that participants were instructed to apply one of either a ruminative approach (perseverating on examination-related cognitions), or a distraction approach (focusing on neutral thoughts). Results showed that high-trait ruminators who were assigned to the rumination induction condition reported the worst sleep quality. The authors suggested that rumination might function as a source of pre-sleep cognitive arousal that maintains sleep-related difficulties. Hence, the sleep of individuals prone to rumination may be significantly more negatively affected by stressful situations. Similarly, Gieselmann et al. (2012) found that state-oriented individuals (who are prone to rumination and hesitation) showed a decrease in subjective sleep quality after an emotional stressor relative to baseline sleep, whereas no such decrease was found in action-oriented individuals (whose emotion regulation is more flexible and adaptive). Zoccola et al. (2009) further expanded this line of work, and found that following an acute psychosocial stressor, trait and state rumination predicted longer sleep onset latency as measured by both objective and subjective measures. It is noteworthy that here again sleep onset was delayed as a function of enhanced emotional activity. It seems that sleep onset latency may be especially sensitive to the effects of emotional focused or ruminative coping styles.

3.2.2. Physiological–emotional reactivity

Another useful framework to understand the effects of stress on sleep lays emphasis on the physiological aspects of emotions. The majority of contemporary etiological theories of insomnia point to a dysregulation of emotional reactivity, and consider hyper-arousal to be a stable characteristic of insomnia patients (Baglioni et al., 2010). In their review of findings concerning hyperarousal and insomnia, Bonnet and Arand (2010) suggest that emotional and cognitive stressors interact with a range of potential physiological predisposing factors of poor sleep to produce insomnia. These physiological factors include elevated heart rate and sympathetic nervous system activation, increased cortisol secretion, increased whole body and brain metabolic activation and increased beta EEG activation. Some of these factors, such as elevated cortisol levels and metabolic activation have been associated with psychological stress (Andreassi, 2007; Dickerson and Kemeny, 2004). Although there is substantial evidence to link physiological–emotional hyperarousal with sleep disturbance, the specific pathways of influence are far from clear.

According to the early "internalization of conflicts model" proposed by Kales et al. (1976), individuals who are predisposed to internalize psychological conflicts tend to develop heightened levels of emotional arousal, which then lead to increased physiological arousal that disrupts sleep. More recently, Perlis et al. (1997) suggested that cortical hyperarousal, experienced by the individual as enhanced cognitive activity (such as intrusive thoughts and worries while trying to commence sleep), leads to elevated levels of physiological arousal that compromises sleep. Contrary to these top-down approaches, Riemann et al. (2010) postulated that a certain genetic vulnerability for sustained hyperarousal on both the biological and the psychological levels may lead to both sleep disturbances and emotional disturbances. Of course, these theories are not contradictory, and possibly several different physiological–emotional pathways may lead to the development of sleep disturbances.

3.3. The effects of other negative emotions on sleep

Apart from stress and anxiety, various other types of negative emotions may affect sleep, with sadness or depressed mood as one of the major categories. From a clinical perspective the association between depression and sleep disturbances has been widely

researched, and exceeds the scope of the present review (for recent reviews on the subject, see Mayers and Baldwin, 2006; Mazza et al., 2005). Unfortunately, studies linking these negative emotions and sleep have almost exclusively relied on correlational designs and therefore their explanatory power has been limited. As in the case of stress, the relationship between depression and sleep has been described as a bi-directional one, as both sleep disruptions and depression have been shown to be predictive of one another. Similarly, several studies have linked suicidal ideation and behaviors with compromised sleep, even after accounting for depression (Bernert and Joiner, 2007). The effect of sadness on sleep in non-clinical samples on the other hand has received significantly less attention. Recently, Talbot et al. (2009) demonstrated that an induction of sad mood (by means of combined playing of melancholic music, autobiographical recall of sad images and an attempt to develop an intense sadness), decreased sleep onset latency relative to the baseline night in healthy participants. The authors suggested that unlike stress, a sad mood tends to decrease arousal and thus aid the process of sleep onset.

Additional negative emotional states have also been linked to disturbed sleep. Research in these domains is more limited and experimental studies are especially scarce, yet several findings are worth noting. Schmidt and Van der Linden (2009) suggested that regret, shame and guilt are counterfactual emotions that may take a particularly heavy toll on an individual's sleep, since they tend to arise at bedtime which is often the first quiet period in the course of the day available to review one's behavior. The frequency of these emotions at bedtime was indeed associated with insomnia severity in a sample of undergraduate students. In another study by this group, regret was also related to insomnia severity and identified as a risk factor for sleep problems in a sample of elderly adults, independently of the effects of depression (Schmidt et al., 2011).

The experience of loneliness has also been suggested to obstruct normal sleep, due to a presumed evolutional need of a secure social environment in order to feel safe and sleep soundly (Kurina et al., 2011). Longitudinal studies have demonstrated that loneliness predicts diminished self-reported sleep quality (Jacobs et al., 2006). In addition, loneliness was associated with poorer sleep efficiency, as indexed by sleep fragmentation, using objective means of assessing sleep, even after accounting for other emotional and demographic risk factors for compromised sleep (Cacioppo et al., 2002; Kurina et al., 2011).

Finally, the emotional state of anger may be salient to sleep in the effect that it enhances arousal. In an early study by Waters et al. (1993) anger correlated with enhanced somatic tension prior to sleep, difficulty falling asleep and poor quality of sleep. Trait anger has been found to predict sleep disturbances, including a difficulty in initiating and maintaining sleep and early-morning awakening (Shin et al., 2005). Elevated levels of anger have also been associated with higher sleep-onset latency, more frequent nightly awakenings and worse sleep quality (Ottoni et al., 2011). In another study, both trait and transient hostility were related to increased sleep disturbances even after adjustment for psychiatric disorders as well as other relevant factors, whereas shorter sleep duration was predicted by transient but not trait hostility (Granö et al., 2008).

3.4. The effects of positive emotions on sleep

Thus, negative emotions such as stress, sadness, regret and anger appear to have detrimental consequences on sleep in many cases. The effect of positive emotional states on sleep on the other hand, received considerably less attention in the literature. Perhaps this is due to the notable attempt to broaden the knowledge regarding etiological factors of sleep problems. It has been demonstrated for example, that the majority of precipitating factors of insomnia were judged to have a negative valence (Bastien et al., 2004), thus most likely initiating negative emotions. Nevertheless, it may be highly informative to explore the role of positive affective states, either as a possible etiological factor of sleep disturbances, or perhaps as a protective factor that may be relevant to the development of treatments for disrupted sleep.

To date, several studies have indicated that well-being is associated with sleep quality (Ryff et al., 2004; Steptoe et al., 2008). Individuals high in the tendency to experience and exhibit positive affect were found to report higher levels of sleep quality relative to individuals low in dispositional positive affectivity (Fortunato and Harsh, 2006). Steptoe et al. (2008) demonstrated a connection between good reported sleep quality and positive affect, as measured using ecological momentary assessment methods. Marital happiness has been linked with fewer sleep disturbances, even after controlling for the relevant covariates (Troxel et al., 2009). Interestingly, falling in love was examined by Brand et al. (2007) as a possible elevator of mood that may influence sleep patterns in adolescents. Results indicated that individuals in early-stage intense romantic love reported better mood and correspondingly improved sleep quality compared to individuals that were in a long-term relationship or not in love.

To the best of our knowledge, experimental studies directly investigating the effect of positive emotion on sleep have yet to be conducted. However, in a study by Talbot et al. (2009) regarding the effect of mood on sleep variables in patients suffering from bipolar disorder, notable results were found concerning the healthy control group. Healthy participants that were asked to concentrate on happy thoughts, listen to cheerful music and develop a positive mood exhibited shorter sleep onset latency relative to baseline. Namely, they were able to benefit from a positive affective state before sleep. Thus, it seems that positive emotions may have a correspondingly positive influence on sleep, although the lack of experimental findings does not permit any firm conclusion at this time.

4. Conclusions and future directions

A growing body of literature suggests that sleep and emotions are closely linked, and that the relationship between these two domains is bidirectional. While extensive experimental research has addressed the effects of sleep variations on emotions, very few experimental studies examined the effects of manipulated emotions on sleep. Considering the effects of sleep deprivation and compromised sleep on emotions, most studies have found an increase in negative emotionality and a decrease in positive emotionality following sleep loss, both in naturalistic and laboratory settings.

The underlying mechanisms of these relationships are gradually being elucidated. FMRI studies have demonstrated alterations in emotional brain networks in sleep deprived individuals, predominantly in the limbic system. REM sleep has been suggested as a modulator of affective brain processes, offering a regulatory function which restructures experiences in an emotionally adaptive manner. Emotional information and memory processing may also be relevant to the understanding of these links, as a negative remembering bias has been shown, by which individuals tend to remember negative but not positive experiences following loss of sleep. Finally, the cognitive-energy model (Zohar et al., 2005) suggests that sleep loss depletes energy levels, thus disrupting adaptive emotional responses. Further research is needed to broaden the understanding of these mechanisms, in an attempt to create a comprehensive theory regarding the processes that underlie sleep's influence on the emotional state.

Evidence indicates that sleep is essential for preserving adaptive emotional reactivity, whereas insufficient sleep may hinder emotional functioning. However, some inconsistencies exist, pointing to a more complex relationship. A few studies have reported no effect of sleep loss on negative or positive emotions, and surprisingly even amplified reactivity to positive stimuli following sleep deprivation. It is possible that methodological diversities generated some of these contrasting

findings. In terms of assessing affect, the context in which emotions were assessed appears to be relevant to their response to lack of sleep. In addition, most studies used self-report measures (mainly the PANAS). Still, several investigations have used more objective physiological measures, such as pupillography. It remains unclear whether subjective and objective methods of emotional assessment are equivalent and reflect similar processes, a topic that should be further explored. Furthermore, in terms of sleep deprivation paradigms, many variations are apparent in the literature, including different durations, acute versus partial sleep loss, and the number of adaptation or restoration nights before or after the deprivation of sleep. These may be extremely influential, in light of Paterson et al. (2011) finding that the lab environment itself may have a negative impact on the emotional status. Naturalistic as well as controlled experimental studies are needed to increase the ecological validity of studies concerning the emotional consequences of sleep deprivation. Broadening the understanding of this relationship seems imperative, due to the vast proportion of individuals in the world today that simply do not get enough sleep. Furthermore, the impact of sleep fragmentation, another ubiquitous phenomenon, on emotions should also receive proper research attention.

Of note is the complementary direction of inquiry, i.e. the investigation of excessive sleep and its emotional consequences. This topic has received limited research attention. Studies regarding increased sleep quantity have been mostly correlative, and indicate that too much sleep is associated with decreased mood, impaired functioning and increased risk for negative health outcomes (Grandner and Drummond, 2007; Patel et al., 2006). Major depression is also linked to excessive sleep, as hypersomnia is part of the diagnostic criteria for the disorder (American Psychiatric Association, 2000). In a review of findings regarding hypersomnia in mood disorders, the presence of excessive sleepiness was found to predict the onset of a major depressive episode (Kaplan and Harvey, 2009). Furthermore, experimental clinical studies have shown that sleep restriction could lead to clinical improvement in depressed patients (Berger and Riemann, 2009).

Given the bound methodological complexity, controlled experimental investigations of these connections are scarce. Nevertheless, a few studies have used nap paradigms to investigate the effects of additional daytime sleep on emotions. Short daytime naps have been found to improve mood (Kaida et al., 2007; Luo and Inoue, 2000), promote physiological habituation to aversive stimuli (Pace-Schott et al., 2011), enhance ratings of positive expressions and reverse amplified negative emotional reactivity to anger and fear (Gujar et al., 2011a). Conversely, Luo and Inoue (2000) found that the magnitude of anger also elevated significantly from pre- to post-nap measurement. Hence, the emotional consequences of napping are inconclusive. Moreover, drawing conclusions from these data as far as the effects of excessive sleep are concerned is not at all obvious, particularly when considering short nap duration paradigms, as the length of the nap also seems to play a role in these processes. Possibly, a U-shaped relationship exists between sleep duration and emotional well-being, consistent with the recently found relationship between sleep duration and hypertension as well as other relevant variables (Gottlieb et al., 2006; Grandner and Drummond, 2007). Clearly much additional work will be required to determine whether Homer's quotation is correct, and indeed “Even where sleep is concerned, too much is a bad thing”.

In terms of the effects of emotions on sleep, several negative emotional states have been examined. Stress has been shown to have a disruptive effect on sleep in numerous studies, both when experimentally induced, and when studied in naturalistic settings. Nevertheless, some studies have yielded contrasting results, indicating that under certain circumstances stress does not appear to compromise sleep. There is data to suggest that an individual's coping style and emotion regulation strategy may moderate this relationship. An emotion-focused coping style was found to be predictive of delayed sleep onset in times of stress, but also of better sleep quality. Avoidant emotion regulation strategies have been associated mostly with disruptions in sleep, but so has rumination. Physiological reactivity may also play a role in the relationship between emotions and sleep. It has been postulated that predisposed physiological hyperarousal interacts with emotional stressors to produce sleep disruptions. Examination of other potential mediators and moderators of these effects, such as the type of stress or additional personality dispositions, may be highly informative to understanding stress' impact on sleep.

Considering other emotional categories, sadness, regret, shame, guilt, loneliness and anger have all been associated with poor sleep, although research in these domains has been limited, with a dearth of experimental studies in particular. The impact of positive emotions on sleep has also received limited attention. Existing data imply a beneficial effect of positive affective states on sleep, but further investigations are needed. Moreover, to the best of our knowledge, the neurophysiological processes underlying the effects of emotions on sleep have yet to be investigated. Namely, it remains unclear which brain networks take part in this relationship. This may also be a promising direction for future investigations.

The focus of the present review has been on healthy populations, and still we believe that much can be learned in terms of clinical interventions from the aforementioned links. It seems that treatments for sleep disorders such as insomnia should take into consideration the etiological significance of emotions in the development and progression of these clinical conditions. Strategies dealing with emotional processes should be developed and evaluated in an attempt to improve existent treatments of sleep disturbances. Regarding possible treatments for emotional disorders, in cases of insufficient sleep or poor sleep quality, interventions may attempt to promote sleep as a main objective. Sleep complaints may be particularly amenable to treatment, unlike other risk factors for psychopathology.

Also, there is much to be learned from the research fields of psychopathology and emotion regulation. Modern research in psychopathology has identified underlying mechanisms such as the attention bias toward threat in anxiety disorders (Bar-Haim et al., 2007) or the combined cognitive biases in depression (Everaert et al., 2012). Exploring the role of sleep in regulating these cognitive processes would be an important future goal. Similarly, research on emotion regulation has received growing attention and new sophisticated research methods have been developed (e.g., Gross, 1999, 2003; Sheppes et al., 2011). Adopting these new insights to the research on sleep and emotion could lead to a better understanding of the underlying mechanisms.

The bidirectional relationship between sleep and emotions has been addressed in this review via both perspectives, i.e. the effects of sleep on emotions and the effects of emotions on sleep. We have attempted to examine these influences independently, but it is clear that in reality such separation does not represent the complex systems involved. Moreover, there appears to be a “vicious cycle” as sleep deprivation tends to compromise emotional regulation, which in many cases leads to increased negative emotion that in turn disrupts sleep, leading to further impairments in emotional well-being. With that said, we believe that understanding these processes and their underlying mechanisms is of great importance, and that additional studies are warranted to further delineate the relationship between sleep and emotions.

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