

Changes in Emotional Responses to Aversive Pictures Across Periods Rich in Slow-Wave Sleep Versus Rapid Eye Movement Sleep

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Objective: Since Freud's "Interpretation of Dreams," sleep has been related to emotional functions, where dreams were assumed to play a cathartic role. In psychophysiological research, this role was attributed mainly to rapid eye movement (REM) sleep. The present study compared processing pictures with negative emotional impact over intervals covering either early sleep dominated by slow-wave sleep (SWS) or late REM sleep-dominated sleep. **Method:** Emotional reactions were assessed by a nonverbal rating procedure along the two emotional dimensions valence (positive vs. negative) and arousal (low vs. high). Two groups of healthy men were tested across 3-hour periods of early and late nocturnal sleep (sleep group) or corresponding intervals filled with wakefulness (wake group). After the intervals, subjects rated new pictures together with old pictures already presented before the interval. Sleep was recorded polysomnographically. **Results:** As expected, the amount of REM sleep was about three times greater during late than early nocturnal sleep, whereas a reversed distribution was observed for SWS ($p < .001$). Valence ratings indicated a shift toward enhanced negative ratings after late sleep ($p < .05$), contrasting with a trend toward more positive ratings after early sleep ($p < .10$). Arousal habituated slightly to repeated presentation of the same stimuli, but sleep generally enhanced subsequent arousal ratings ($p < .05$). Effects of sleep did not depend on whether pictures had low or high emotional impact. **Conclusions:** Indicating a priming-like enhancement of emotional reactivity after periods rich in REM sleep, results do not confirm a cathartic function of REM sleep or sleep in general. **Key words:** REM sleep, emotion, affective picture processing, IAPS, cortisol.

REM = rapid eye movement; SWS = slow-wave sleep; IAPS = International Affective Picture System; SAM = Self Assessment Manikin; EEG = electroencephalogram; EMG = electromyogram; EOG = electrooculogram; HPA axis = hypothalamo-pituitary-adrenocortical axis.

INTRODUCTION

A century ago, Sigmund Freud (1) first related sleep and dreaming to mechanisms of emotional processing. He assumed that dreaming serves to express and fulfill unconscious wishes in a disguised manner during sleep. Because of a lack of convincing empirical evidence, however, this interpretation remained highly speculative. Psychophysiological investigation of dream functions only began after dreaming was conceptualized physiologically by REM sleep (2), which was found to be closely related to vivid dreams (3), although dreaming also occurs during non-REM sleep (4, 5). A specific interest emerged to dissociate functions of REM sleep and SWS. Whereas numerous stud-

ies dealt with memory functions of these sleep stages (for overviews, 6, 7), surprisingly few addressed emotional functions (8–13). Similar to Freud's original proposal, the majority of these studies suggested a specific role for REM sleep in emotional adaptation. Thus, memory for emotional material but not for neutral material was found to depend critically on REM sleep (8, 11–13). Apart from memory functions, REM sleep dreaming was shown to be associated with overnight mood improvement in normal subjects (9), and adaptation to stress induced by viewing an emotionally arousing film was reduced after REM-deprived sleep compared with non-REM-deprived or undisturbed sleep (10). These results point to a cathartic function of REM sleep, which is also suggested by clinical findings that affective disorders such as depression (14, 15) and war neurosis (16) are typically accompanied by shortened REM sleep latency and increased REM density and REM time, indicating an enhanced REM pressure in conditions of extreme emotional strain. On the other hand, based on phylogenetic and ontogenetic considerations, it has also been argued that SWS may be more critically involved in basic emotional functions than REM sleep (17, 18). However, apart from the studies by Greenberg et al. (10) and Cartwright et al. (9) mentioned above, there is no direct experimental evidence indicating any specific role for one or the other sleep stage in emotional processing independently of memory functions.

This was the issue of the present experiments. Affective reactions to previously viewed emotional stimuli were assessed after defined 3-hour periods of sleep differing in the proportions of SWS and REM sleep. Rather than applying a REM sleep-deprivation technique, which has been subject to profound criticism

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(19–21), we adopted an experimental design from Ekstrand's group (22–24) comparing undisturbed sleep intervals of early and late nocturnal sleep known to be filled with high amounts of either SWS or REM sleep, respectively. Subjects had to view and evaluate pictures with moderately and highly negative content before and after these sleep periods. Emotional responses were assessed by a standardized nonverbal rating system distinguishing two independent emotional dimensions: arousal (intensity of emotion: weak to strong) and valence (direction of emotion: positive to negative). These two emotional dimensions are well validated in terms of physiological and verbal measures (25–28). On both dimensions, effects of sleep were investigated with respect to two aspects of emotional processing: changes in affective reactions to the same stimuli *across* sleep (here referred to as emotional habituation) and changes in affective responsiveness in comparison with novel stimuli *after* sleep (here referred to as emotional reactivity).

METHODS

Subjects

Twenty-four healthy male nonsmokers aged 18 to 30 years (mean 23.4 years) without a history of sleep disturbances and with a regular sleep-wake rhythm served as paid subjects. They were equally assigned to an experimental sleep group and a wake control group. Participants got up before 7:00 AM on the morning before experimental nights and were not allowed to take any naps during the day. They did not take any medications or drugs. Subjects were acclimated to the experimental sleep condition by spending 1 night of adaptation in the sleep laboratory under experimental conditions, including the placement of electrodes. The experiment was approved by the local ethics committee. Subjects gave written informed consent and were allowed to leave the experiment at any time.

Materials and Tasks

Two hundred pictures of the IAPS (29) with moderately to highly negative content were chosen for the experiment. The picture topics ranged from simple objects (eg, spider, gun) to bloody mutilations in accident and violence victims. This item pool was subdivided into four subsets of pictures (each containing 50 pictures), which were compiled parallel in valence and arousal according to the mean ratings of a standardization sample of male subjects provided by Lang et al. (30). Mean ratings for the pictures in each subset were 3.2 to 3.3 for valence and 5.0 to 5.1 for arousal on a 9-step rating scale (see below) in this standardization sample. Two of the four subsets were used for a single session, thus allowing testing on two experimental nights for each subject. In each session, subjects had to judge pictures on two occasions: once before (judgment 1) and once after (judgment 2) a 3-hour interval of either early or late nocturnal sleep or wakefulness (see below). One subset of the picture set (termed old) was presented both before and after the 3-hour interval, the other subset (new) was presented only after the 3-hour interval. To prevent possible blunting effects, an additional 42 distractor pictures with mostly positive emotional content were included in each

session but were not considered in statistical analyses. The order of picture presentation was randomized for judgment phases 1 and 2 but held constant across subjects.

Subjects rated each picture on the emotional dimensions valence and arousal using the paper-and-pencil version of the SAM rating system (27, 31) (Figure 1). SAM is a nonverbal instrument for the assessment of emotional responses to a stimulus, which proved to be suitable for this purpose in several previous studies using IAPS pictures (eg, 25, 32–34). Specifically, a high convergent validity was demonstrated for the valence and arousal ratings with verbal measures such as the Semantic Differential of Osgood et al. (35) and with different physiological measures (26, 28). A third SAM dimension, dominance, was not considered here because it is correlated with valence and its validity has been doubted (25). To obtain affective ratings for the 64 pictures before (50 experimental pictures, 14 distractors) and for the 128 pictures after the 3-hour interval (50 old, 50 new, and 28 distractors), two booklets were compiled with the corresponding number of SAM figures. The order of rating dimensions was permuted across pictures. Ratings were given by placing an X on or between any of the five figures representing an emotional dimension, thus providing a 9-step rating scale for each dimension.

At the beginning of each experimental night, subjects were informed about the experimental procedure and the meaning of the two affective dimensions valence and arousal and how to rate them with the SAM system. The SAM figure booklet for emotional ratings was provided on the desk in front of the subject. Pictures were presented one after the other on a 17-inch color monitor situated on the same desk. Exposure time for each picture was 5 seconds. Subjects were instructed to view each picture for the whole time of presentation and to indicate afterward on the next SAM figure in the booklet the emotional reaction they had felt while viewing the picture. There was no time limit for the rating, but subjects were instructed to give their ratings as quickly and as spontaneously as possible. Thereafter, subjects triggered presentation of the next picture by a mouse click.

General Design

The experiment was carried out in the sleep laboratory of the Department of Physiological Psychology at the University of Bamberg. The general study design is shown in Figure 2. Each subject was tested on two experimental nights with 5 to 10 days between both sessions. In one of these sessions, the first half of the night was the relevant test interval, and in the other session, the second half of

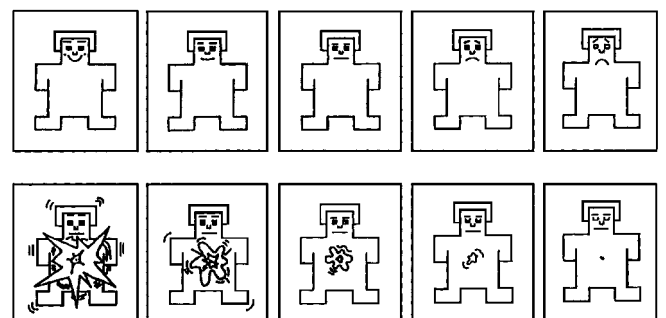


Fig. 1. SAM rating system (27) used to assess the two emotional dimensions valence (*top row*) and arousal (*bottom row*). Subjects had to place an X on or between any of the five pictures, resulting in a 9-step scale for each emotional dimension.

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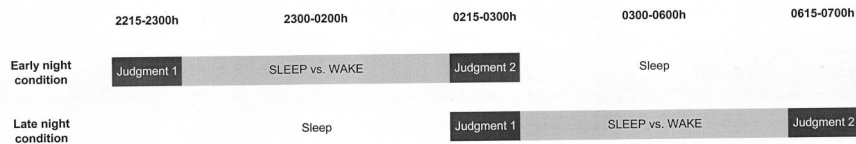


Fig. 2. Study design. Subjects were tested on two nights (early- vs. late-night condition) with the order balanced across subjects. On the early-night condition, the first rating (judgment 1) took place at 10:15 to 11:00 PM, followed by a 3-hour interval filled with sleep or wakefulness and a second rating (judgment 2). On the late-night condition, subjects first slept between 11:00 PM and 2:00 AM (to “consume” SWS). Judgment 1 took place at 2:15 to 3:00 AM, followed by a 3-hour interval of sleep or wakefulness and subsequently by judgment 2. The experimental sleep group slept during the 3-hour interval, and judgment 2 took place 15 minutes after awakening. The control group remained awake during these intervals.

the night was the relevant test interval. The order of both conditions was balanced across subjects as well as the assignment of the two picture sets to these conditions.

In the experimental sleep group, subjects tested in the first half of the night (early-sleep interval) reported to the laboratory at 9:30 PM and, after attachment of electrodes for sleep recordings, started judgment 1 at about 10:00 PM. After finishing this task, they went to bed and lights were turned off at 11:00 PM to enable sleep. Sleep was monitored by standard polysomnography, including EEG, EMG, and vertical and horizontal EOG recordings. Sleep stages were classified online according to the criteria described by Rechtschaffen and Kales (36). Three hours after the onset of sleep, subjects were awakened as soon as they reached sleep stages 1 or 2. Because arousal from other sleep stages may influence subsequent test performance (37), awakenings from SWS or REM sleep were avoided. Fifteen minutes after awakening, judgment 2 was performed (about 2:15–3:00 AM). When tested in the second half of the night (late-sleep interval), the same subjects arrived at the sleep laboratory at 10:30 PM and went to bed at 11:00 PM, immediately after electrodes had been placed. They were awakened after 3 hours of sleep, and 15 minutes later, judgment 1 began (about 2:15 AM). After this task, they again went to bed at about 3:00 AM and slept for another 3 hours. Fifteen minutes after awakening, judgment 2 was performed (about 6:15–7:00 AM).

For subjects in the wake control group, the procedure was exactly the same, the only exception being that the corresponding 3-hour intervals between judgment 1 and judgment 2 were filled with wakefulness instead of sleep. As in the experimental sleep group, the late test interval was preceded by 3 hours of sleep. In the periods of wakefulness, subjects played simple dice games with the experimenter during one half of the time and watched a videotape causing little cognitive and emotional strain during the other half. These standardized activities were well suited to prevent thinking about the previously judged picture material on the one hand and to keep subjects awake without triggering high arousal levels on the other hand.

Because activity of the HPA axis is known to influence memory consolidation during sleep (38) and may also be critically involved in the processing of emotional stimuli, cortisol levels during the night were assessed in saliva samples obtained immediately before and after each 3-hour interval with the Salivette sampling device (Sarstedt Inc., Rommelsdorf, Germany). Samples were kept at -20°C until assay.

Dependent Variables and Data Analysis

Sleep. Polysomnographic recordings were evaluated for the 3-hour sleep intervals. Total sleep time, sleep onset latency, and absolute and relative time spent in the different sleep stages were

determined according to Rechtschaffen and Kales (36). SWS time was calculated as the sum of the time spent in sleep stages 3 and 4.

Cortisol. Saliva cortisol was measured by radioimmunoassay (Hermann Biermann, Bad Nauheim, Germany; sensitivity $0.01\ \mu\text{g}/\text{dl}$, intraassay coefficient of variation $<3\%$ between 0.1 and $5\ \mu\text{g}/\text{dl}$, intraassay coefficient of variation $<10\%$). The two cortisol concentrations obtained immediately before and after a 3-hour interval were averaged as an estimate of HPA activity during this interval.

Affective ratings. The 9-step SAM scales were transformed into numerical rating scales ranging from 1 to 9, with 9 indicating the most positive valence rating and the highest arousal rating. With regard to the pictures presented at judgment 1 immediately before the relevant 3-hour processing interval, two different measures were determined separately for valence and arousal: 1) emotional reactivity after the processing interval, as indicated by the difference in the mean rating between old and new pictures at judgment 2 after the 3-hour interval (variable old-new) and 2) emotional habituation (or sensitization) across the processing interval, as indicated by the difference between the mean rating of old pictures before and after the 3-hour interval (variable after-before). These variables reflect two different, although closely related, aspects of emotional processing. Whereas habituation represents a change over a specific time interval, emotional reactivity can only be assessed at a given point of time (which, in this case, is preceded by a defined period filled with sleep or wakefulness).

Statistical Analysis

Data analysis for affective ratings (valence and arousal) based on a $2 \times 2 \times 2$ analysis of variance (ANOVA) model. In general, ratings for old pictures before the 3-hour interval (indicating the baseline rating level for each subject) were introduced as a covariate. The three factors were a group factor representing the sleep condition (sleep/wake) and two repeated measures factors for nighttime (early/late) and level of emotionality (low/high). The latter factor was introduced to disclose possible effects depending on the emotional impact of the material. For this purpose, a split half division of the pictures was performed to generate two classes of pictures with low vs. high valence and arousal, respectively. Sleep and cortisol data were compared using pairwise *t* tests. The significance level was set to $\alpha = .05$. Degrees of freedom were adapted using the Greenhouse-Geisser correction.

RESULTS

Sleep and Cortisol

Results from sleep recordings during the 3-hour intervals of early and late sleep are shown in Table 1. As

TABLE 1. Sleep Data

Sleep Parameter	Early 3-Hour Interval		Late 3-Hour Interval		<i>t</i> (11)
	Mean	SEM	Mean	SEM	
Sleep onset (min)	18.00	5.23	13.67	3.69	0.74
Sleep time (min)	183.00	4.70	190.29	5.93	-0.85
Wake %	0.83	0.65	0.22	0.14	1.20
S1 %	6.53	1.00	7.71	1.57	-0.60
S2 %	53.94	4.08	53.95	3.17	0.00
SWS %	29.16	2.72	4.19	1.22	11.51***
REM %	9.58	1.65	33.92	2.82	-9.50***

S1, sleep stage 1; S2, sleep stage 2; SWS, slow-wave sleep; REM, rapid eye movement sleep.

*** $p < .001$ for pairwise comparison between early and late sleep.

expected, sleep architecture of both time periods differed substantially with respect to SWS and REM sleep. SWS covered about 29% of the early sleep interval but only 4% of the late sleep interval ($t(11) = 11.51$, $p < .0001$). Conversely, REM sleep only covered less than 10% of early sleep but 34% of late sleep ($t(11) = -9.50$, $p < .0001$). No significant differences between early and late sleep were found concerning the other sleep parameters. Moreover, for none of the sleep parameters was a significant difference between sleep during the early processing interval and sleep before the late processing interval found.

In accordance with normal circadian variation, saliva cortisol concentrations were substantially lower during the early than during the late 3-hour interval in both the experimental sleep group (0.03 ± 0.01 vs. 0.28 ± 0.04 $\mu\text{g/dl}$, $p < .001$) and the wake control group

(0.04 ± 0.01 vs. 0.25 ± 0.05 $\mu\text{g/dl}$, $p < .001$). Differences between the cortisol measures obtained in corresponding intervals in the sleep and the wake group were not significant.

Affective Ratings

Valence. Valence ratings are summarized in Table 2 (upper panel). There were no significant differences between sleep and wake groups in the absolute ratings of valence either before the 3-hour processing interval (judgment 1) nor thereafter (judgment 2). Old pictures were generally rated somewhat more negative than new pictures at judgment 2 (negative old-new differences), but this effect failed to reach significance ($p > .10$). However, old-new differences indicated a significant effect of sleep on emotional reactivity depending

TABLE 2. Valence and Arousal Ratings

	Early 3-Hour Interval			Late 3-Hour Interval		
	Sleep	Wake	<i>t</i> (22)	Sleep	Wake	<i>t</i> (22)
	Mean \pm SEM	Mean \pm SEM		Mean \pm SEM	Mean \pm SEM	
Valence						
Judgment 1 (before)	3.20 \pm 0.15	3.23 \pm 0.13	0.11	3.31 \pm 0.14	3.44 \pm 0.17	0.64
Judgment 2 (after)						
Old	3.33 \pm 0.15	3.21 \pm 0.16	-0.54	3.29 \pm 0.12	3.33 \pm 0.18	0.16
New	3.31 \pm 0.16	3.35 \pm 0.17	0.18	3.45 \pm 0.10	3.34 \pm 0.17	-0.60
Old-new (at judgment 2)	0.02 \pm 0.06	-0.15 \pm 0.06	-1.84(*)	-0.16 \pm 0.04	-0.01 \pm 0.06	2.27*
After-before (for old pictures)	0.12 \pm 0.07	-0.02 \pm 0.10	-1.22	-0.02 \pm 0.06	-0.11 \pm 0.07	-1.11
Arousal						
Judgment 1 (before)	5.73 \pm 0.28	6.14 \pm 0.18	1.21	5.18 \pm 0.35	5.78 \pm 0.26	1.37
Judgment 2 (after)						
Old	5.68 \pm 0.30	6.00 \pm 0.23	0.83	5.01 \pm 0.37	5.68 \pm 0.24	1.53
New	5.55 \pm 0.29	5.96 \pm 0.20	1.16	4.97 \pm 0.30	5.69 \pm 0.22	1.93(*)
Old-new (at judgment 2)	0.13 \pm 0.05	0.04 \pm 0.08	-0.98	0.03 \pm 0.11	-0.01 \pm 0.08	-0.33
After-before (for old pictures)	-0.05 \pm 0.08	-0.14 \pm 0.13	-0.61	-0.18 \pm 0.13	-0.11 \pm 0.15	0.37

Valence and arousal ratings on Self Assessment Manikin (SAM) scale. Ratings range from 1 (most negative and least arousing) to 9 (most positive and most arousing).

* $p < .05$; (*) $p < .10$.

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on the nighttime of the processing interval. Compared with ratings after corresponding intervals filled with wakefulness, old-new differences were more positive after early sleep and more negative after late sleep ($F(1, 21) = 8.45, p < .01$, for sleep/wake \times nighttime interaction). Pairwise comparisons confirmed significance for the more negative old-new difference after late sleep than late wakefulness ($p < .05$) and a trend toward more positive old-new values after early sleep than early wakefulness ($p < .10$; Figure 3 and Table 2). Old-new differences after late sleep were distinctly more negative than those after early sleep ($t(11) = 2.29, p < .05$; Figure 3). In view of this differential pattern across early and late sleep, which was unexpected, it was an intriguing question which direction would be found for the old-new difference over a total night of sleep. Therefore, in a supplementary experiment, nine additional subjects rated the affective pictures before and after a whole night of sleep (between 11:00 PM and 6:00 AM) in the same way as the subjects of the main experiment. (An overnight wake control condition was not introduced because here the outcome

would be confounded with emotional and cognitive impairments due to prolonged sleep deprivation.) Like the late-night sleep condition, the total-night sleep condition revealed a highly significant negative old-new valence difference ($-0.32 \pm 0.09; p < .01$; Figure 3, right bar), suggesting that mechanisms modulating emotional reactivity during late sleep also determine the effects of normal, undisturbed sleep over the whole night. The negative effect of 7 hours of sleep across the total night was only slightly stronger than that of 3 hours of sleep across the late night ($p < .10$; Figure 3).

The effects of sleep appeared to be somewhat more pronounced for moderately than highly emotional pictures ($F(1, 21) = 3.25, p < .10$, for the sleep/wake \times nighttime \times emotionality interaction). Independent of sleep, the old-new difference was in general more negative for pictures with low emotional impact than for pictures with high emotional impact ($F(1, 21) = 5.64, p < .05$), pointing to greater emotional reactivity for moderately than for highly negative stimuli. Analysis of the after-before difference for old pictures did not indicate any significant effects of sleep and wakefulness.

Arousal. Again, absolute ratings did not differ between the experimental sleep and wake group at judgment 1 or 2 (Table 2, lower panel). However, emotional reactivity as indicated by the old-new difference for arousal ratings after the 3-hour processing interval was greater after sleep than wakefulness ($F(1, 21) = 4.41, p < .05$, for main effect of sleep/wake). Supporting these results, old pictures also were rated somewhat more arousing than new pictures after a total night of sleep (supplementary experiment; $p < .10$). There was no differential effect of early and late sleep on old-new differences ($p > .64$ for sleep/wake \times nighttime interaction). The after-before difference for old pictures was found to be generally negative ($p < .10$), indicating that arousal habituated slightly to repeated presentation of emotional pictures. Independent of sleep, this general habituation effect tended to be stronger over late than early nocturnal processing intervals ($F(1, 21) = 3.35, p < .10$, for main effect of nighttime). However, there was no similar habituation effect in the total night sleep condition (supplementary experiment), suggesting that the effect is only transitory.

DISCUSSION

This study investigated sleep-related processing of emotional material by comparing the effects of early, SWS-rich sleep and late, REM sleep-rich sleep on valence and arousal ratings of aversive pictures in healthy humans. Different patterns of changes were obtained for ratings of valence and arousal, which is in accord with the view that these two dimensions reflect

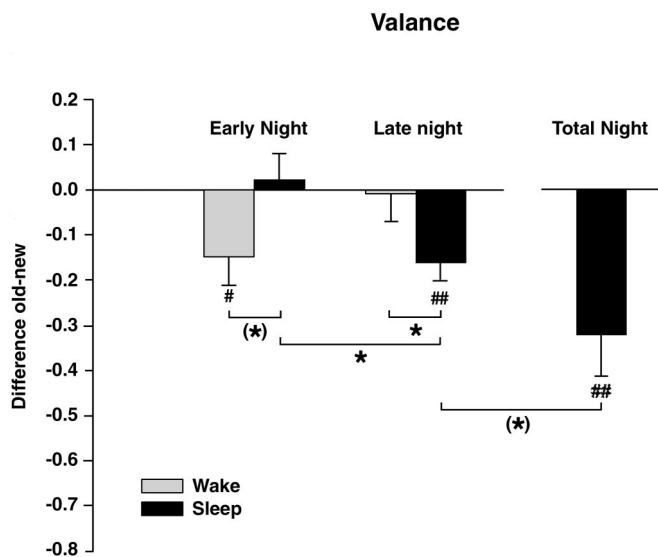


Fig. 3. Difference in valence ratings for old (familiar) and new (unfamiliar) aversive pictures obtained at judgment 2 after 3-hour intervals of sleep (black) and wakefulness (gray) during the early (left) and late night (middle). Right, results of a supplementary condition, in which judgments were obtained before and after a period of sleep across a total night (11:00 PM–6:00 AM). Note enhanced negativity for old-new difference (ie, increased emotional reactivity) after late sleep compared with late wakefulness and with early sleep. The total 7-hour period of sleep likewise revealed enhanced negativity, which was also significant in comparison with the effects of early sleep and late wakefulness (not shown) and tended to be more pronounced than after late sleep. # $p < .05$, ## $p < .01$ for difference from zero; * $p < .05$, (*) $p < .10$ for comparisons between conditions.

different aspects of emotional responses. Although statistical significance was confirmed even with a relatively small subject sample, effects of sleep were generally of moderate size only and were restricted to the old-new measure of emotional reactivity after sleep, although the after-before measure across sleep periods remained unaffected. The focus of the effects of sleep on emotional reactivity to old as compared with new pictures (presented after the 3-hour processing interval) points to a proactive priming-like influence, where sleep processes amplify emotional responses to familiar stimuli previously processed in comparison with unfamiliar stimuli. In fact, the effects on emotional reactivity resemble those typically observed in repetition priming paradigms, in which processing of stimuli in a first (study) phase primes performance on the same (old) stimuli in comparison with unfamiliar (new) stimuli in a later second test phase (eg, 39, 40), although the term priming is commonly used for mnemonic rather than for evaluative processes. Thus, sleep seems to modulate subsequent evaluative responses such that emotional reactivity to an aversive event is affected differentially depending on whether it is novel or familiar.

The most salient effect of the study was that of REM sleep-dominated late sleep on ratings of valence. Compared with early sleep and with the effects of corresponding wake periods, late sleep shifted emotional reactivity toward enhanced negative valence ratings. An opposite trend was observed after SWS-rich early sleep. Because early and late sleep conditions, as expected, differed only concerning SWS and REM sleep, their differential effects on subsequent valence ratings must be suspected to be caused by the different proportions of these sleep stages. Specifically, the more negative valence ratings of old pictures after late sleep suggest that REM sleep enhances aversive reactivity to these stimuli. Interestingly, results of the supplementary total-night sleep condition likewise revealed a negative valence change, indicating that mechanisms of emotional processing effective during late, REM sleep-rich sleep also determine the effects of normal, undisturbed sleep over a total night. The negative shift over a total night of sleep tended to be more pronounced than that over late sleep, which could be due to cumulative effects of the (relatively short) REM sleep periods during early sleep and the (considerably longer) REM sleep periods during late sleep. To the best of our knowledge, these are the first data pointing to a specific aggravating influence of REM sleep on the valence aspect of emotional responses. It is interesting to relate this outcome to the clinical observation of characteristic changes of REM sleep in affective disorders (eg, 14–16, 41–43). Reduced REM sleep latency

and increased REM density and REM time are commonly observed in depressed patients. On the other hand, REM sleep deprivation can alleviate depressive symptoms (14), and most antidepressant drugs also reduce REM sleep (eg, 15, 44, 45). A prominent symptom of depression is a mood-related bias toward negatively valenced memories (46–49) and judgments (50). Thus, in conjunction with the present results, signs of enhanced REM sleep pressure in depressed patients may reflect a primary symptom of the disorder rather than a mechanism compensating for the affective disturbance (51).

In contrast with valence, ratings of arousal were not differentially affected by early and late sleep. However, the old-new difference indicated a generally enhanced emotional reactivity on this dimension after sleep compared with wake periods. Moreover, in line with earlier findings (10), after-before differences for pictures presented both before and after the 3-hour interval revealed slight habituation to repeated stimulus presentation on the arousal dimension. Habituation was not affected by sleep, which contrasts with results of Greenberg et al. (10), who reported signs of enhanced self-rated tension anxiety to stressful stimuli in subjects deprived of REM sleep compared with non-REM sleep deprivation. However, awakenings from REM sleep, more than awakenings from any other sleep stage, can cause considerable emotional disturbances (19–21), which per se are likely to influence subsequent emotional responses. This would explain the differential outcome in comparison with the present data.

Taken together, the present results fail to support the assumption of a cathartic function for REM sleep on emotional responses to aversive stimuli, both with respect to valence, which shifted toward more negative ratings after REM sleep-dominated late sleep, and with respect to arousal, which was enhanced by sleep in general. However, some restricting remarks should be added here regarding the experimental design of the study, comparing effects of undisturbed sleep (vs. wakefulness) in the first and second half of the night. Although this design appears to be advantageous in comparison with alternative approaches including frequent awakenings or prolonged sleep deprivation (19–21), this approach also entails some specific problems, which are to be considered. First, subjects in the present design are always tested immediately after the defined 3-hour period of sleep or wakefulness. Thus, the focus is set on short-term effects, the persistence of which over longer time intervals needs to be confirmed. More important, in this paradigm, the early night conditions are always preceded by wakefulness, whereas the late night conditions are preceded by

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sleep (52). It cannot be ruled out that this kind of confounding had some impact on the variables of emotional reactivity in the present study. However, the fact that the condition of sleep across the total night, which was not preceded by sleep, yielded similar results as the late sleep condition argues against this possibility.

Another possible confounding factor are circadian variations overlapping with sleep effects in the early and late night. Not only endocrine variables (as demonstrated by the cortisol data here) but also psychological variables such as vigilance, alertness, reasoning, global vigor, and global affect are known to be subject to circadian variations, typically with a trough in the early morning hours (53–57). These variations may also have an impact on emotional judgments at different times of the night and may distort direct comparisons between early and late sleep conditions. However, our experimental approach included also time-matched conditions of wakefulness in the early and late night. Thus, the main outcome of the experiment that the pictures were rated more negative after late sleep proved to be significant also in comparison with a period of late wakefulness. This comparison is unlikely to be confounded by circadian variations because the respective judgments (old-new valence differences) refer to the same time of day (ie, in the morning) and also the first presentation of the old pictures occurred at the same time of the night in both of these conditions.

Finally, it should be noted that the present paradigm relies on the differential distribution of the critical sleep stages, SWS and REM sleep, across the early and late halves of the night. Although early and late sleep were found to differ substantially only in SWS and REM sleep, these sleep stages only cover about one third of early and late sleep, respectively. Thus, pure effects of periods filled just with the critical sleep stage cannot be assessed, which may be one factor responsible for the relatively modest effect sizes here.

With these limitations in mind, the present results must be considered preliminary. So far, amazingly few studies have been devoted to the relationship between sleep stages and emotional processing, and none of these studies considered the useful distinction between the aspects of valence and arousal in emotional reactions. Thus, as a pilot study, the present investigation may point in a new and fruitful direction of research. In addition to stimuli with negative emotional content, future studies should also address processing of positive stimuli as well as possible sex differences in sleep-related emotional processing. Moreover, the application of the same paradigm not only to healthy subjects but also to depressed patients

showing characteristic changes in sleep architecture would be promising.

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