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FULL-LENGTH REPORT

Pre- to postsleep change in psychophysiological reactivity to emotional films: Late-night REM sleep is associated with attenuated emotional processing

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Abstract

Rapid eye movement (REM) sleep has been postulated to facilitate emotional processing of negative stimuli. However, empirical evidence is mixed and primarily based on self-report data and picture-viewing studies. This study used a full-length aversive film to elicit intense emotion on one evening, and an emotionally neutral control film on another evening while psychophysiological and experiential responses were measured. Subsequent sleep was monitored polysomnographically, and specific film scenes were presented again on the next morning. Correlation analyses revealed that participants with longer late-night REM sleep after the aversive film showed higher increase of electrodermal reactivity and less reduction of facial corrugator muscle reactivity to negative film scenes on the next morning. This indicates that REM sleep may be associated with attenuated emotional processing of prolonged and intense emotional stimuli from pre- to postsleep.

Descriptors: Emotion, Memory, Rapid eye movement, Electrodermal activity, Electromyography, Polysomnography

Sleep not only powerfully supports cognitive functions such as memory encoding and consolidation (Diekelmann, Wilhelm, & Born, 2009) but also plays an important role in affect regulation (e.g., Vandekerckhove & Cluydts, 2010). A sleep-related decrease in reactivity to an emotional stimulus, which can be conceptualized as sleep-related emotional processing, is crucial for everyday life functioning in healthy individuals (Repetti, Taylor, & Seeman, 2002; Silk, Steinberg, & Morris, 2003) and may enhance extinction of phobic anxiety in psychotherapy (Kleim et al., 2013; Pace-Schott, Verga, Bennett, & Spencer, 2012). On the other hand, diminished or dysfunctional sleep-related emotional processing after an aversive event may put individuals at risk for mental disorders, including posttraumatic stress disorder and depression (e.g., Edge, 2010; Germain, 2013).

Recent empirical work has led to the formulation of the sleep to forget, sleep to remember (SFSR) theory (Walker, 2009, 2010; Walker & Van der Helm, 2009), which links rapid eye movement (REM) sleep with sleep-related emotional processing. Specifically, during multiple phases of REM sleep, the declarative core of an emotional memory is strengthened (i.e., better remembered), whereas the "affective tone" of this memory (operationalized by reactivity to any reminder of the emotional event or stimulus) is attenuated as consequence of successful emotional processing (i.e., in part forgotten). But why is REM sleep particularly important for this decoupling process? As reviewed by Walker (2009, 2010; Walker & Van der Helm, 2009), considerable overlap exists between neural networks and neurotransmitter systems activated by emotional stimuli during wakefulness and REM sleep. It has been suggested that REM sleep thus provides an ideal situation for the reactivation and neural integration of emotional events (Cahill, 2000; McGaugh, 2004). REM sleep is associated with increased activity in the hippocampus and amygdala (Maquet et al., 1996), and involves dominant theta oscillations and a minimal amount of aminergic neurotransmission (Buzsaki, 2002; Pace-Schott & Hobson, 2002). Together, this may facilitate the processing of emotional experiences by offering emotion- and memory-relevant networks

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during REM sleep in the absence of aminergic neurotransmitters related to stress activation (Sullivan, Coplan, Kent, & Gorman, 1999). Two central predictions for the processing of emotional events derive from this model: reactivity to specific negative emotional stimuli should decrease after REM sleep, and the extent to which this reactivity is reduced should be proportional to the amount of REM sleep.

An alternative, still rather tentative account has recently emerged, which is in stark contrast to the SFSR theory, predicting a negative relationship between REM sleep and emotional processing. This account relates REM sleep to the consolidation of emotional salience (e.g., Baran, Pace-Schott, Ericson, & Spencer, 2012; Pace-Schott et al., 2011). It suggests that especially REM sleep—as a very active brain state—may reinforce emotional salience by consolidating neuroplastic changes related to the viewing of negative stimuli. This may consequently interfere with habituation to these stimuli, resulting in less emotional processing (i.e., less decrease in or even enhanced emotional reactivity from pre- to postsleep). But what is the evidence for the SFSR theory or the emotional salience consolidation (ESC) account?

REM Duration and Emotional Processing

A number of studies have investigated the association between REM duration and emotional processing (see Table 1). The general approach has been either to manipulate the amount of (REM) sleep between participants and measure differences in emotional processing between groups, or to correlate REM duration with measures of emotional processing. For example, one study presented images of emotional facial expressions before and after a nap in one group (with post hoc assignment into participants with and without REM sleep) and before and after wakefulness in a second group (Gujar, McDonald, Nishida, & Walker, 2011). A positive association of REM duration with emotional processing was found: only the REM group showed decreased emotional reactivity (i.e., lowered intensity ratings) to fearful expressions after sleep. Similarly, a study using negative and positive valence pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) in a REM deprivation design (REM-D; participants were awakened when REM sleep was detected online) found increased emotional reactivity after REM-D but no change after the control condition (with awakenings in non-REM sleep; Rosales-Lagarde et al., 2012). In line with these picture-based studies, an earlier study using film clips found elevated anxiety ratings in REM sleep-deprived compared to nondeprived participants (Greenberg, Pillard, & Pearlman, 1972; in Table 1, all studies showing a positive association between REM sleep and emotional processing are shaded in gray). Together, these studies support the SFSR theory by showing decreased emotional reactivity after REM sleep, or increased emotional reactivity after REM deprivation.

On the other hand, several studies found a negative association between REM sleep and emotional processing; that is, more REM sleep was associated with attenuated decrease in emotional reactivity from pre- to postsleep (cf. studies not shaded in gray in Table 1). These studies are taken by the authors to support their ESC account, that is, in which REM sleep plays an interfering role in the habituation to negative stimuli, due to the consolidation of emotional salience. For example, a recent study presented negative and neutral IAPS pictures before and after a full night of sleep or daytime wakefulness; the change of emotional reactivity in the sleep group was then correlated with REM sleep duration (Baran et al., 2012). It found that more late-night REM sleep (in the third quarter of the night) correlated with less decrease in self-reported emotional reactivity (i.e., negative valence ratings) to the negative pictures. Similarly, a nap study also reported a negative association between REM sleep and attenuated decrease in emotional reactivity measured by electrodermal activity (Pace-Schott et al., 2011).

In summary, these studies—either supporting the SFSR theory or the opposing ESC account—revealed a remarkably mixed evidence pattern regarding the role of REM sleep duration in emotional processing.

Aside from the researchers favoring different theoretical assumptions, these contrary findings are difficult to reconcile. They cannot easily be attributed to specific sleep research methodologies, since both the studies showing a negative relationship and the studies showing a positive relationship used a variety of sleep designs (e.g., whole nights, naps during the day, REM sleep deprivation, or comparisons between early- and late-night sleep, see Table 1). However, an interesting point is that all reported studies (except Greenberg et al., 1972) have stimulated emotional processing with overall presentation durations of only a few minutes (see Table 1). The Greenberg et al. study used a film of 8-min duration, but its results may be unreliable due to its small sample size (group *N*s between 5 and 9). Overall, the mixed findings may be a consequence of the relatively short-duration emotional stimulation used in previous studies, which constitutes a weak test of the importance of REM sleep in emotional processing considering that individuals may experience emotional episodes of much greater magnitude in daily life.

To overcome some of the limitations of short-duration emotional stimulation in emotion research, mainly with static pictures, the alternative approach with emotional films has gained prominence. Emotional films have a high potency for eliciting emotional responses across different domains (psychophysiology, self-report, and overt behavior) and have relatively high ecological validity (Gross & Levenson, 1995; Rottenberg, Ray, & Gross, 2007). They are capable of creating realistic memory contents through dynamic visual and auditory sequences that generate a vivid narrative. Consequently, they represent an interesting model to test whether and how REM sleep alters emotional reactivity. Until now, none of the investigations regarding REM sleep and emotional processing have used an intense and prolonged aversive stimulation before sleep, which can optimally be implemented by full-length aversive films. This should increase the "dosage" of presleep emotion load and thus optimally probe REM sleep-related emotional processing mechanisms.

Effects of Presleep Emotional Activation on REM Sleep

An interesting logical deduction from the SFSR theory is that REM sleep should be particularly stimulated (and thus REM sleep duration prolonged) during the night after an intensely emotional event to promote emotional processing of this event (whereas the ESC account has no clear prediction on this). Several earlier studies investigated effects of emotional or stressful films on subsequent sleep (for review, see Kim & Dimsdale, 2007). Cluydts and Visser (1980), for example, presented to participants a short surgery film clip before sleep, which induces emotions of fear and disgust. However, they found no overall differences in subsequent sleep architecture including REM sleep duration, in comparison to the night after a neutral film. Other research groups used similar film emotion-induction designs, but changes due to this stimulation only emerged for more qualitative REM sleep parameters like awakenings from REM sleep, REM density (i.e., frequency of eye

Table 1. *Overview of Studies Evaluating Sleep-Related Emotional Processing from Pre- to Postsleep*

Study	Sleep design, REM duration	Emotional stimuli	Overall duration of negative stimuli	Emotion reactivity measures	Associations of REM with emotional processing
Greenberg et al. (1972)	REM-D vs. NREM-D vs. control (no awakenings); REM-D: REM = 7.0–19.0 min; NREM-D & control: REM = 53.0–97.0 min	Autopsy film fragment	8 min	Self-report: POMS scales; physiological: finger sweat, heart/respiration rates, skin potential	REM-D group (less REM sleep): less decrease of anxiety (in the POMS)
Wagner et al. (2002)	Early vs. late sleep (3 h); early sleep: REM = 17.5 min; late sleep: REM = 64.5 min	50 negative & 14 positive IAPS pictures	250 s	Self-report: arousal & valence	Late REM group (more REM sleep): increased negative valence
Lara-Carrasco et al. (2009)	REM-D vs. REM control; REM-D: REM = 52.8 min; REM control: REM = 95.2 min	36 negative & 36 neutral IAPS pictures	216 s	Self-report: arousal & valence; behavior & physiology recorded but not reported	REM control group (more REM sleep): less decrease of arousal
Gujar et al. (2011)	Nap vs. no-nap (1.5 h); Nap: mean REM = 10.2 min, post hoc assignment into REM vs. no REM groups	Emotional face recognition task (fearful, angry, sad, happy faces; 10 for each category)	90 s	Self-report: emotional intensity	REM group: decreased intensity of fearful expressions and increased intensity of happy expressions
Pace-Schott et al. (2011)	Nap vs. no-nap (2 h); Nap: mean REM = 17.6 min, post hoc assignment into REM vs. no REM groups	6 negative & 6 neutral IAPS pictures (5×)	120 s	Self-report: arousal & valence; behavior: cEMG; physiology: SCR, HRD	REM group: less decrease of SCR
Baran et al. (2012)	Full night vs. day of wakefulness; Full night: REM = 95.5 min	90 negative & 90 neutral IAPS pictures	120 s	Self-report: arousal & valence	Full night group: less decrease of negative valence & arousal; negative correlation between REM3 and decrease of negative valence
Rosales-Lagarde et al. (2012)	REM-D vs. NREM-D; REM-D: REM = 4.0 min; NREM-D: REM = 20.8 min	40 negative & 20 positive IAPS pictures	28 s	Self-report: number of high vs. low emotional reactivity trials; behavior: RT; physiology: fMRI	REM-D group (less REM sleep): increased emotional reactivity (self-report & physiological)

Note. Studies shaded in gray support the hypothesis of a positive association between REM sleep duration and emotional processing; the other studies support a negative association between REM sleep duration and emotional processing. REM = rapid eye movement sleep; REM-D = REM sleep deprivation (by awakenings during REM); NREM-D = non-REM sleep deprivation (by awakenings during non-REM); POMS = Profile of Mood States Questionnaire (McNair, Lorr, & Droppleman, 1971); IAPS = International Affective Picture System; cEMG = corrugator muscle electromyogram; SCR = skin conductance response; HRD = heart rate deceleration; REM3 = REM sleep in the third quarter of the night; RT = reaction time.

movements), or REM latency and not for overall REM duration (Baekeland, Koulack, & Lasky, 1968; Goodenough, Witkin, Koulack, & Cohen, 1975; Lauer, Riemann, Lund, & Berger, 1987). A recent study using 10-min films even showed the opposite result: the increase in REM duration from the first to the second half of the night was reduced after an aversive film (Talamini, Bringmann, de Boer, & Hofman, 2013). However, since these studies (except Lauer et al., 1987) did not use full-length films of high emotional intensity, these results cannot be considered evidence disproving the possibility that strong emotional events may alter REM duration in a direction consistent with the SFSR theory. The only study using an intensely emotional full-length film (90 min) was unfortunately not designed to measure REM duration since participants were awakened during REM sleep to elicit dream reports (Lauer et al., 1987).

The Present Study

The aim of the present study was to expand previous research on REM sleep and emotional processing to the realm of more naturalistic and intense emotional stimuli while focusing on night sleep and keeping sleep relatively undisturbed, in contrast to the various studies that had used sleep deprivation, nap, or other sleep designs. Participants were shown an emotionally highly aversive full-length film, went to bed, and watched specific scenes of the film again on the next morning. The design included negative and neutral scenes within the aversive film as well as a completely neutral control film (on another night). Pre- and postsleep emotional reactivity to the same film scenes were compared to assess to what degree naturalistic REM sleep is related to changes in emotional reactivity, which would point to a role of REM sleep in emotional processing—either in line with the SFSR theory (i.e., REM support in emotional processing) or the opposing ESC account (i.e., REM interference in emotional processing). The current study focused on psychophysiological measurements for quantifying changes of emotional reactivity from pre- to postsleep. Psychophysiological variables are well-validated measures of emotional reactivity and are in some respects superior to self-report data because they are less susceptible to judgment heuristics and biases (e.g., Wilhelm & Roth, 2001). Specifically, we measured electrodermal activity (skin conductance level, SCL) as an often used and well-validated objective index of sympathetic nervous system arousal associated with threatening stimuli (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Wilhelm & Roth, 1998). We measured facial electromyography (EMG) over the frowning muscle (musculus corrugator supercilii; cEMG) as well-validated objective index of valence-specific negative affect (Bradley, Codispoti, Sabatinelli, & Lang, 2001), which has been shown to be responsive to intracerebral stimulation of the amygdala (Lanteaume et al., 2007). Surprisingly, to our knowledge only one study has used psychophysiological measures to operationalize REM-related changes in emotional processing (Pace-Schott et al., 2011, see Table 1).

We chose an experimental design that allowed measuring psychophysiological reactions to exactly the same film scenes within the whole emotional film before sleep, and on the subsequent viewing of these scenes on the next morning. Regarding the REM-related change in emotional reactivity from pre- to postsleep, the SFSR theory would predict a positive relationship of the amount of REM sleep with emotional processing, that is, a stronger decrease in psychophysiological emotional reactivity. However, the ESC account would predict a negative relationship between the amount of REM sleep and emotional processing. Given these opposing views and predictions, our study was designed to shed more light on this controversial topic by enhancing the intensity of the emotional stimulus. Since our study design is most closely related to especially two studies supporting the ESC account assuming REM interference in emotional processing, we tentatively refer to these studies to derive directional hypotheses: Baran et al. (2012) also used an undisturbed full night with measurements of self-reported valence and arousal before and after sleep and correlated these measurements with REM sleep duration. They found a negative association between longer REM sleep duration in the third quarter of the night and emotional processing (i.e., pre- to postsleep changes in negative valence ratings to IAPS pictures). The study by Pace-Schott et al. (2011) is the only study on this topic using psychophysiological measurements (electrodermal and facial muscle activity to IAPS pictures) to index emotional reactivity and found less decrease of electrodermal response in the REM compared to the non-REM group (in a nap design). Based on that, we expected a negative relationship between REM sleep and emotional processing after the intense emotional film. Thus, higher amount of REM sleep should be correlated with attenuated decrease in psychophysiological emotional reactivity (SCL, cEMG) from pre- to postsleep in between-subject analyses, particularly in the second—REM rich—part of the night (i.e., in the third and fourth quarters of the night; Baran et al., 2012; Carskadon & Dement, 2005). We expected this relationship particularly for the negative film scenes, but due to associative processes during the whole film viewing this can be expected for neutral scenes as well (e.g., Wegerer, Blechert, Kerschbaum, & Wilhelm, 2013). However, we did not expect such a relationship for the scenes of the neutral control film.

In addition to psychophysiological measures, we included self-reported valence and arousal ratings as secondary measures of emotional reactivity. In addition to REM duration, we explored other REM-related sleep parameters (e.g., REM latency, awakenings, and arousal index in REM sleep), because more qualitative characteristics of REM sleep might be important as well. Additionally, within-participant analyses explored whether the aversive film would impact subsequent REM sleep more than the neutral film, shown prior to another test night. The precise timing and kind of change in REM sleep is difficult to predict based on the mixed results in previous studies. We primarily focused on REM sleep duration; however, we also investigated qualitative REM-related variables (e.g., REM latency, awakenings, and arousals in REM sleep) as most promising candidates for sleep alterations after the aversive film (Baekeland et al., 1968; Goodenough et al., 1975; Lauer et al., 1987; Talamini et al., 2013).

Method

Participants

Participants were 29 healthy female undergraduates at the University of Salzburg aged between 19 and 31 years, M (SD) = 23.55 (3.30). All participants were non- or only occasional smokers with no history of mental, neurological, or sleep disorders. To assure regular sleep cycles, participants had to complete daily sleep diaries during the whole study period of 11 days. Comparing self-reported total sleep time (TST) and sleep latency (SL) for the night before the aversive and neutral films, respectively, we found no significant differences, ts(28) < .66, ps > .513, ds < .24. Participants reported an average of 8.07 h (SD = 1.13) for TST and of 14.38 min (SD = 15.97) for SL for the night before the aversive film, and an average of 7.94 h (SD = 1.46) for TST and of 12.07 min

(*SD* = 11.21) for SL for the night before the neutral film. Concerning general subjective quality of sleep during the last month, we accepted values up to 7 in the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), extending the typically used cutoff of 5. Three participants had a PSQI score of 6 and one of 7, but scores up to 7 can still be considered within a normal range of sleep quality in female student populations (Pranada, 2005). The study was approved by the local ethics committee. Participants signed written informed consent before the study and were compensated with course credit or payment of 100 Euro after the last session.

Materials

We chose two different films for stimuli: the aversive film was the *Antichrist* (Lars von Trier, Director, 2009, 104 min) and the neutral film was the documentary *Living in a Monastery* (SpiegelTV, 94 min, http://www.spiegel.tv/filme/kloster-leben-verliebt-gott/). The *Antichrist* tells the story of a couple who, after the tragic death of their child and a subsequent mourning and depression of the mother, retreat to a cabin in the forest. There, the man—a psychotherapist—is trying to treat his wife, but is increasingly confronted with bizarre behavior of his wife and experiences strange visions himself. The film has a gloomy atmosphere and contains several violent and disturbing (including sexual) scenes, symbols, and metaphysical elements. We chose this film because (a) it has the potential to create a wide range of strong emotions and emotional memories, (b) it is interesting and relevant to psychology undergraduates who are learning about psychopathology and psychotherapy in their courses, and (c) it is acceptable from an ethical point of view because it has received several international awards. The neutral documentary *Living in a Monastery* describes the daily routine of nuns in a convent without any obvious positive or negative emotional content.

For assessment of emotional reactivity, 12 scenes lasting 10–15 s were chosen from each film. For the aversive film, half of the scenes were negative in emotional valence and the other half were neutral. For the neutral film, all 12 scenes were of neutral valence. The film scenes were selected and validated in a pilot study with 11 participants who provided valence and arousal ratings for all scenes.

Procedure

The study comprised a total of four visits to the Clinical Stress and Emotion Lab of the University of Salzburg, separated by 1 to 4 days. The whole study period consisted of 11 days: the entrance examination, which took place at least 3 days prior to the first night, the 3 nights in the lab each separated by 1 night, and a final 3 days of sleep assessment by sleep diaries (the sleep diary was completed during the whole study period). The first night in the lab (i.e., night 4 within the whole study period) was used for adaptation and screening purposes to detect sleep disturbances like sleep apnea, insomnia, and periodic leg movements, which did not occur in any of the participants. Participants came to the lab around 9 pm and completed several questionnaires including assessment of sleep quality (PSQI), trait anxiety (State-Trait Anxiety Inventory, STAI; German version by Laux, Glanzmann, Schaffner, & Spielberger, 1981), depressive symptoms (General Depression Scale, ADS-L; German version by Hautzinge & Bailer, 1993), general medical and psychological health condition, as well as general television consumption. After electrodes were attached, they went to bed and were woken up after 8 h time in bed.

The second and third nights in the laboratory (i.e., nights 6 and 8 within the whole study period) were conducted as experimental nights with presentation of the aversive or neutral film (counterbalanced across participants), with all participants seeing both films. On both experimental nights, participants were seated on a chair placed 40 inches in front of a 24-inch full HD monitor. Electrodes and sensors for measuring sleep and emotional responses were attached. While participants watched the film, psychophysiological measurements were recorded, and immediately after the film participants provided self-report ratings on different aspects of the film viewing (presleep condition). Electrodes for measuring emotional responses (SCL, cEMG) were removed, and participants were asked to go to bed, which was in the same room. On the following morning (postsleep condition), participants were woken up after 8 h time in bed by a knock at the door. After freshening up in the bathroom, the electrodes for measuring emotional responses were attached again. The 12 selected scenes from the film shown on the previous evening were then presented in randomized order after a minimum of 30 min after awakening to prevent possible influences of sleep inertia on mood and emotional reactivity (Tassi & Muzet, 2000); participants provided self-report ratings for each film scene. A physiological baseline of 2-min duration was obtained before the start of the films in the evening and the film scenes in the morning. Stimulus presentation of the film (scenes) was controlled by E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA).

Responses to Films: Psychophysiological and Self-Report Measurements

Wake psychophysiological measurements of emotional reactivity to the film scenes were recorded using a 32-channel amplifier (Twente Medical Systems International [TMSi], EJ Oldenzaal, The Netherlands) and the recording software package Polybench 1.22 (TMSi) using a sampling rate of 1024 Hz. The amplifier includes customized channels for measuring SCL and cEMG. The recordings for emotional responses contained measurements of SCL obtained by applying a constant voltage (0.5 V) between digit 3 and 4 of the nondominant hand, using an isolated electrodermal amplifier module supplied by Becker Meditec (Karlsruhe, Germany), Ag/AgCl electrodes with 1-cm inner diameter, and isotonic electrode paste. Additionally, cEMG (above the left musculus corrugator supercilii) was recorded using a pair of sintered Ag/AgCl electrodes filled with EEG gel and attached above the participant's left eyebrow with adhesive rings. Signals were analyzed using the software ANSLAB 2.51 (Wilhelm & Peyk, 2005). The electrodermal signal was low-pass filtered (1 Hz), and SCL was computed as the average for each experimental period of interest (in μS). The EMG signal was processed with a high-pass (28 Hz) and a notch filter (50 Hz), and cEMG was also computed as the average for each experimental period of interest (in μV). In the context of this study, SCL indicates sympathetic arousal and cEMG indicates facially expressed negative emotional valence.

Self-report measurements were conducted by having participants make ratings on the computer screen (rating scales programmed in E-Prime 2.0) for arousal and valence using an adaptation of the self-assessment manikin scales (Bradley & Lang, 1994). Immediately after watching the full-length film, participants were asked to make a cursor input on visual analog scales (0 = *not at all* to 100 = *extremely*) regarding how aroused and how

unpleasant they felt regarding the overall film. These ratings were also asked in the morning, but after each film scene separately.

Polysomnographic Night Recordings

Measurements taken during the nights contained full polysomnography (PSG). The EEG was recorded using a separate 32-channel amplifier (TMSi) attached next to the bed and the software package Polybench 1.22 (TMSi). Signals were digitized with a 256 Hz sampling rate. During recording, 0.5 Hz low-pass and 70 Hz high-pass filters were applied. 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 rereferenced to the two additional electrodes on the contralateral mastoids (A1, A2). Furthermore, four electrooculogram (EOG) channels, two EMG (left and right chin), one bipolar electrocardiogram (ECG), two bipolar respiratory (thorax and abdomen), one oxygen saturation, and one finger pulse plethysmography channel were recorded. In the screening/adaptation night, two additional bipolar EMG channels (musculus tibialis on both sides) and one additional respiratory channel (air flow) were recorded to be able to rule out different sleep disorders. Sleep recordings were scored semiautomatically (i.e., in two stages, computerized followed by manual scoring) by The Siesta Group in Vienna (Somnolyzer 24 × 7; cf. Anderer et al., 2004, 2005) according to standard criteria of the American Academy of Sleep Medicine (AASM; Iber, Ancoli-Israel, Chesson, & Quan, 2007).

Statistical Analysis

For analyses involving SCL and cEMG (for the aversive film), one participant had to be excluded because of missing data. For the manipulation check, overall reactivity to the films was quantified by subtracting averages of SCL and cEMG of the prefilm baselines from the whole film averages. In addition, the films were also compared by arousal and valence ratings conducted after the films. Reactivity to the aversive versus neutral films for these variables was compared by *t* tests. For analyses concerning changes in emotional reactivity from pre- to postsleep, the average of film scene values for SCL and cEMG were computed separately for negative and neutral scenes within the whole aversive film (and for the neutral scenes of the neutral film) in the evening. Prefilm baseline values were subtracted from these measures to obtain the emotional reactivity scores ΔSCL and ΔcEMG. This procedure was applied to the same negative and neutral film scenes presented on the next morning, using the baseline preceding these film scenes. Therefore, we were able to compare psychophysiological reactivity to exactly the same film scenes within the whole film and after sleep on the next morning. Finally, to obtain emotional processing scores, presleep ΔSCL and ΔcEMG reactivity scores were subtracted from postsleep ΔSCL and ΔcEMG reactivity scores. Change scores in emotional reactivity were also computed for self-report data. However, because we did not want to interrupt film viewing for the full-length film to maintain immersion and emotional intensity, only overall ratings for the film were available, but not separate ratings for the negative and neutral film segments. On the next morning, such separate ratings were obtained. To obtain approximate emotional processing scores, presleep arousal and valence ratings for the whole film were subtracted from postsleep average valence and arousal ratings for the neutral and negative film scenes. Because there was no full correspondence between the stimuli rated, we used self-report data only for supplementary analyses, not for hypothesis testing.

Emotional responses for the aversive film night were compared using repeated measures analyses of variance (ANOVAs) including the factor time (pre- vs. postsleep) and scene valence (negative vs. neutral film scenes) for psychophysiological variables ΔSCL and ΔcEMG with follow-up paired sample *t* tests. For self-reported emotional responses (arousal, valence), we could not differentiate between negative and neutral film scenes; therefore, we only used the factor time (pre- vs. postsleep). The same analyses—with only the factor time (pre- vs. postsleep)—were used to examine physiological (ΔSCL, ΔcEMG) and self-reported responses (arousal, valence) for the neutral film night. We used Pearson correlations to assess whether between-participant differences in late-night REM sleep were related to changes in emotional reactivity from pre- to postsleep. Following the approach of Baran et al. (2012), we focused specifically on REM sleep in the third and fourth quarters of the night (i.e., REM duration in minutes within the third and fourth quarters of the individual's total sleep time). We concentrated on late-night REM sleep because REM sleep is much more prominent in this part of the night compared to the first half of the night (Carskadon & Dement, 2005), enhancing signal-to-noise ratio for examining REM-related hypotheses. Furthermore, this is consistent with the previous literature since many studies only refer to amounts of late-night REM sleep, sometimes separately for the third and fourth quarters of the night (REM3, REM4; Baran et al., 2012; Groch, Wilhelm, Diekelmann, & Born, 2013; Wagner, Fischer, & Born, 2002; Wagner, Gais, & Born, 2001). In secondary, more explorative analyses, the relationships of emotional processing with further REM-related parameters like overall REM duration, REM latency (defined as time from falling asleep until the first REM period), awakenings in REM sleep, and arousal index in REM sleep (defined as number of arousals in REM sleep, i.e., sudden frequency shifts toward faster rhythms like theta, alpha, beta, but not spindle activity, that shortly interrupt sleep continuity for at least 3 s, divided by REM sleep time; Iber et al., 2007) were also computed.

Effects of presleep emotional activation on REM sleep were explored by comparing the aversive versus neutral film for our primary variables REM3 and REM4 (as well as combined REM sleep in the second half of the night) using paired sample *t* tests, and again for other REM-related sleep variables like total REM duration, REM latency, number of awakenings in REM sleep, and arousal index in REM sleep. Additionally, we examined the increase in total REM sleep duration from the first to the second half of the aversive night compared to the neutral night by following the approach of Talamini et al. (2013). We used repeated measures ANOVA including the factor night half (first vs. second half of the night) and film valence (aversive vs. neutral film).

The α level for primary statistical analyses was set to 0.05. For secondary analyses, α levels should not be interpreted confirmatively but are provided for descriptive purposes. We report effect sizes—Cohen's *d* for *t* tests, η^2 for ANOVAs, and Pearson's *r* for correlational analyses. Corresponding nonparametric methods were used when distributional assumptions for parametric tests were not met (Kolmogorov-Smirnoff test $< .05$). Two sleep variables of the aversive film night (awakenings in REM sleep, and arousal index in REM sleep) were not normally distributed; for these nonparametric Wilcoxon *U* tests or Spearman's rho correlations were used.

Table 2. *Means and Standard Deviations for Reactivity Measurements and Self-Reported Values for Aversive and Neutral Films*

	Presleep		Postsleep	
	Mean	*SD*	Mean	*SD*
Aversive film				
ΔSCL [μS]				
Negative scenes	0.32	1.56	0.91	0.80
Neutral scenes	−0.69	1.37	0.65	0.65
ΔcEMG [μV]				
Negative scenes	6.15	4.41	2.05	2.54
Neutral scenes	3.20	2.46	1.11	1.43
Arousal rating (0–100)	70.41	23.41	47.81	9.91
Negative valence rating (0–100)	76.00	17.60	60.77	13.15
Neutral film				
ΔSCL [μS]				
Neutral scenes	−1.24	1.24	0.36	0.48
ΔcEMG [μV]				
Neutral scenes	1.15	2.05	−0.06	1.37
Arousal rating (0–100)	10.66	13.51	10.48	11.74
Negative valence rating (0–100)	28.81	21.37	30.24	17.01

Note. ΔSCL, ΔcEMG = film scene values of skin conductance level (SCL) and facial electromyogram (cEMG) minus prefilm baselines; $N = 28$ for ΔSCL/ΔEMG; $N = 29$ for arousal and negative valence.

Results

Demographic and Psychometric Variables

Trait anxiety and depressive symptoms were in the normal range—trait anxiety: M (SD) = 35.21 (10.08) (Laux et al., 1981); depressive symptoms: M (SD) = 11.31 (7.76) (Hautzinger & Bailer, 1993). Participants reported television consumption on 4.71 days per week on average (SD = 1.93) with a total 11.86 h (SD = 8.75). On a Likert scale (1 = *never* to 5 = *always*) participants rated their consumption of comedies, love stories, series, or soap operas: median (range) = 3.00 (2.00–4.00) and horror, thriller, action movies: median (range) = 2.50 (2.00–3.00) at an intermediate level. None of our participants had previously seen the two employed films.

Full-Length Film Emotion Elicitation Manipulation Check

The aversive film evoked significantly higher emotional responses than the neutral film, both in psychophysiological and self-report measures, indicating robust and successful emotion elicitation. During both films, a reduction in SCL compared to the prefilm baseline was found (SCL, in μS, aversive film: M (SD) = -.44 (1.28); neutral film: M (SD) = -1.20 (1.21), $t(27) = 3.36$, $p = .002$, $d = .61$). This corresponds to the typical downward drift in SCL during long quiet sitting intervals (here, over a duration of about 90 min; note that several factors can be responsible for the observed drift: habituation to the laboratory and film viewing context, increasing circadian fatigue throughout the evening, increasing sweat reuptake by the skin, and change in electrode gel consistency; see Boucsein, 2012). Concerning facial cEMG, we found, as expected, an increase from prefilm baseline levels during both films (cEMG, in μV, aversive film: M (SD) = 3.34 (2.17); neutral film: M (SD) = 1.21 (2.05), $t(27) = 4.08$, $p < .001$, $d = 1.01$). The self-reported arousal ratings (scale 0–100) showed strong negative responses for the aversive film, M (SD) = 70.41 (23.41), compared to the neutral film, M (SD) = 10.66 (13.52), $t(28) = 11.40$, $p < .001$, $d = 3.13$; self-reported valence ratings (scale 0–100) revealed the same pattern (aversive film: M (SD) = 76.00 (17.60); neutral film: M (SD) = 28.81 (21.40); $t(28) = 9.17$, $p < .001$, $d = 2.41$).

Psychophysiological and Self-Reported Reactivity to Pre- and Postsleep Film Scenes

Table 2 depicts pre- and postsleep values for psychophysiological and self-reported emotional responses for the aversive and neutral film conditions, separated for negative and neutral film scenes only within the aversive film. Psychophysiological responses for the aversive film showed significant main effects of time (ΔSCL: $F(1,27) = 13.32$, $p = .001$, $\eta^2 = .33$; ΔcEMG: $F(1,27) = 31.58$, $p < .001$, $\eta^2 = .55$), scene valence (ΔSCL: $F(1,27) = 40.25$, $p < .001$, $\eta^2 = .60$; ΔcEMG: $F(1,27) = 23.34$, $p < .001$, $\eta^2 = .46$), and Time × Scene Valence interaction effects (ΔSCL: $F(1,27) = 22.27$, $p < .001$, $\eta^2 = .45$; ΔcEMG: $F(1,27) = 9.02$, $p = .006$, $\eta^2 = .25$). Post hoc testing indicated that psychophysiological emotional responses to negative film scenes for both ΔSCL and ΔcEMG were higher as compared to the neutral film scenes at all time points, ts(27) > 2.76, ps ≤ .010, ds > .36. Regarding ΔSCL, responses to both negative and neutral scenes significantly increased from the evening to the next morning (negative scenes: $t(27) = -2.07$, $p = .048$, $d = .48$; neutral scenes: $t(27) = -5.07$, $p < .001$, $d = 1.25$). This pattern was even stronger for the neutral compared to the negative scenes, $t(27) = -4.72$, $p < .001$, $d = .51$, comparing pre- to postsleep difference scores. For ΔcEMG, we found overall decreases from pre- to postsleep for negative, $t(27) = 5.30$, $p < .001$, $d = 1.14$, and neutral films scenes, $t(27) = 4.52$, $p < .001$, $d = 1.04$. A stronger decrease for negative scenes compared to neutral scenes was found, $t(27) = -3.00$, $p = .006$, $d = .59$. Regarding self-reported ratings, we did not distinguish between negative and neutral scenes (as described in Method section). Significant main effects of time, showing overall decreases from pre- to postsleep, could be found for arousal, $F(1,28) = 21.79$, $p < .001$, $\eta^2 = .45$, and valence ratings, $F(1,28) = 54.63$, $p < .001$, $\eta^2 = .67$.

Concerning the neutral film, psychophysiological emotional responses revealed a similar pattern as seen for the aversive film: ΔSCL significantly increased from pre- to postsleep, $F(1,28) = 47.71$, $p < .001$, $\eta^2 = .63$, whereas ΔcEMG significantly decreased, $F(1,28) = 7.08$, $p = .013$, $\eta^2 = .20$. Self-reported ratings of arousal and valence did not change from pre- to postsleep, Fs(1,28) < .27, ps > .605, η^2s < .01.

REM Duration and Pre- to Postsleep Change in Reactivity to Film Scenes

To investigate the relationship between late-night REM sleep duration and emotional processing (i.e., the change in ΔSCL and ΔcEMG for negative scenes of the aversive film from pre- to postsleep), we compared psychophysiological and self-reported reactivity to specific film scenes within the whole film and the same scenes on the next morning. Results indicate, on the one hand, more time in REM4 was correlated with a more pronounced increase of ΔSCL from pre- to postsleep, $r(26) = .41$, $p = .030$ (see Figure 1.a). On the other hand, more time in REM3 was correlated with attenuated decrease of ΔcEMG for negative scenes of the aversive film, $r(26) = .40$, $p = .036$ (see Figure 1.). Thus, both associations are indicating overall relative enhancement of

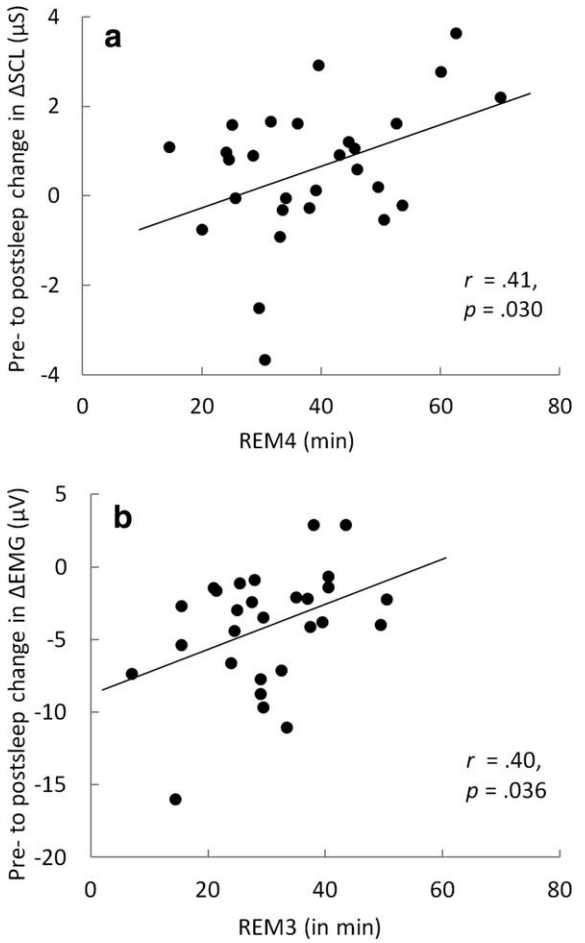

Figure 1.. Relationships between late-night REM sleep duration following the aversive full-length film and pre- to postsleep change of ΔSCL and ΔcEMG to negative film scenes. a: More REM sleep in the fourth quarter of the night (REM4) is associated with a relative enhancement of ΔSCL from evening to the next morning. b: More REM sleep in the third quarter of the night (REM3) is associated with attenuated decrease of ΔcEMG from evening to the next morning. Panels a and b indicate that individuals with longer late-night REM sleep show relatively enhanced psychophysiological reactivity from pre- to postsleep assessments, pointing to less effective emotional processing.

emotional reactivity from pre- to postsleep with higher late-night REM sleep duration. The correlation between REM4 sleep and change in ΔSCL remained significant after removing one outlier (i.e., 2.77 *SD*s below SCL mean: $r = .41$, $p = .032$). However, when removing an outlier in panel b (i.e., 2.91 *SD*s below cEMG mean), the correlation between REM3 and ΔcEMG was no longer significant, $r(26) = .29$, $p = .136$. Consistent with this general pattern of results, a corresponding correlation was found for higher REM4 duration and attenuated decrease of self-reported arousal from pre- to postsleep, however, only approaching significance, $r(27) = .35$, $p = .063$.[1] For late-night REM sleep (second half of the night), the pattern of results was similar to the REM3/REM4 correlations but only marginally significant (late-night REM and change in ΔSCL: $r(26) = .34$, $p = .079$; late-night REM and change in ΔcEMG: $r(26) = .33$, $p = .084$). For other REM-related parameters like total REM duration, REM latency, awakenings, and arousal index in REM sleep, no significant results could be found, $-.15 < rs(26) < .31$, $ps > .111$.

We also analyzed neutral scenes from the aversive film since they should have obtained some of the emotional impact of negative scenes by associative processes during the whole film viewing and thus be processed similarly during the night. In fact, the neutral scenes of the aversive film showed similar correlations as the negative film scenes. The pre- to postsleep change of ΔSCL to the neutral scenes showed a significant correlation with REM4, $r(26) = .38$, $p = .046$, and the change of ΔcEMG to the neutral scenes showed a significant correlation with REM3, $r(26) = .52$, $p = .004$. On the other hand, for neutral film scenes from the neutral full-length film, which can be considered a reasonable control condition, no correlations were found between REM3/4 duration (in the night after the neutral film) and pre- to postsleep change of emotional responses to these neutral film scenes, $-.14 < rs(27) < .10$, $ps > .470$.

Effects of Presleep Emotional Activation on REM Sleep

Additionally, we explored the influence of the aversive film on subsequent sleep, particularly on REM sleep duration and other REM-related variables (see Table 3). We performed three types of analyses: comparisons between the aversive and the neutral night, the increase in REM sleep from the first to the second half of the aversive versus the neutral night (according to Talamini et al., 2013), and further analyses comparing high- and low-responding participants. Although the aversive film elicited strong emotional responding, no significant results were found for any of these analyses. We did not find an effect of film type (aversive, neutral) on REM3 duration, REM4 duration, or on the combined REM duration in the second half of the night. Further REM-related sleep variables like total REM duration, REM latency, and awakenings in REM sleep also showed no significant differences. Only a tendency for a higher arousal index in REM sleep for the aversive night was found, $U = 1.89$, $p = .059$, $d = .38$.[2] No differences were found regarding the increase in REM sleep from the first to the second half of the night between the aversive and the neutral night, and high- versus low-responding participants also revealed no differences in any REM-related sleep parameters.

Discussion

The present study focused on the question to what degree REM sleep duration relates to changes of emotional reactivity to negative stimuli from pre- to postsleep, which can be conceptualized as REM-related emotional processing. In contrast to previous research examining this question, this study strived to optimize ecological validity by using an intensely emotional full-length film and by leaving participants' sleep undisturbed. Furthermore, in contrast to

1. Excluding the four participants with PSQI scores above 5, results were largely equivalent. The correlation between REM3 and pre- to postsleep change of ΔcEMG for negative film scenes remained significant, $r(26) = .42$, $p = .043$. The correlation between REM4 and pre- to postsleep change of ΔSCL for negative film scenes just failed significance, $r(26) = .36$, $p = .081$, whereas the correlation between REM4 and the change in arousal ratings reached significance, $r(27) = .49$, $p = .014$.

2. This pattern of results did not change, only the tendency for a higher arousal index in REM sleep after the aversive night did not survive exclusion of the four participants showing a PSQI above 5. No effects of film type (aversive vs. neutral) could be found for REM duration and other REM-related sleep variables, including the arousal index in REM sleep, $ts(28) < 1.26$, $ps > .209$, $ds < .32$.

Table 3. *Means and Standard Deviations of Polysomnographic Sleep Variables for Both Experimental Nights and Pairwise Comparisons*

	Aversive film night		Neutral film night	
	Mean	*SD*	Mean	*SD*
REM-related sleep variables				
Stage REM 3rd quarter (min)	30.09	10.31	31.17	11.67
Stage REM 4th quarter (min)	38.67	13.27	38.57	10.67
Stage REM 2nd half (min)	68.76	16.14	69.74	15.93
Stage REM (min)	102.00	20.76	101.64	20.17
REM latency (min)	74.50	18.94	76.38	24.19
Awakenings in REM[a] (number)	1.45	1.55	1.76	1.75
Arousal index REM[a] (number/REM)	8.96	10.11	6.89	6.61

Note. $N = 29$. All $ts/Us \leq 1.89$; all $ps \geq .059$; all $ds \leq .38$. REM = rapid eye movement.
[a]Wilcoxon tests were used (including U values instead of t).

many of the previous studies regarding this topic, we focused on psychophysiological emotion activation indices to make sure that results are not subject to self-report biases. Regarding the relationship of pre- to postsleep changes of emotional reactivity with REM sleep, our results do not support the SFSR theory, which postulates a facilitating effect of REM sleep on emotional processing, like some other studies (e.g., Gujar et al., 2011; Rosales-Lagarde et al., 2012; Van der Helm et al., 2011). Rather, in line with the ESC account and a different set of studies (e.g., Baran et al., 2012; Lara-Carrasco, Nielsen, Solomonova, Levrier, & Popova, 2009; Pace-Schott et al., 2011; Wagner et al., 2002), we found that more late-night REM sleep was associated with relatively enhanced electrodermal emotional reactivity and with attenuated decrease of corrugator muscle activity (objectively operationalized as psychophysiological change in reactivity to negative film scenes from pre- to postsleep).

The ESC account relates pre-to postsleep changes in emotional reactivity to the consolidation of emotional salience of negative stimuli (Baran et al., 2012; Pace-Schott et al., 2011). Researchers supporting this account propose that REM sleep in particular may play a role in consolidation processes of emotional salience for negative stimuli, interfering with emotional processing. In the study by Pace-Schott et al. (2011), occurrence of REM during a nap was associated with a reduced decrease in electrodermal responding to negative stimuli. The authors suggest that, because REM is a highly brain-activated state especially involving regions implicated in emotional processing, it may act to adaptively reinforce emotional salience and thereby reduce neuronal habituation and interfere with emotional processing. Although shown after one full night of sleep (not just including REM sleep) compared to daytime wakefulness, imaging studies support this by showing enhanced activity or stronger connectivity in response to negative emotional pictures in brain regions that are involved in emotional processing like the amygdala (Lewis, Cairney, Manning, & Critchley, 2011; Payne & Kensinger, 2011). One factor that may well play a role in such differential REM-based emotional processing is the intensity of emotion elicitation. Some studies with low intensity emotional stimuli might have primarily elicited reductions in responding from the first to the second presentation, which is thought to be due to the close matching of the repeated stimulus with its memory representation (Sokolov, 1963). For such low-intensity stimuli, REM may be effective in decoupling (and helping integrate and consolidate) the information content from the emotional component and subsequently leading to less reactivity, consistent with the SFSR theory. On the other hand, for high intensity stimuli before sleep, responses may be more likely to become sensitized; that is, responses may even increase in intensity with repeated presentation (Groves & Thompson, 1970; Rankin et al., 2009; Thompson & Spencer, 1966). REM sleep-related consolidation of emotional salience may well play a role in this process, as proposed by the ESC account.

In line with these considerations concerning stimulus intensity, we reviewed previous literature and found that studies with overall negative stimulation of less than 120 s typically showed a positive association between REM sleep and emotional processing, while studies with an overall stimulation of 120 s or longer typically showed a negative association (see Table 1). Our study clearly belongs to the second category. It may be that the full-length aversive film in the present study led to a particularly high emotional processing "load" due to its intense mix of different emotions and emotionally charged themes. Therefore, one could speculate that strong emotional stimulation might first reveal a pattern of increased emotional responding in the presence of more REM (i.e., an interfering role of REM sleep in emotional processing due to the consolidation of emotional salience) followed by a decrease in emotional responding in the presence of more REM on subsequent nights (i.e., a facilitating role of REM sleep in emotional processing due to complete decoupling of the informational and emotional content). Put differently, high intensity/duration stimuli might require more nights with sufficient REM sleep for emotional processing to be successful than low intensity/duration stimuli. All mentioned studies, as well as our study, only investigated the first night (or sleep period) after negative emotional stimulation, leaving the possibility that this period or night of sleep may not have been sufficient for effective emotional processing, particularly for more intense emotional stimuli. To answer this important open question, future studies might experimentally vary emotional stimulus intensity, for example, by varying negative valence and/or presentation duration of film scenes, and investigate the course of emotional reactivity to these scenes over several nights. Similar correlations between higher amounts of late-night REM sleep and change in emotional reactivity from pre- to postsleep (enhancement of ΔSCL with REM4, decrease of ΔcEMG with REM3) were found for the neutral film scenes of the aversive film as for its negative film scenes. As could be expected, emotional responses to negative film scenes were more pronounced, both in the evening and on the next morning. However, since the aversive film was presented as a whole in the evening without interruption, neutral film scenes were intermixed with negative film scenes. Therefore, negatively valenced associations were likely being attached to the neutral scenes, particularly since they included the same actors and other cues that served as reminders of the aversive scenes (for the conditioning of neutral stimuli to negative film scenes, see Wegerer et al., 2013). Less aversive parts of the film (e.g., scenes involving the actors in normal conversation) became predictors of more aversive scenes (involving these actors) by associative processes, and this association may even be strengthened by REM sleep (Menz et al., 2013). This may have resulted in a rather similar processing of neutral and negative film scenes of the aversive film during REM sleep. Interestingly, the correlation between REM3 and facial muscle activity for the neutral scenes appears to be even stronger than for the negative scenes. Emerging evidence suggests that sleep-related memory consolidation (at least for declarative aspects) is greater for weakly compared to strongly encoded associations (Diekelmann et al., 2009; Drosopoulos, Schulze, Fischer, &

Born, 2007). Although highly speculative at this point, our results suggest that this might also be the case for REM-related emotional memory consolidation and might have led to a stronger relation between REM sleep in the third quarter of the night and cEMG for the probably more weakly encoded neutral film scenes. On the other hand, no correlations were found between REM sleep after the neutral film and response change to the neutral scenes of this film, which serves as a control condition that does not include the possibility of such emotional carry-over effects.

Interestingly, our results point to specific effects for measurements of arousal (SCL and, as a trend, arousal ratings) with REM sleep in the fourth quarter of the night, and for corrugator muscle activity (cEMG, related to negative valence) with REM sleep in the third quarter of the night, for both the negative and neutral scenes within the aversive film. Arousal and valence constitute the two main axes for a dimensional framework of emotion ("affective space," Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang, Bradley, & Cuthbert, 1990), and they may influence memory consolidation of emotional stimuli via distinct pathways. For example, emotional memory for arousing information has been found to depend more on an amygdalar-hippocampal network, whereas negatively valenced but not very arousing information depends more on a prefrontal-hippocampal network (Kensinger, 2004; Kensinger & Corkin, 2003, 2004). Although these studies used other stimulus types (e.g., emotional words), it is plausible that arousal and valence aspects in pictures and films may also at least in part be consolidated via distinct brain networks, and these may become differentially activated in different segments of the night. REM sleep is characterized by a relative activation (compared to wakefulness) in many brain regions, and especially in the amygdala, whereas prefrontal regions show relative deactivation (Maquet et al., 1996; Nofzinger, Mintun, Wiseman, Kupfer, & Moore, 1997). One may consider that the amygdalar-hippocampal network may be especially salient in the last quarter of the night characterized by particularly high REM phase density. Although this explanation must remain speculative, differential changes in arousal- and valence-related measurements over sleep have been reported in other studies as well (e.g., Baran et al., 2012; Groch et al., 2011; Lara-Carrasco et al., 2009; Pace-Schott et al., 2011; Wagner et al., 2002).

Concerning one of the secondary parameters, REM sleep latency (a parameter sometimes suggested to be related to emotional processing), we found no significant correlations with changes of emotional reactivity from pre- to postsleep. REM sleep latency, defined as time from falling asleep to the start of the first REM period, might not be directly linked with emotional processing since a shift in the beginning of REM may alter early-night REM duration only to a small degree and not have any effect on late-night REM duration. In fact, research has linked REM latency mainly with declarative memory performance of emotional contents and not with affective responses (e.g., Nishida, Pearsall, Buckner, & Walker, 2009).

We also explored the question to what degree the full-length aversive film affects subsequent sleep by comparing REM duration and other REM-related parameters between the night after the aversive film and the night after the neutral film. While watching the aversive film, participants showed much stronger psychophysiological and experiential emotional responses compared to the neutral film, demonstrating robust emotion elicitation before sleep. Emotionally "charged" memory in that way could be expected to prompt intense emotional processing, which may be reflected in enhanced REM duration (*in sensu* SFSR theory) during subsequent sleep. However, our results indicate that watching aversive films before sleep (which is a common activity in industrialized countries) does not appreciatively alter subsequent REM sleep, at least in an order to be detectable in a medium-sized sample. All investigated parameters (i.e., REM duration and other REM-related parameters) did not differ significantly between the aversive and neutral nights. Furthermore, participants with particularly high emotional reactivity to the aversive film did not show increased REM sleep alterations. A recent study reported an attenuated increase in REM sleep duration from the first to the second half of the night after an aversive film of 10-min duration (Talamini et al., 2013), which did not replicate in our study. However, we observed a (nonsignificant) tendency for subtle REM sleep alterations (i.e., arousals in REM sleep were somewhat elevated after the aversive film, $p = .059$), which may justify further study of this question.

Earlier studies also had shown subtle effects of emotional films on subsequent sleep, such as increased awakenings from REM sleep (Baekeland et al., 1968). Similar to our results, no alterations of REM sleep duration (Baekeland et al., 1968; Cluydts & Visser, 1980; Lauer et al., 1987) were found. Research in rodents has shown that an experience of psychological stress before sleep increases REM sleep fragmentation (i.e., the number of REM arousals or REM periods across the entire sleep; see Pawlyk, Morrison, Ross, & Brennan, 2008, for review). In humans, presleep stressful experience (although not from emotional films) has also been related to increased REM fragmentation in a recent, well-controlled study (Vandekerckhove et al., 2011). Our lack of strong findings in this regard does of course not exclude that aversive emotional films may alter more specialized REM-related parameters that were not assessed in our study. For example, Goodenough et al. (1975) showed that increased self-reported anxiety during a stressful film was associated with enhanced respiratory irregularities within REM sleep. Similarly, Baekeland et al. (1968) observed increased REM density (i.e., the frequency of rapid eye movements) under similar conditions.

Some limitations have to be considered when interpreting the current findings. First, like other studies, we only investigated the first night after the emotion-eliciting stimuli, which may not represent the entire window of emotional processing of intense emotion films during sleep. Second, our results may to some degree depend on the specific film we selected and may not necessarily generalize to other film types. Nevertheless, we chose the *Antichrist* movie because of its potential to create a wide range of negative emotions and emotional memories at a moderate level of stressfulness as well as its suitability for research within the constraints of ethical guidelines for emotion research. It is only one exemplar of emotional stimuli, but due to its length has the potential to induce various negative emotions, including anger, anxiety, sadness, and disgust. Third, we used a correlational design because this design has high ecological validity due to the relatively undisturbed sleep and has only seldom been used for studying emotional processing during REM (e.g., only Baran et al., 2012, provide results of this type). However, we cannot confidently draw causal interpretations from our results in the sense that more REM sleep results in attenuated emotional processing. The negative association we found may also be the result of a third variable that was not included in the design. Furthermore, manipulating REM sleep, as often done in other studies, may allow for more directly proving causal links, but brings along other difficulties. For example, REM sleep deprivation methods do not only affect REM sleep duration but also lead to REM fragmentation, which may be problematic in studies on emotion since chronic REM fragmentation is associated with insomnia and posttraumatic stress disorder (Riemann et al., 2012; Spoormaker & Montgomery,

2008). Daytime nap studies are often divided post hoc into REM and no-REM groups, which may induce a bias in the results; for example, participants with higher levels of arousal or sleeping problems will often end up in the no-REM group. A daytime interval of wakefulness, as is sometimes used as no-(REM) sleep comparison condition, has the disadvantage of inducing uncontrolled emotional stimulation over the day. In contrast, a full night of sleep has the highest ecological validity as it usually occurs every day in healthy individuals and also contains a significant proportion of REM sleep. Fourth, to enhance ecological validity, we showed a full-length movie in the evening and compared specific film scenes from the movie between the evening and morning sessions. Of course, the morning scenes were separated from the whole movie context, which might have influenced emotional reactivity measures. This may be particularly relevant for SCL and may in part explain the divergent pattern of pre- to postsleep changes in reactivity scores we observed: ΔSCL showed an overall increase, whereas ΔcEMG as well as self-reported arousal and valence showed an overall decrease. Due to the linear decrease in SCL during the full-length film in the evening, lower SCL values might be expected in comparison with SCL measures on the next morning (during shorter film scenes), resulting in an overall increase from pre- to postsleep. Nevertheless, this and any other potentially confounding factors such as circadian phase or drop in participants' glucose level similarly affected all participants and should not have created a selective bias in individual difference correlational analyses. Importantly, after the aversive film, participants with higher amounts of REM sleep showed a relative enhancement in emotional reactivity from pre- to postsleep compared to other participants with lower amounts of REM sleep, and this was not the case after the neutral film. Regarding the relationship between REM3 and the change in ΔcEMG from pre- to postsleep after the aversive film, this correlation was no longer significant after excluding one outlier. Therefore, this specific result should be interpreted with caution. The use of a full-length movie in the evening versus specific film scenes in the morning also decreased comparability of the subjective arousal and negative valence ratings. This may have increased error variance and weakened the statistical power to detect significant correlations involving these ratings. Fifth, we focused only on young women's sleep to avoid sex- and age-related factors that may influence both sleep and emotional responding (Bianchin & Angrilli, 2012; Bradley, Codispoti, Sabatinelli, & Lang, 2001; Wrase et al., 2003). Therefore, present findings should not be generalized to men or older age populations without considering these facts. In relation to the previous point, we did not control for menstrual cycle phase of participants. However, we think this did not appreciably affect results: the sample revealed a divergent pattern regarding this factor, including about two thirds of participants taking oral contraceptives, which is known to be associated with flattening of menstrual cycle hormone fluctuation (Fleischman, Navarrete, & Fessler, 2010). In addition, participants were unsystematically assigned to testing dates and order was randomized for the emotional versus neutral film night, which should overcome systematic bias due to gonadal hormone effects in the women not taking oral contraceptives. Finally, it is possible that some smaller effects have not been found as the relatively low sample size limits statistical power.

Despite these limitations, we believe that we used an effective and novel procedure that allowed investigation of REM-related changes in emotional reactivity from pre- to postsleep with high ecological validity. In contrast to many other studies that only relied on self-report data, we used well-validated psychophysiological measures for assessing emotional arousal and valence. Our results are in line with the ESC account and several recent studies confirming a negative relationship between REM sleep duration and emotional processing. But, they also point to factors that need closer scrutiny in this line of research, namely, the intensity and/or duration of negative presleep stimulation, the temporal trajectory of poststimulation emotional processing across several nights, and quantification of additional variables to probe qualitative aspects of REM sleep. Therefore, we suggest a broader perspective combining the SFSR theory with the ESC account: immediately after intense emotional stimuli increased REM sleep may first lead to enhanced emotional reactivity (REM interference in emotional processing due to the consolidation of emotional salience), but will lead to decreased emotional reactivity over a longer time period (REM facilitation of emotional processing due to successful decoupling of the information content and the emotional component). Including the mentioned factors and their interactions more explicitly in theories of emotional processing during REM sleep will help investigate this broader perspective and will build a solid foundation for this emerging field of affective science. Progress in this basic research is likely to inform clinical theory building by delineating the exact role of REM sleep as risk or resilience factor in the face of adversity.

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