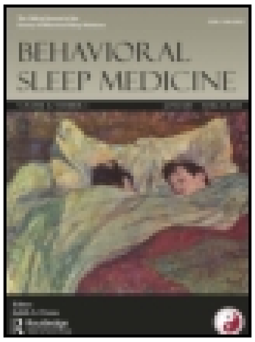

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Differential Effects of REM Sleep on Emotional Processing: Initial Evidence for Increased Short-term Emotional Responses and Reduced Long-term Intrusive Memories

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ABSTRACT

Background: Rapid eye movement (REM) sleep has been postulated to facilitate emotional processing of negative stimuli. However, empirical evidence is mixed and the conditions under which higher amounts of REM sleep lead to decreased or increased emotional responses are unclear. We proposed that the time course between REM sleep and measurement of emotional responses is a crucial factor and hypothesized that more REM sleep will enhance emotional responses shortly after sleep, but will lead to decreased emotional responses in the long-term.

Participants and Methods: Seventy-six healthy young women watched negative and neutral pictures before a polysomnographically-recorded nap including three different groups (1: no REM sleep, 2: REM sleep awakening, 3: REM sleep). Short-term emotional responses were measured using aversiveness ratings of negative pictures; aversiveness ratings of intrusive picture memories on the three subsequent evenings were used to measure long-term emotional responses.

Results: For short-term emotional responses, no significant interaction indicating group differences was found. However, we found correlations between longer REM sleep duration and higher aversiveness ratings of negative pictures. In contrast, lower aversiveness of intrusive picture memories after two days was found in participants with a full REM sleep period compared to individuals without REM sleep. Correlational analyses also supported this pattern of results.

Conclusions: Results suggest that REM sleep may increase reactivity to emotional stimuli in the short-term and this effect of REM sleep appears to facilitate emotional processing during subsequent nights leading to reduced intrusive picture memories in the long-term.

Emotional processing during sleep is one crucial aspect of mental health (Repetti, Taylor, & Seeman, 2002; Silk, Steinberg, & Morris, 2003), and especially rapid eye movement (REM) sleep has been suggested to play an important role. The *Sleep to forget, sleep to remember* theory elaborates on this idea by differentiating between two components of emotional memory: the declarative memory content of the specific emotional event and the emotional responses to this event (Walker, 2009; Walker & Van der Helm, 2009). According to this theory, based on its unique neurobiology REM sleep provides the ideal milieu to decouple the declarative memory content from emotional responses in order to successfully process emotional events. More precisely, specific emotion-related structures like amygdala and hippocampus show increased activation during REM sleep and offer an opportunity to reactivate and process emotional experiences (Maquet et al., 1996). The

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Supplementary data for this article can be accessed here.

predominance of theta waves during REM sleep leads to large-scale networks that allow a contextual integration of these experiences into existing memory structures (Buzsaki, 2002). Moreover, aminergic neurotransmitters that are linked to stressful and anxious states are largely absent during REM sleep, which may facilitate neural decoupling of declarative information and emotional connotation (Pace-Schott & Hobson, 2002). In sum, due to the reactivation of emotional experiences during REM sleep, in the absence of aminergic neurotransmitters and with the possibility to integrate these experiences into existing memory networks, two predictions for REM sleep-related emotional processing arise from this model. Whereas the declarative memory content is maintained or even strengthened, emotional responses are decreased across periods of sleep, especially REM sleep.

Empirical evidence strongly supports the strengthening of the declarative memory content of emotional stimuli across phases of REM sleep (e.g., Cunningham, Pardilla-Delgado, Alger, & Payne, 2014; Hu, Stylos-Allan, & Walker, 2006; Payne & Kensinger, 2010; Wiesner et al., 2015). However, empirical evidence regarding the relationship between REM sleep duration and the processing of emotional responses is quite mixed (for overview, see Cunningham et al., 2014; Werner, Schabus, Blechert, Kolodyazhniy, & Wilhelm, 2015). Some studies support a REM sleep-dependent decrease of emotional responses from pre- to post-sleep (Cunningham et al., 2014; Greenberg, Pillard, & Pearlman, 1972; Gujar, McDonald, Nishida, & Walker, 2011; Rosales-Lagarde et al., 2012), while other studies find the opposite effect, with longer REM sleep duration being related to less decrease or even enhancement of emotional responses (Baran, Pace-Schott, Ericson, & Spencer, 2012; Gilson et al., 2015; Lara-Carrasco, Nielsen, Solomonova, Levrier, & Popova, 2009; Pace-Schott et al., 2011; Wagner, Fischer, & Born, 2002; Werner et al., 2015). The latter set of studies is rather in line with an alternative account that has recently emerged and that relates REM sleep to the consolidation of emotional salience (Baran et al., 2012; Pace-Schott et al., 2011; Werner et al., 2015). Within this *emotional salience consolidation account*, REM sleep is assumed to reinforce emotional salience by consolidating neuroplastic changes related to the viewing of emotional stimuli. This may consequently interfere with successful processing of the associated emotion, resulting in less decreased or even enhanced emotional responses from pre- to post-sleep, at least in the short-term.

Aiming at a clarification of these mixed results, we previously proposed that particularly for strong emotional stimulation (e.g., long-duration, highly aversive films), REM sleep-related emotional processing may best be described by an activation-attenuation pattern: an initial increase in emotional responding after more REM sleep (i.e., an emotion-salience enhancing effect of REM sleep) stimulates further processing (e.g., during subsequent nights with REM sleep), which ultimately leads to decreased emotional responding in the long-term (Werner et al., 2015). Also the *Sleep to forget, sleep to remember* theory implies that failure of emotional processing during the first night after the emotional event will lead to repeated attempts to downregulate emotional responses during subsequent nights (Walker & Van der Helm, 2009). Others have also suggested that the downregulation of emotional responses might be initiated during the first night after the emotional event, but that this process requires several nights to be completed (Deliens & Peigneux, 2014). However, both Walker and Van der Helm (2009) and Deliens and Peigneux (2014) did not mention a possible increase in emotional responses with increasing REM sleep as suggested by the *emotional salience consolidation account*, nor did they investigate the entire temporal unfolding of this process by including short- and long-term emotional responses.

Interestingly, even for short-duration emotional pictures or emotional stories with low intensity (used in many studies), REM sleep has been linked with increased emotional responses when measured directly after sleep (e.g., Gilson et al., 2015; Lara-Carrasco et al., 2009; Wagner et al., 2002), whereas at least three hours after awakening from sleep, REM sleep (versus no REM sleep) has been shown to lead to decreased emotional responses (e.g., Gujar et al., 2011). These findings suggest different short- and long-term effects of REM sleep on emotional processing on a time-scale of hours.

In sum, REM sleep is beginning to emerge as an important and logical candidate mechanism for understanding how sleep is related to effective emotional processing. However, the temporal unfolding, i.e., whether longer REM sleep duration eventually intensifies or attenuates emotional responses, is currently unclear, or what the factors may be that are associated with one or the other theoretical account. Diminished emotional processing might exert an enduring effect on overall mental health, resulting in maladaptive consolidated emotions, and thus, it is critical to understand how certain aspects of sleep could make these experiences better or worse. Recent reports discuss the importance of investigating the time course of emotional responses over longer periods and more specifically the short- as well as the long-term effects of REM sleep on emotional processing (Gilson et al., 2015; Palmer & Alfano, 2016). Nevertheless, these studies are still lacking.

Therefore, the aim of the present study was to investigate both short- and long-term effects of REM sleep after emotional picture viewing on emotional responding. Self-reported emotional responses to negative pictures were examined shortly before and after a nap in the early afternoon (i.e., within 15 minutes and after one hour) by subjective aversiveness ratings of these pictures. Additionally, emotional responses were measured after several hours on the same evening and on the two subsequent evenings by asking participants about the aversiveness of spontaneous memories elicited by the negative pictures.

We expected longer REM sleep duration immediately after picture viewing to be associated 1) with higher picture aversiveness ratings shortly after sleep, and 2) with lower aversiveness ratings of picture memories on subsequent days.

Materials and methods

Participants

Participants were 76 healthy women (93% university students) between 18 and 32 years of age (*Mean* = 22.05, *SD* = 3.03). All participants were non- or only occasional smokers with no history of mental, neurological, or sleep disorders. We only accepted participants who were considered in the normal range of subjective sleep quality, as defined by values in the Pittsburgh Sleep Quality Index up to 5 (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989).

Procedure

The whole study spanned 10 days and took place as part of a larger study, including also a declarative memory task as well as psychophysiological measurements. However, the focus of the present investigation was only the relationship between REM sleep and subjective short- and long-term emotional responses. The study included three visits in the Clinical Stress and Emotion Laboratory of the University of Salzburg. The baseline assessment to evaluate sleep quality took place at least 7 days before the experimental session. In the experimental session participants rated negative and neutral pictures and were given a 75–115 minutes nap opportunity, before rating the pictures again. Additionally, participants came to a final visit after two consecutive days of follow-up ambulatory assessment regarding spontaneous aversive memories of the emotional pictures.

During the first 7 days, between the baseline assessment and the experimental session in the lab, participants were asked to keep a regular sleep-wake cycle which was monitored via daily sleep dairies. The reported average bedtime was 12:15am and the average wake-up time was 8:25am. Participants reported to sleep on average 7 hr 55 min (*SD* = 0 hr 49 min) per night during day 1 to day 6. On day 7, the day of the experimental session in the lab, participants were instructed to get up around 1.5 hours earlier than usually in order to increase homeostatic sleep pressure for the afternoon nap and the probability to be able to fall asleep as well as to enter REM sleep. The average total sleep time on day 7 was 6 hr 46 min (*SD* = 0 hr 53 min) with an average bedtime of 12:01am and a wake-up time of 7:06am.

On the day of the experimental session participants came to the lab at around 11:30am. First, they were seated on a chair placed around 20 inches in front of a 24-inch full HD monitor and electrodes for measuring sleep were attached. Second, participants completed several questionnaires including assessment of trait anxiety (State-Trait Anxiety Inventory, STAI; German version by Laux, Glanzmann, Schaffner, & Spielberger, 1981), depressive symptoms (German version of the Center for Epidemiologic Studies Depression Scale; Hautzinger & Bailer, 1993; Hautzinger, Bailer, Hofmeister, & Keller, 2012; CESD: Radloff, 1977) as well as general medical and psychological health condition. Then, the experiment started which included three sessions (before the nap, within the first 15 minutes after the nap and about 1 hour after the nap; see Figure 1) with presentation of negative and neutral pictures (each for 4 seconds). *Short-term emotional responses* to the pictures were measured using self-reported aversiveness ratings.

Participants were equally assigned to one of three groups before the nap started: Group 1, in which participants were woken up before the first REM sleep period (no REM sleep group), Group 2, in which participants were allowed to achieve at least some REM sleep and were therefore woken up during REM sleep (REM sleep awakening group), and Group 3, in which participants were woken up in sleep stage 2, after having achieved at least one full period of REM sleep (REM sleep group). Because not all participants initially assigned to Groups 2 and 3 reached REM sleep or were woken up during REM sleep, toward the end of the experiment participants were preferentially assigned to Group 2 and 3 leading to 29 participants in Group 1, 28 in Group 2 and 19 in Group 3. The groups were matched regarding variables like age and general subjective sleep quality (PSQI) as well as current mood, sleepiness and calmness (Multidimensional Mood Questionnaire, MDMQ; Steyer, Schwenkmezger, Notz, & Eid, 1997). Final Group belongingness was then determined by analysis of polysomnographic data (see 2.3 below), indicating no (Group 1, $N = 25$), interrupted (Group 2, $N = 22$), or completed (Group 3, $N = 29$) REM sleep (a detailed overview of the flow of participants can be found in the Supplement, Figure S1). Overall, a total of $N = 15$ participants had to be reassigned based on these polysomnographic data analysis. For full disclosure, please note that we also assessed a fourth group (i.e., wake condition). However, due to methodological shortcomings this group cannot be interpreted, therefore this condition was not further included in the analyses.

On the evening of the experimental session, as well as on the two subsequent evenings *long-term emotional responses* were measured via specific questions within the daily sleep diaries regarding the aversiveness, number, and duration of spontaneous picture memories. After completing the whole study procedure, participants came to the lab one more time and were compensated with course credits or 20€.

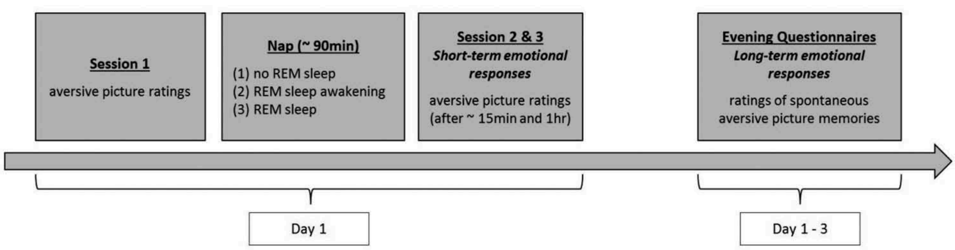

Figure 1. Main study elements including the nap as well as measurements of short- and long-term emotional responses. Participants were assigned to three groups with different REM sleep durations. In order to assess short-term emotional responses, participants rated the pictures´ aversiveness (0 = "not aversive at all" to 10 = "extremely aversive") after the first picture presentation (Session 1) as well as 15 minutes and one hour after the nap (Sessions 2 and 3). In the evening of the same day (Day 1) as well as in the evenings of the two subsequent days (Days 2 and 3), a diary assessed long-term emotional responses that were defined as spontaneous, aversive picture memories and picture-related thoughts or feelings. Participants reported the number, duration, and aversiveness (0 = "not aversive at all" to 10 = "extremely aversive") of picture memories that occurred throughout the day.

Polysomnographic nap recordings

A full polysomnography (PSG) sensor array was measured during the nap. The electroencephalogram (EEG) was recorded with Polybench 1.22 software using a 32-channel amplifier (TMSi, Ej Oldenzaal, The Netherlands) attached next to the bed. Signals were digitized with a 512 Hz sampling rate. During recording, 0.5 Hz low-pass and 35 Hz high-pass filters were applied for all skull electrodes. Seven Ag/AgCl electrodes (F3, F4, C3, Cz, C4, O1, O2) were attached with Genuine Grass electrode paste (Grass Technologies, Warwick, RI) according to the International 10/20 system with common reference and were later re-referenced to the two additional electrodes on the contralateral mastoids (A1, A2). Impedances were kept under 5 kΩ. Furthermore, four electrooculogram (EOG), two electromyogram (EMG; left and right chin), two bipolar respiratory (thorax and abdomen) channels, one bipolar electrocardiogram (ECG), one oxygen saturation, and one finger pulse plethysmography channel were recorded. Contralateral re-referenced sleep recordings were scored semiautomatically (i.e., computerized followed by manual scoring) by The Siesta Group in Vienna (Somnolyzer 24 x 7; cf. Anderer et al., 2005, 2004) according to standard criteria of the American Academy of Sleep Medicine (AASM; Iber, Ancoli-Israel, Chesson, & Quan, 2007).

Short- and long-term emotional responses

Short-term emotional responses were measured using aversiveness ratings of negative stimuli in Sessions 1 to 3 on a visual analog scale from “0 = not aversive at all” to “10 = extremely aversive”. Overall, 80 pictures (40 negative, 40 neutral) from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) were used in this study. In each session, we presented 60 pictures of which 20 pictures were replaced in Session 2 and 3. Therefore, only a subset of 40 pictures (20 negative, 20 neutral) was presented in all three sessions and short-term emotional responses were only based on these pictures (a list of all 40 pictures including IAPS number as well as normative valence ratings can be found in the Supplement, Table S1). Pictures were pseudo-randomized with five different lists with the restriction that no more than two consecutive negative or neutral pictures could occur. Ratings took place directly after the presentation of each picture.

Long-term emotional responses were measured as spontaneous occurrence of aversive picture memories in daily life for which participants completed an adapted version of the Intrusion Memory Questionnaire (IMQ; Ehring, Fuchs, & Klasener, 2009; Zetsche, Ehring, & Ehlers, 2009) before going to bed on the day of the experiment (Day 1) and on the two subsequent evenings (Day 2 and Day 3). The IMQ was adapted to assess number and duration (in minutes) of picture memories as well as, most importantly, the aversiveness of these memories which was measured by a visual analog scale from “0 = not aversive at all” to “10 = extremely aversive”. The instructions for the IMQ defined memories as “thoughts about the negative emotional pictures” that participants had seen in the lab including the “presence of thoughts or feelings” that they had while watching the negative pictures.

We decided to not expose participants to the pictures after the laboratory session on Day 1 since this may primarily tap into processes related to habituation with repeated aversive picture exposure rather than into processes relevant for long-term spontaneous emotional processing. Instead, we assessed spontaneously occurring picture memories in daily life to obtain an index of how emotional experiences are naturally processed. Consequently, long-term emotional responses only referred to memories regarding negative pictures and long-term responses to neutral pictures were not separately investigated.

Statistical analyses

Two participants had to be excluded as they were not able to sleep at all (both from Group 1 without REM sleep). Group comparisons on the basis of the three nap groups were computed using analysis of variance (ANOVA). Corresponding non-parametric group comparison methods were used when distributional assumptions for parametric tests were not met (defined as Kolmogorov-Smirnov test, Lilliefors corrected ≤ .001); this was the case for all variables of long-term intrusive memories (number, duration and aversiveness of picture memories). Alpha level was set to .05.

Short-term emotional responses

After exclusion of one extreme outlier (aversiveness ratings in Sessions 1 and 2, $z < -3.29$ or $z > 3.29$) the sample for short-term emotional responses contained 73 participants (see Figure S1 in the Supplement for a detailed overview of the number of participants for each analysis). The three nap groups (no REM sleep, REM sleep awakening, REM sleep) were compared regarding aversiveness ratings of negative pictures using a repeated measures ANOVA with the factors GROUP (no REM sleep, REM sleep awakening, REM sleep) and SESSION (Session 1, 2, 3), and were followed up using post-hoc Scheffé and independent sample *t*-tests.

Long-term emotional responses

After exclusion of four extreme outliers (aversiveness ratings, number or duration of intrusive memories on Days 1 to 3, $z < -3.29$ or $z > 3.29$) the sample for long-term emotional responses contained 70 participants. Due to additional missing data the sample size for Day 1 and 2 analyses was 69 and for Day 3 analyses was 68 (see Supplement, Figure S1). As all variables of the IMQ were not normally distributed (Kolmogorov-Smirnov test, Lilliefors corrected ≤ .001), non-parametric Kruskal-Wallis tests and post-hoc Mann-Whitney tests were used to analyze differences between specific nap groups. These non-parametric analyses required three calculations instead of one repeated measures ANOVA (including the three days), therefore we used the Bonferroni correction and alpha was set to .05/3 = .02 for these analyses. Effect size *r* was used for post-hoc Mann-Whitney tests using the formula $r = Z/\sqrt{N}$.

Additionally, as many earlier studies used a correlational approach, secondary analyses that pooled participants from the three sleep groups were examined as well and can be found in the Supplement.

Results

Demographic, psychometric and sleep variables

The mean age of the final sample containing 74 participants was 22.14 (SD = 3.02). Trait anxiety and depressive symptoms were in the normal range (trait anxiety: M (SD) = 35.99 (7.94); Laux et al. (1981); depressive symptoms: M (SD) = 11.31 (6.54); Hautzinger and Bailer (1993). The overall sample further indicated good sleep quality with an average PSQI score of 3.74 (SD = 1.17; N = 73 due to one missing value). Polysomnographic analyses in the sample further showed a mean total sleep time (TST) of 70.43 min (SD = 19.73), mean sleep efficiency (EFF) of 77.79% (SD = 19.19), and a mean REM sleep duration of 6.91 min (SD = 7.52). This corresponds to 8.79% (SD = 9.27) REM sleep of the TST.

The different nap groups did not differ regarding age, subjective sleep quality, anxiety and depressive symptoms, as well as current mood, sleepiness, and calmness at the beginning of the experiment (see Table 1). Table 1 also provides an overview of sleep parameters in the different nap groups. A shorter total sleep time, lower sleep efficiency, increased sleep onset latency as well as longer duration (wake after sleep onset) and frequency of awakenings were shown for participants without REM sleep (Group 1) compared to participants with medium and higher amounts of REM sleep (Group 2: REM sleep awakening; Group 3: REM sleep) and may arise as a natural consequence of group assignment. The significantly higher duration and percentage of REM sleep in the two REM sleep groups (Groups 2 and 3) compared to the no REM sleep (Group 1) indicated a successful manipulation of REM sleep duration within this experiment. However, although Group 2 descriptively showed a medium REM sleep duration it was not significantly different from Group 3.

Table 1. Overview of study variables in the different nap groups.

	Group 1 no REM sleep	Group 2 REM sleep awakening	Group 3 REM sleep	Inferential Statistics	
	N = 23	N = 22	N = 29		
	Mean (±SD)	Mean (±SD)	Mean (±SD)	*F*	*p*
Age	22.57 (±2.57)	21.68 (±2.67)	22.14 (±3.60)	0.47	.625
Sleep Quality (PSQI) [a, c]	3.65 (±1.30)	3.91 (±1.23)	3.68 (±1.02)	1.38	.501
Depressive Symptoms [c]	10.59 (±5.66)	12.95 (±7.57)	11.03 (±6.47)	0.79	.457
Anxiety [c]	35.09 (±6.64)	38.33 (±9.70)	35.28 (±7.53)	1.15	.322
Mood (before Session 1)	33.43 (±3.29)	34.09 (±4.12)	33.31(±4.51)	0.25	.776
Sleepiness (before Session 1)	21.43 (±5.2)	22.95 (±5.60)	22.86 (±4.76)	0.64	.529
Calmness (before Session 1)	29.74 (±4.13)	31.81 (±4.28)	32.41 (±3.75)	2.99	.057
Total Sleep Time (min) [a]	53.80 (±22.71) [1]	74.70 (±11.95) [2]	80.38 (±12.61) [2]	20.03	.000
Sleep Efficiency [a]	59.20 (±23.65) [1]	86.54 (±7.56) [2]	85.89 (±8.10) [2]	22.56	.000
Wake after Sleep Onset (min)[a]	22.11 (±20.74) [1]	3.23 (±3.48) [2]	5.71 (±6.16) [2]	9.57	.008
Sleep Onset Latency (min) [a]	20.24 (±9.41) [1]	13.02(±6.76) [2]	12.78 (±7.01) [2]	11.21	.004
Number of Awakenings [a]	5.61 (±3.66) [1]	2.91 (±1.97) [2]	3.76 (±3.70) [2]	7.76	.021
Number of Arousals [a]	33.09 (±21.74)	34.36 (±19.04)	35.86 (±17.47)	0.79	.675
Frequency of Stage Shifts	27.22 (±14.83)	27.91 (±10.17)	28.66 (±9.28)	0.10	.904
REM Sleep Latency (min) [b]	-	67.45 (±10.36) [1]	58.55 (±11.54) [2]	2.85	.006
Sleep Stage N1 (min) [a]	16.50 (±11.92)	14.23 (±6.44)	16.71 (±9.03)	0.81	.667
Sleep Stage N1 (%) [a]	34.03 (±21.93) [1]	19.40 (±8.70) [2]	21.71 (±13.53) [2]	8.18	.017
Sleep Stage N2 (min)	21.54 (±9.25) [1]	29.61 (±9.05) [2]	32.43 (±9.83) [2]	8.90	<.001
Sleep Stage N2 (%) [a]	42.55 (±14.11)	40.10 (±12.64)	40.71 (±10.23)	1.13	.569
Sleep Stage N3 (min) [a]	15.76 (±16.79)	22.68 (±15.41)	19.60 (±15.05)	2.84	.242
Sleep Stage N3 (%) [a]	23.44 (±21.39)	29.46 (±17.80)	23.56 (±17.04)	1.75	.417
Sleep Stage REM (min) [a]	0 [1]	8.18 (±5.56) [2]	11.43 (±7.90) [2]	49.50	.000
Sleep Stage REM (%) [a]	0 [1]	11.05 (±7.32) [2]	14.06 (±9.37) [2]	49.03	.000

Different number superscripts indicate significant differences in post-hoc tests ($p < .05$).
[a]non-parametric Kruskal-Wallis tests were used, with χ^2 being displayed instead of *F*.
[b]only Groups 2 and 3 were compared with an independent sample t-test, with *t* being displayed instead of *F*.
[c]*N* = 22 in Group 1, *N* = 21 in Group 2, *N* = 28 in Group 3 due to missing data.

Short-term emotional responses

Regarding short-term emotional responses, Table 2 provides an overview of short-term emotional reactivity in the different nap groups.

A repeated measures ANOVA for aversiveness ratings of the negative pictures including GROUP (no REM sleep, REM sleep awakening, REM sleep) and SESSION (Session 1, 2, 3) showed no main effect of SESSION, $F(2,140) = .27$, $p = .733$, $\eta^2 = .00$, and no significant SESSION x GROUP interaction, $F(4, 140) = .53$, $p = .690$, $\eta^2 = .02$. However, a marginally significant main effect of GROUP was found, $F(2, 70) = 2.73$, $p = .072$, $\eta^2 = .07$. Post-hoc multiple comparisons (Scheffé) showed a marginally significant difference between the no REM sleep and the REM sleep group ($p = .088$; see Figure 2). Although not indicated by a significant interaction, post-hoc independent sample *t*-tests showed slightly lower aversiveness ratings for the negative pictures in Session 1, $t(50) = 1.74$, $p = .089$, $d = .49$, and significantly lower aversiveness ratings in Session 2, $t(50) = 2.29$, $p = .026$, $d = .65$, and Session 3, $t(50) = 2.34$, $p = .023$, $d = .66$, for the no REM sleep group compared to the REM sleep group. No further (marginally) significant differences were found between the groups ($ps \geq .236$).

Long-term emotional responses

As expected, long-term emotional responses revealed the opposite pattern of results. Descriptive values for aversiveness, number, and duration of picture memories can be found in Table 3.

Non-parametric Kruskal-Wallis tests including the three REM sleep groups, separately for Day 1, Day 2, and Day 3, showed no significant differences on Day 1 and Day 2, χ^2s(2) < 2.85, $ps > .241$. However, on Day 3 significant differences were found for aversiveness, $\chi^2(2) = 8.86$, $p = .012$, number, $\chi^2(2) = 9.29$, $p = .010$, as

Table 2. Descriptive values of short-term emotional responses (aversiveness ratings for negative and neutral pictures).

	N	M	SD
Session 1			
Aversiveness ***negative*** pictures			
Group 1: no REM sleep	23	7.80	0.58
Group 2: REM sleep awakening	21	8.15	0.74
Group 3: REM sleep	29	8.13	0.74
Aversiveness ***neutral*** pictures			
Group 1: no REM sleep	23	3.12	0.81
Group 2: REM sleep awakening	21	3.03	0.85
Group 3: REM sleep	29	3.21	0.80
Session 2			
Aversiveness ***negative*** pictures			
Group 1: no REM sleep	23	7.79	0.67
Group 2: REM sleep awakening	21	8.13	0.74
Group 3: REM sleep	29	8.24	0.71
Aversiveness ***neutral*** pictures			
Group 1: no REM sleep	23	2.92	0.90
Group 2: REM sleep awakening	21	2.74	0.84
Group 3: REM sleep	29	3.07	1.09
Session 3			
Aversiveness ***negative*** pictures			
Group 1: no REM sleep	23	7.80	0.68
Group 2: REM sleep awakening	21	8.13	0.71
Group 3: REM sleep	29	8.26	0.73
Aversiveness ***neutral*** pictures			
Group 1: no REM sleep	23	2.86	0.94
Group 2: REM sleep awakening	21	2.88	0.86
Group 3: REM sleep	29	3.00	1.07

Descriptive values of short-term emotional responses (aversiveness ratings for negative and neutral pictures; in Session 1, Session 2, and Session 3; scale 0–10) for the separate REM sleep groups.

well as duration of spontaneous picture memories, $\chi^2(2) = 8.89$, $p = .012$ (all Bonferroni-corrected, see Figure 3). Post-hoc Mann-Whitney tests indicated no significant differences between the REM sleep awakening and the REM sleep group, $-.46 < Zs < -.87$, $ps > .385$, $rs < -.13$. In comparison to the no REM sleep group, the REM sleep awakening group showed slightly less aversiveness, reduced number as well as shorter duration of picture memories, $-1.83 < Zs < -2.19$, $ps < .067$, $rs < -.35$. Differences between the REM sleep group and the no REM sleep group were even stronger. Here, the REM sleep group showed significantly less aversiveness, lower number as well as shorter duration of picture memories, $-2.68 < Zs < -2.98$, $ps \leq .007$, $rs > -.43$.

Overall, secondary correlational analyses (see Supplement) supported these findings by indicating a link between longer REM sleep and increased short-term emotional reactivity as well as between longer REM sleep and decreased intrusive picture memories after two days (see Table S2 and Figure S2 for short-term emotional responses as well as Table S3 and Figure S3 for long-term intrusive memories). Correlations are based on all participants, including also participants with no REM sleep and who did not experience intrusive memories (see Supplement).

Discussion

The present study investigated short- and long-term effects of REM sleep on emotional processing. Although previous studies already suggested differential effects of REM sleep on emotional processing, to our knowledge, no study had examined short and long-term effects in conjunction. Results point to increased short-term emotional reactivity to negative pictures after the nap in the REM sleep group compared to the no REM sleep group. In contrast, intrusive picture memories after our observation period of two days were lower in the REM sleep group than in the no REM sleep group.

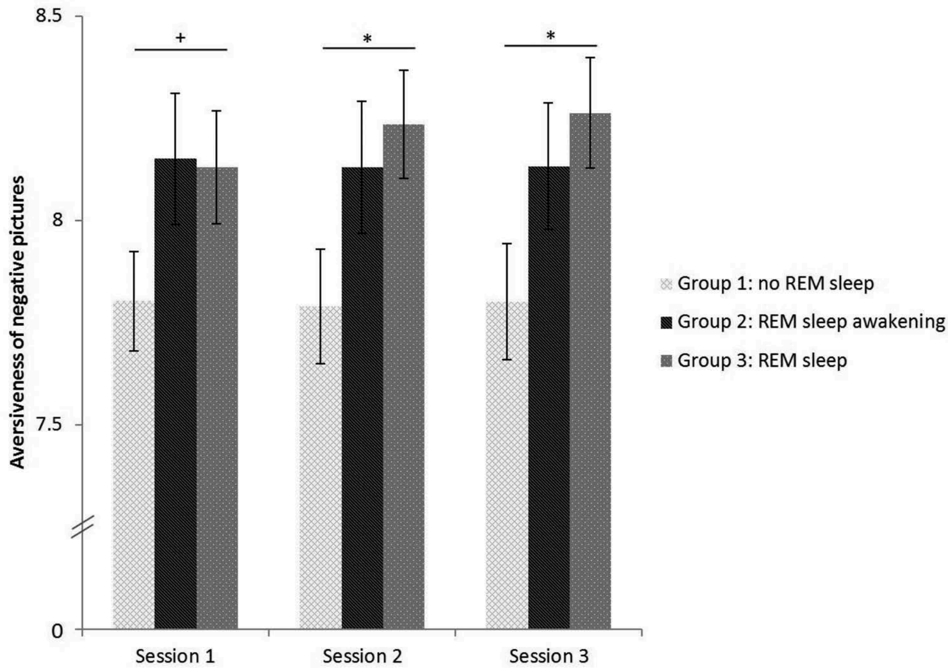

Figure 2. Short-term emotional reactivity for the negative pictures in the different nap groups. $^{+}$ $p \leq .10$, * $p \leq .05$. Participants who achieved at least one full REM sleep period showed increased aversiveness ratings of negative pictures compared to participants with no or only a short amount of REM sleep. $^{+}$ $p \leq .10$, * $p \leq .05$.

Additionally, correlational analyses revealed that higher amounts of REM sleep went along with higher emotional reactivity directly after the nap, whereas higher amounts of REM sleep were related to reduced aversiveness, number, and duration of spontaneous picture memories on the second day after the experiment. By additionally taking the time course of emotional processing into account, these results are a first step to shed light on some of the mixed results of earlier studies within this research area.

Regarding short-term emotional responses, the pattern of results was somewhat mixed. Whereas correlational analyses showed higher aversiveness ratings after more time spent in REM sleep, this pattern was not supported by group comparisons of the three nap groups (no REM sleep, REM sleep awakening, REM sleep). Post-hoc analyses indicated that the significantly less aversive picture ratings of the no REM sleep group compared to the REM sleep group directly following the nap (in Session 2 and 3) already tended to be present during Session 1.

Regarding long-term emotional responses, we mainly found significant results on the second day after the experiment, but not on the same day or the day afterward. Specifically, group comparisons indicated significantly less aversiveness, number and duration of intrusive picture memories in the REM sleep group compared to the no REM sleep group (on Day 3). Furthermore, also on Day 3, correlational analyses showed that longer REM sleep duration during the nap was associated with less aversive, reduced number, and shorter duration of picture memories. Up to now, prevalent support for this more long-term amelioration effect of REM sleep on emotional processing is rather indirect and mainly comes from studies using REM sleep deprivation designs. For example, increased (or less decreased) emotional responses have been shown for REM sleep deprivation groups in comparison to non-REM sleep deprived participants after one day (around 10 hours; Rosales-Lagarde et al., 2012). Using a nap design, Gujar et al. (2011) also showed a reduction in emotional responses to negative stimuli only in the REM sleep versus the no-REM sleep group after

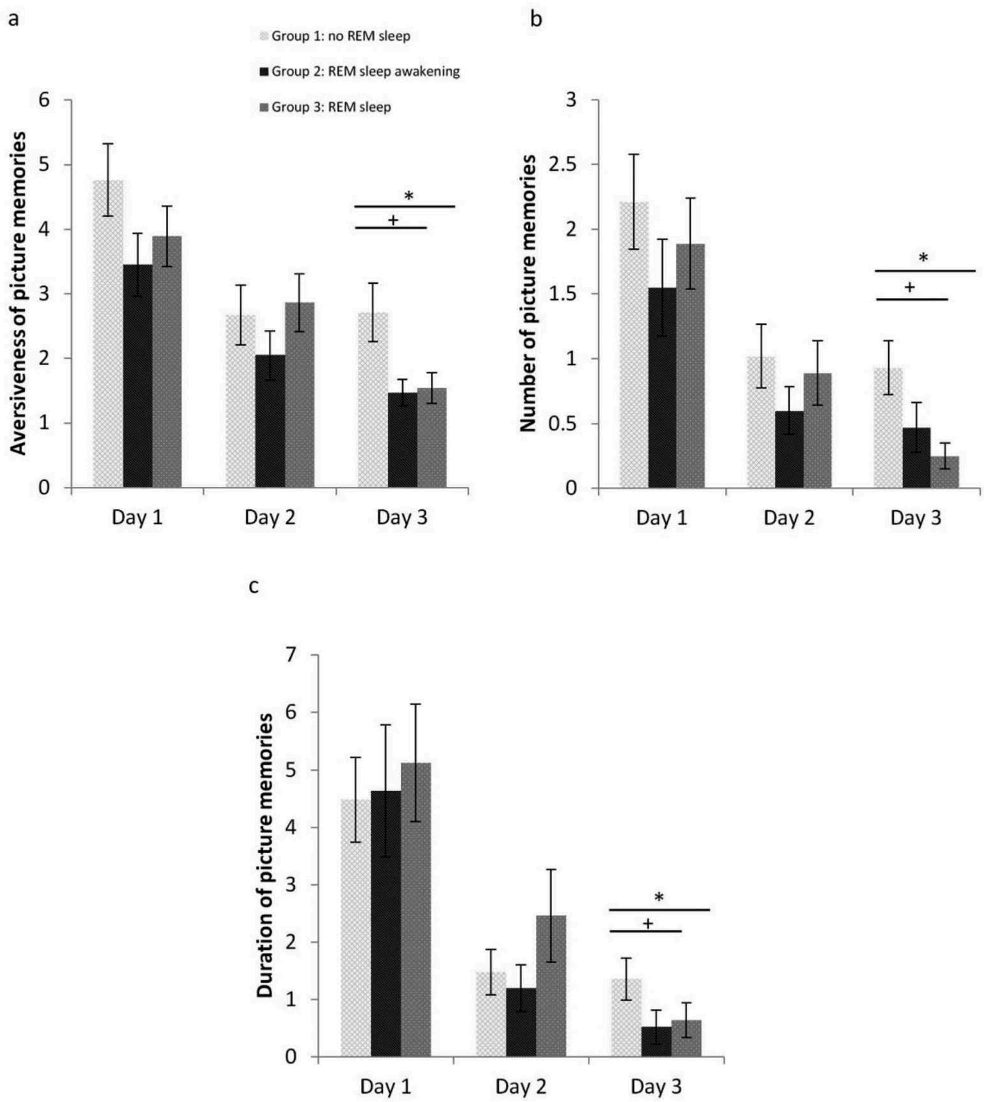

Figure 3. (a–c) Long-term intrusive memories (aversiveness, number, and duration) in the different nap groups. Participants who achieved at least one full REM sleep period showed reduced aversiveness (a), number (b), and shorter duration (c) of intrusive picture memories in comparison to participants with no or only a short amount of REM sleep $^{+}$ $p \leq .07$, * $p \leq .02$ (Bonferroni-corrected).

a delay of around 2 to 3 hours. However, to our knowledge, the current study is the first to show a direct link between longer REM sleep duration and reduced long-term intrusive memories.

Differentiating between short- and long-term emotional responses may explain conflicting findings of earlier studies. For example, the initial effect of REM sleep on emotional processing might be seen in an actual enhancement (or less decrease) of emotional responses from pre- to post-sleep (e.g., Werner et al., 2015). However, even maintained emotional responses (in contrast to decreases in emotional responses) in relation to REM sleep can be interpreted as activated emotional processing (Baran et al., 2012). For example, Pace-Schott et al. (2011) found that skin conductance responses to negative pictures generally decreased from pre to post-sleep (nap) compared to wakefulness. Nevertheless, REM sleep was associated with less decrease in skin conductance responses to negative

Table 3. Descriptive values of long-term intrusive memories (aversiveness, number and duration of picture memories) on the same evening (Day 1), Day 2 and Day 3 for separate REM sleep groups.

	N	M	SD
Day 1 (same evening)			
Aversiveness of picture memories			
Group 1: no REM sleep	21	4.76	2.57
Group 2: REM sleep awakening	20	3.45	2.19
Group 3: REM sleep	28	3.89	2.47
Number of picture memories			
Group 1: no REM sleep	21	2.21	1.68
Group 2: REM sleep awakening	20	1.55	1.67
Group 3: REM sleep	28	1.89	1.86
Duration of picture memories			
Group 1: no REM sleep	21	4.48	3.37
Group 2: REM sleep awakening	20	4.63	5.14
Group 3: REM sleep	28	5.12	5.42
Day 2			
Aversiveness of picture memories			
Group 1: no REM sleep	21	2.67	2.13
Group 2: REM sleep awakening	20	2.05	1.70
Group 3: REM sleep	28	2.86	2.38
Number of picture memories			
Group 1: no REM sleep	21	1.02	1.12
Group 2: REM sleep awakening	20	.60	.82
Group 3: REM sleep	28	.89	1.31
Duration of picture memories			
Group 1: no REM sleep	21	1.48	1.81
Group 2: REM sleep awakening	20	1.20	1.82
Group 3: REM sleep	28	2.46	4.27
Day 3			
Aversiveness of picture memories			
Group 1: no REM sleep	21	2.71	2.08
Group 2: REM sleep awakening	19	1.47	.91
Group 3: REM sleep	28	1.54	1.26
Number of picture memories			
Group 1: no REM sleep	21	.93	.95
Group 2: REM sleep awakening	19	.47	.84
Group 3: REM sleep	28	.25	.52
Duration of picture memories			
Group 1: no REM sleep	21	1.36	1.67
Group 2: REM sleep awakening	19	.52	1.30
Group 3: REM sleep	28	.64	1.59

Scale 0– 10 for all variables.

pictures directly after the nap (in comparison to participants who did not enter REM sleep). This is in line with one of our own studies where we used a high-intensity, negative emotional film as well as responses to film reminders after a full night of sleep (Werner et al., 2015). In this study, the aversiveness of the film reminders (i.e., facial corrugator muscle activity as well as arousal and negative valence ratings) also showed an overall decrease, however longer REM duration was associated with less decrease in aversiveness (facial corrugator muscle activity and arousal, but not negative valence ratings). Thus overall, longer REM duration was again linked with less decreased emotional responding. Which pattern of results emerges, as well as how fast more long-term, attenuated emotional responses might be achieved, may also depend on factors such as stimulus intensity or type of sleep study design (nap, whole night, or sleep deprivation).

The overall time course of emotional processing in the present study might also be related to the chosen measurements of emotional responses. In real life, emotionally distressing events are often experienced only once and their processing solely relies on memories of the respective event. Thus, the occurrence or absence of spontaneous memories represents an ecologically valid and naturalistic indicator of emotional processing. However, it is possible – and important to keep in mind – that frequently repeated presentation of the same emotional stimuli (as done in other studies) for the assessment of long-term emotional processing trajectory might lead to different results. For example, possibly due to habituation (Rankin et al., 2009) or reconsolidation interference effects (Scully, Napper, & Hupbach, 2017), repeated presentation of emotional stimuli might change the spontaneous course of long-term, uninterrupted emotional processing. Furthermore, it has also been suggested that the use of subjective versus objective measures of emotional responses (Bolinger, Born, & Zinke, 2018) as well as the ambiguity of emotional stimuli (Lerner et al., 2016) may differentially influence the link between sleep and emotional processing.

Some recent studies suggest that also non-REM sleep stages may play a role in emotional processing. For example, Cairney, Durrant, Power, and Lewis (2015) showed that slow wave sleep predicted better memory for negative pictures. However, the effects of non-REM sleep are less clear and seem to be specifically related to declarative components of emotional memory (e.g., Kaestner, Wixted, & Mednick, 2013; Kaida, Niki, & Born, 2015).

Clinical implications

Clarifying the role of REM sleep in emotional processing assessed by more long-term spontaneous memory recall in healthy individuals also has important clinical implications. Involuntary memories of aversive material can be seen as an analogue measure of intrusive trauma memories, especially for posttraumatic stress disorder (PTSD), and may help studying vulnerability markers (Holmes & Bourne, 2008). For example, it has been suggested that early reexperiencing of a traumatic event (indicated by intrusive trauma memories) may predict later PTSD as well as other psychological disorders (Bryant, Creamer, O'Donnell, Silove, & McFarlane, 2012; O'Donnell, Elliott, Lau, & Creamer, 2007). Therefore, understanding the general link between REM sleep and emotional processing is fundamental for shedding light on the question how REM sleep abnormalities in mental disorders may contribute to the insufficient processing of distressing events.

In PTSD, sleep disorders are highly prevalent and often exacerbate symptom severity, with up to 70% of patients reporting nightmares and up to 90% suffering from insomnia symptoms (e.g., Harvey, Jones, & Schmidt, 2003; Lamarche & De Koninck, 2007; Ohayon & Shapiro, 2000). Studies assessing sleep objectively in PTSD patients show mixed results, but indicate a high prevalence of REM sleep abnormalities and fragmentation in this patient group (i.e., shorter REM latency, higher REM density, more REM-to-wake or N1 transitions; for review see Baglioni et al., 2016; Kobayashi, Boarts, & Delahanty, 2007; Spoormaker & Montgomery, 2008). Notably, the link between REM sleep and intrusive memories – although clinically extremely relevant – is still poorly understood. So far, the limited set of existing studies indicates that especially for individuals who develop PTSD, sleep and REM sleep disturbances are already prevalent in the early aftermath of the traumatic event and tend to persist (Mellman & Hipolito, 2006). In turn, Mellman, Pigeon, Nowell, and Nolan (2007) further showed a link between higher duration of continuous (i.e., not fragmented) REM sleep within one month post-trauma and lower PTSD symptom severity two months later. This is in line with our results showing a link between longer REM sleep duration and decreased intrusive memories (as one specific PTSD symptom). Although our results have implications for this clinical question, it still remains to be tested if stronger, traumatic life events would evoke the same pattern of emotional responding in relation to REM sleep.

Interestingly, three recent studies using an analogue trauma film paradigm revealed results that can be interpreted in line with our findings. These studies compared a sleep versus wake group and – at first – seem to indicate conflicting results. On the one hand and in line with our results, one study showed a reduced number and less stressful intrusive memories after sleep compared to wakefulness (daytime wakefulness as well as sleep deprivation; Kleim, Wysokowsky, Schmid, Seifritz, & Rasch, 2016). On the other hand, the two other studies showed a higher number of intrusive memories after sleep versus sleep deprivation (Porcheret, Holmes, Goodwin, Foster, & Wulff, 2015; Porcheret et al., 2019). However, the protective effect of sleep deprivation in the studies by Porcheret et al. (2015); Porcheret et al. (2019)) occurred within one or two days following analog trauma exposure, whereas the protective effect of sleep in the study by Kleim et al. (2016) occurred during the following week. Similar to our findings, the latter study even described (non-significantly) higher affective distress in the sleep group on the first day of the experiment, and that this group reported significantly fewer intrusions during the subsequent days (i.e., on day 3, 6, and 7 after the analogue trauma). Porcheret et al. (2019) also described reduced intrusive memories in the sleep group (compared to sleep deprivation) on the second day. Hence, these studies together again support the idea that sleep leads to more short-term increased emotional responses (higher number of intrusive memories) as well as more *long-term* decreased intrusive memories after analog traumatic experiences. However, the specific role of REM sleep parameters in these studies remains unknown.

Limitations and future research

Some limitations have to be considered when interpreting the current findings. First, we chose to not show the original aversive stimuli (pictures) again during long-term assessments to reduce habitation and at the same time assess – in line with other studies – the naturalistic and spontaneous trajectory of emotional processing. Therefore, our measures of short- and long-term emotional responses were not identical, might rely on different memory systems, and are therefore not directly comparable. However, these results are in line with other studies using only intrusive memories as emotional responses. They showed increased intrusive memories on the first two days after an analog traumatic experience (Kleim et al., 2016; Porcheret et al., 2015) as well as reduced intrusive memories after three days (Kleim et al., 2016). Second, we only measured (REM) sleep during the nap, but not during the following nights after the experiment. These nights may also play a role in further processing of emotional memories and should be taken into account in future studies. Third, our correlational results are based on all participants including the no REM group and individuals who did not experience intrusive memories; additionally, we did not correct our correlational analyses for multiple comparisons. Fourth, our sample included only young women in order to reduce possible sex- and age-related sources of variance regarding sleep as well as emotional responses (Bianchin & Angrilli, 2012; Bradley, Codispoti, Sabatinelli, & Lang, 2001; Wrase et al., 2003). This might, however, lead to reduced generalizability of the present results.

Conclusion

In conclusion, this study extends prior literature in providing preliminary evidence for the specific role of REM sleep in emotional processing. The data indicates that REM sleep is linked to increased emotional reactivity directly after sleep, but to reduced aversiveness, number, and duration of spontanous picture memories after two days. From an overall perspective, REM sleep therefore seems to activate emotional processing during the first sleep period which might lead to preserved or even enhanced emotional responses in the short-term. However, this initial, REM sleep accentuated activation may facilitate continuing emotional processing, subsequently leading to attenuated intrusive memories, possibly promoting mental health in the long run.

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