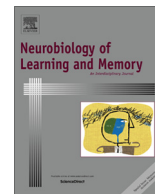




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The effect of selective REM-sleep deprivation on the consolidation and affective evaluation of emotional memories

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ABSTRACT

Emotion boosts the consolidation of events in the declarative memory system. Rapid eye movement (REM) sleep is believed to foster the memory consolidation of emotional events. On the other hand, REM sleep is assumed to reduce the emotional tone of the memory. Here, we investigated the effect of selective REM-sleep deprivation, SWS deprivation, or wake on the affective evaluation and consolidation of emotional and neutral pictures. Prior to an 9-h retention interval, sixty-two healthy participants (23.5 ± 2.5 years, 32 female, 30 male) learned and rated their affect to 80 neutral and 80 emotionally negative pictures. Despite rigorous deprivation of REM sleep or SWS, the residual sleep fostered the consolidation of neutral and negative pictures. Furthermore, emotional arousal helped to memorize the pictures. The better consolidation of negative pictures compared to neutral ones was most pronounced in the SWS-deprived group where a normal amount of REM sleep was present. This emotional memory bias correlated with REM sleep only in the SWS-deprived group. Furthermore, emotional arousal to the pictures decreased over time, but neither sleep nor wake had any differential effect. Neither the comparison of the affective ratings (arousal, valence) during encoding and recognition, nor the affective ratings of the recognized targets and rejected distractors supported the hypothesis that REM sleep dampens the emotional reaction to remembered stimuli. The data suggest that REM sleep fosters the consolidation of emotional memories but has no effect on the affective evaluation of the remembered contents.

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1. Introduction

Ever since the first description of REM sleep (Aserinsky & Kleitman, 1953), scientists have wondered about the function of this sleep stage and whether it is necessary at all (Dement, 1960). In an early experiment, Dement (1960) deprived participants of 65–75% of normal REM sleep for 5 consecutive nights. He characterized the occurring psychological disturbances as not catastrophic but encompassing anxiety, even panic, and irritability. Hence, emotional stability seemed to depend on REM sleep. A lot of studies conducted in the last 15 years document the role of REM sleep not only in the affective evaluation (Goldstein & Walker, 2014) but also the consolidation (Rasch & Born, 2013) of emotional memories. One theory about the role of REM sleep that has gotten a lot of attention in recent years is that of Walker and colleagues (Goldstein & Walker, 2014; Walker & van der Helm, 2009). The

authors propose the so-called “sleep to forget and sleep to remember” hypothesis (SFSR): REM sleep as compared to wake or other sleep stages is supposed to foster the memory consolidation of emotional events as compared to neutral events (“sleep to remember”). On the other hand, REM sleep is assumed to reduce the emotional tone of the memory (“sleep to forget”). That is, REM sleep is believed to attenuate the potential of a memory to elicit emotional reactions during recall. Note that the hypothesis only applies to declarative and especially episodic memory.

There are some studies supporting the “sleep to remember”-part of the hypothesis (Groch, Wilhelm, Diekmann, & Born, 2013; Groch, Zinke, Wilhelm, & Born, 2014; Nishida, Pearsall, Buckner, & Walker, 2009; Wagner, Gais, & Born, 2001). According to these studies, REM sleep indeed fosters the sleep-dependent consolidation of emotional memories. In an early, well controlled study, Wagner et al. (2001) used the split-night design to investigate the influence of REM sleep on emotional memory formation. In the split-night design, SWS-rich sleep in the first half of the night is compared with REM-sleep-rich sleep in the second half

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of the night and corresponding wake intervals to control for circadian effects. The results showed that only late sleep rich in REM selectively fostered the consolidation of emotional in comparison to neutral texts. Nishida et al. (2009) compared the effects of a short nap and an interval spent awake on emotional memory consolidation. The nap design allows a strict control of circadian effects but has to rely on mere correlations of sleep stages during the nap with behavioral measures. The authors report that a nap fostered the consolidation of emotional but not neutral memories and that the amount of REM sleep correlated with the extent of emotional memory facilitation. Groch et al. (2013) conducted an experiment using the split-night paradigm but without wake control conditions (compare Wagner et al., 2001). They investigated the influence of early and late-night sleep on the consolidation of memories for negative and neutral pictures. The results supported the “sleep to remember”-hypothesis: REM-sleep rich, late nocturnal sleep compared to SWS-rich, early sleep enhanced the consolidation of emotional pictures as compared to neutral pictures. Recently, Groch et al. (2014) published two studies employing the split-night paradigm. The studies elucidate on the critical question of which part of a declarative memory representation profits from REM sleep versus SWS. Concerning the memory for items such as pictures, only late-night REM-sleep rich sleep fostered the emotional memory enhancement. SWS-rich, early sleep helped to consolidate the memory for contexts in which the items were encountered during encoding. In summary, the most evidence in favor of the “sleep to remember”-hypothesis (Goldstein & Walker, 2014; Walker & van der Helm, 2009) comes from experiments using the split-night design.

Although the SFSR-hypothesis has inspired a lot of studies, there is only one study supporting the notion of the “sleep-to-forget”-part, that REM sleep helps to tune down the emotional tone of negative memories. Van der Helm and colleagues reported a correlation between a REM sleep EEG parameter and the attenuation of the emotional reaction to repeatedly viewed pictures (van der Helm et al., 2011). The authors compared emotional reactivity after a night of sleep relative to a day of wake (i.e. a day-night design) and specifically looked at the role of REM sleep physiology. They focus on prefrontal gamma EEG activity as a marker of central adrenergic activity and report that this marker predicted emotional reactivity as measured by amygdala activity and behavioral reactivity. In particular, they found that anterior prefrontal gamma-activity during REM sleep was correlated with the decrease of emotional reactivity to pictures. Unfortunately the authors do not report correlations of the amount of REM sleep or SWS with emotional reactivity.

The present study aims to investigate the “sleep-to-remember sleep-to-forget”-hypothesis. In a previous study using REM sleep deprivation, we were not able to replicate the “sleep to remember” effect (Morgenthaler et al., 2014). However, we did not measure the affective evaluation of the pictures after sleep and did not include a NREM-sleep deprivation condition as control for the effects of awakenings (Morgenthaler et al., 2014). Therefore, in the present study we compare the effects of selective, REM-sleep deprivation (REMD) and selective SWS deprivation (SWSD) as compared to wake on the consolidation and change of the emotional evaluation of neutral and negative (“emotional”) pictures. Selective sleep deprivation allows to experimentally manipulate sleep stages right up to almost complete elimination of REM sleep or SWS. This offers the opportunity to further elucidate the causal role of these sleep stages for the consolidation and affective evaluation of emotional memories.

The “sleep-to-remember”-part of hypothesis states that REM sleep is necessary or at least advantageous to consolidate emotional memories. Therefore, we expected a REM-sleep-deprived group

to show worse memory performance, especially with the emotional pictures. Moreover, the (residual) time spent in REM sleep was expected to correlate with this emotional memory bias. The “sleep-to-forget”-part of the hypothesis states that REM sleep decreases the potential of repeatedly encountered negative pictures to elicit an emotional response. Therefore, we expected that the arousal ratings of negative pictures would drop and that the valence rating would only shift to neutral during the night in the SWS-deprived group where REM sleep was present.

2. Materials and methods

2.1. Participants

Sixty-two healthy students (23.5 ± 2.5 years, 32 female, 30 male) were recruited at the University of Kiel campus and were paid 70 EUR for participation. All participants gave written informed consent before taking part. The study protocol was approved by the local ethics committee of the school of medicine of the Christian-Albrechts University of Kiel. Exclusion criteria were a history of neurological or psychiatric disorders, sleep disorders, medications (except contraceptives), nicotine dependence, left-handedness, defective vision, or a body-mass-index above 30. A telephone interview and questionnaires were used to assess these criteria. Psychiatric symptoms were assessed by a German version of the symptom checklist (SCL-90-R, Franke & Derogatis, 2002). Participants were screened for sleep disturbances by the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). The Fagerstrom test for nicotine dependence (Bleich, Havemann-Reinecke, & Kornhuber, 2002) was used to assure that no participant suffered from nicotine dependence. The Edinburgh-Handedness-Inventory (Oldfield, 1971) was used to ensure that all participants were consistent right-handers. All values of the respective questionnaires were in the normal range. All participants had normal or corrected-to-normal vision and reported no color blindness. To ensure that the participants of the sleep groups were able to sleep, we asked them to maintain a regular sleep schedule on the days before the experimental night and to fill out sleep protocols (Hoffmann, Müller, Hajak, & Cassel, 1997). Furthermore, they were asked to abstain from caffeine, nicotine, and alcohol consumption on the day before the experiment. One participant included in the original sample (SWSD group) had to be excluded due to questionable understanding of the instructions. The accuracy score for high-confidence recognition of neutral pictures was more than two standard deviations below the mean ($.067$ as compared to $.492 \pm .177$). The whole sample of 62 participants was divided into a REM-sleep-deprivation group (REMD), a SWS-deprivation group (SWSD), and a Wake group (Wake). Note, that all other sleep stages, including SWS,

Table 1
Sleep parameters across groups.

	REM-deprived mean (SEM)	SWS-deprived mean (SEM)	<i>t</i>	df	<i>p</i>
N1 (min)	67.89 (4.59)	72.35 (4.16)	−0.718	39	.477
N2 (min)	139.12 (10.91)	166.51 (5.99)	−2.200	30.9*	.035
N3 (min)	89.38 (5.62)	7.52 (0.71)	14.46	20.6*	<.001
REMS (min)	2.05 (0.55)	56.67 (5.15)	−10.54	19.4*	<.001
TST (min)	293.67 (12.61)	303.09 (5.93)	−0.676	28.4*	.505
TST/TIB (%)	68.05 (3.17)	68.00 (1.54)	0.01	28.8*	.989
Awakenings	12.33 (5.74)	22.20 (5.30)	−5.712	39	<.001

Sleep stages according to the AASM classification: N1, N2, N3, non-REM sleep stages; REMS, REM sleep; TST, Total Sleep Time; TIB, time in bed; sleep efficiency = TST/TIB in %.

* df adjusted due to significant Levene test for equal variances.

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