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Overnight emotional adaptation to negative stimuli is altered by REM sleep deprivation and is correlated with intervening dream emotions

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SUMMARY Rapid eye movement (REM) sleep and dreaming may be implicated in cross-night adaptation to emotionally negative events. To evaluate the impact of REM sleep deprivation (REMD) and the presence of dream emotions on a possible emotional adaptation (EA) function, 35 healthy subjects randomly assigned to REMD ($n = 17$; mean age 26.4 ± 4.3 years) and control ($n = 18$; mean age 23.7 ± 4.4 years) groups underwent a partial REMD and control nights in the laboratory, respectively. In the evening preceding and morning following REMD, subjects rated neutral and negative pictures on scales of valence and arousal and EA scores were calculated. Subjects also rated dream emotions using the same scales and a 10-item emotions list. REMD was relatively successful in decreasing REM% on the experimental night, although a mean split procedure was applied to better differentiate subjects high and low in REM%. High and low groups differed – but in a direction contrary to expectations. Subjects high in REMD% showed greater adaptation to negative pictures on arousal ratings than did those low in REMD% ($P < 0.05$), even after statistically controlling sleep efficiency and awakening times. Subjects above the median on $EA_{valence}$ had less intense overall dream negativity ($P < 0.005$) and dream sadness ($P < 0.004$) than subjects below the median. A correlation between the emotional intensities of the morning dream and the morning picture ratings supports a possible emotional carry-over effect. REM sleep may enhance morning reactivity to negative emotional stimuli. Further, REM sleep and dreaming may be implicated in different dimensions of cross-night adaptation to negative emotions.

KEYWORDS dreaming, emotional adaptation, emotion-induction task, rapid eye movement sleep, standardized picture stimuli, valence/arousal of emotions

INTRODUCTION

A growing research literature supports the claim that rapid eye movement (REM) sleep is implicated in the processing of emotional events, especially in the consolidation of emotional memories and the downregulation of reactions to dysphoric stimuli – commonly referred to as emotional adaptation (EA). Experimental deprivation of REM sleep (REMD) has been shown to impair memory consolidation of emotional stimuli (Cartwright *et al*., 1975; Greenberg *et al*., 1983; Wagner *et al*., 2001) and to interfere with EA to anxiety-producing films (Greenberg *et al*., 1972). Other studies demonstrate associations between REM sleep abnormalities and affective disorders, anomalies such as high first REM period densities, short REM sleep latencies and the presence of nightmares

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predicting depression (Cartwright *et al*., 1998b, 2003; Modell *et al*., 2005) and suicidal behavior (Agargun and Cartwright, 2003; Agargun *et al*., 2007).

It remains unclear whether dreaming plays any role in this purported mediation of emotion during REM sleep. Emotions are recognized to be central to dream phenomenology, appearing in the majority (70–95%) of dreams reported at home or after REM sleep awakenings (Foulkes *et al*., 1988; Kahn *et al*., 2002; Merritt *et al*., 1994; Nielsen *et al*., 1991). Negative emotions appear more frequently than positive ones, with fear and anxiety being most common (Foulkes *et al*., 1988; Merritt *et al*., 1994; Nielsen *et al*., 1991), and are related to presleep affective state. Stressful periods are often accompanied by an increase in dysphoric dream emotions, and even by the emergence of bad dreams and nightmares (Köthe and Pietrowsky, 2001; Schredl, 2003). Similarly, many experimental situations, such as aversive films (De Koninck and Koulack, 1975; Greenberg *et al*., 1972; Lauer *et al*., 1987) and stressful intellectual activity (Cohen and Cox, 1975; Koulack *et al*., 1985; Stewart and Koulack, 1993), influence dream emotions.

Furthermore, dream emotions are associated with cross-night emotional changes. One study found that dreaming about an anxiogenic stimulus was associated with evening-to-morning mood improvement (Cohen and Cox, 1975). A second series of studies showed that evening-to-morning improvements in 'unhappiness' correlated with the density of dreamed characters but not with physiological sleep parameters (Kramer, 1993, 2007). A third series of studies found that clinically depressed divorcees who dreamed emotionally about their ex-spouses at intake were better adjusted at 1-year follow-up than were those who did not report this type of dreaming (Cartwright, 1991).

While such studies generally support a functional role for dreaming in EA, some discrepant findings exist. Sleep that is rich in REM sleep is associated with more negative morning evaluations of pictures, whereas sleep rich in slow-wave sleep is not (Wagner *et al*., 2002). Moreover, incorporations of presleep stressful stimuli have been linked with increased evening-to-morning anxiety (De Koninck and Koulack, 1975; Koulack *et al*., 1985).

Such findings are deemed discrepant in that EA is most commonly conceptualized as a decrease in physiological and psychological reactivity following re-exposure to a negative event. The work of Davidson (2000) suggests that increased reactivity and a failure to rapidly recover after a negative event is a crucial component of vulnerability to anxiety and mood disorders. Depression and anxiety following negative stimuli are, in fact, associated with exaggerated negative effect (Cook *et al*., 1991, 1992) and a longer recovery time (Davidson, 2000). EA may be assessed by presentation (and re-presentation) of standardized dysphoric pictures followed by ratings of the pictures' valence and intensity. Minimal habituation to repeated presentations of such pictures is taken to reflect poor EA (Houtveen *et al*., 2001). Habituation has been demonstrated for intervals of several minutes (Lang *et al*., 1993) to several weeks (Larson *et al*., 2000).

The principal goal of this study was to assess the potential involvement of both REM sleep and dreaming in an EA function. We used a partial REMD procedure to experimentally manipulate the presence of REM sleep- and dreaming-related EA and a standardized dysphoric picture task to measure pre- to postsleep EA. We examined whether REMD alters self-rated valence and intensity of unpleasant pictures presented in the evening and again in the morning. In the present study, high EA was defined as greater habituation to the negative pictures, i.e. by a larger decrease in either self-rated valence (negative to positive) or intensity (high to low) upon second viewing of the pictures. We predicted that: (1) REMD subjects would show less EA to negative pictures than would control subjects and (2) well-adapted subjects would show more negative dream emotion in their dreams than would poorly adapted subjects.

MATERIALS AND METHODS

Subjects

Forty healthy paid volunteers aged between 18 and 35 years (26 women, 14 men; mean age 25.2 ± 4.5 years) were recruited by advertising and word of mouth. They reported recalling at least one dream per week and that they were free from severe sleep/psychiatric disorders and the use of medications. Written consent was obtained and each subject received a monetary compensation of $25 per recording night. Subjects were instructed not to nap and to avoid consuming alcohol and caffeine 24 h prior to each laboratory visit.

Questionnaires

After giving informed consent, subjects completed several questionnaires, including French versions of the Spielberger State and Trait Anxiety Inventory (STAI) (Bergeron, 1980), the Beck Depression Inventory (BDI) (Bourque and Beaudette, 1982) and the Sleep Disorders Questionnaire (SDQ) (Douglass *et al*., 1994) abbreviated version (SDQ-A). The STAI (range 20–80) and BDI (range 0–63) were used for screening of severe psychiatric disorders (i.e. STAI ≥ 60 or BDI ≥ 14) and the SDQ-A to assess sleep disorders (results not reported here). No subjects were excluded at this step.

Experimental design

Each subject spent two consecutive nights undergoing polysomnographic recording in a quiet shielded room containing a single bed. A video camera, microphone and intercom system were used to maintain visual and voice contact at all times. The length of each recording night, including the application and removal of electrodes, was about 12 h. Lights off was between 22:00 and 24:00 hours, and lights on between 06:00 and 09:00 hours. The first recording (N1) night was an adaptation/baseline night and the subject's sleep was undisturbed. The second night (N2) was for experimental REM sleep awakenings and dream collection. After the application of electrodes, the emotion-induction task was explained and then presented 1 h before lights off. The same task was presented once more in the morning, 1 h after lights on. The Self-Assessment Manikin (SAM) rating system (Lang, 1980) was used to assess reactions during the emotion-induction task. This system assesses emotional reactions on three dimensions with 1–9 scales: valence, arousal and dominance. Only the most commonly used valence (1 = unpleasant to 9 = pleasant) and arousal (1 = not at all intense to 9 = extremely intense) scales were evaluated here.

Sleep recordings

Sleep was recorded with an electrode montage of four 10–20 electroencephalogram channels (C3, C4, O1 and O2), four electro-oculogram (EOG) channels (left, right, vertical and horizontal) and reference channel A2, all referenced to A1, as well as four bipolar electromyogram (EMG) channels (submental, dominant finger extensor, anterior tibialis and orbicularis oris). Referential electrodes were re-referenced off-line to (C3-A2, O2-A1 and EOG-linked ear) for standardized sleep stage scoring. Three channels were used to record the electrocardiogram D-I, D-II and D-III), and one each to record respiration (thermistance), finger skin conductance and the onset/offset of auditory stimulus presentations. All-night recordings were made using either a Grass Model 12 or Grass Model 15 polygraph (Grass Technologies, Astro-Med Inc., West Warwick, RI, USA) and archived under the control of Harmonie version 6.0a EN-0 software (Stellate System, Montreal, QC, Canada). Signals were appropriately sampled between 64 and 1024 Hz.

REM deprivation

On the experimental night, subjects were matched by age and sex and randomly assigned to one of two groups: (1) a REM sleep deprivation (REMD) group containing 12 women and eight men (mean age 26.7 ± 4.2) and (2) a comparison (control) group, containing 14 women and six men (mean age 23.7 ± 4.2). REMD subjects were allowed to sleep normally through the first and second REM sleep periods then were awakened 5 min after the appearance of the first REM of each subsequent REM period. Control subjects were treated similarly except that they were awakened only 25 min after the appearance of the first rapid eye movement of each REM period after the second. To limit the severity of REMD, a maximum of six awakenings per night was conducted. In the control condition, all awakenings took place within REM periods as standardly defined; in fact, no shifts to stages other than REM lasted for more than 10 consecutive minutes. Moreover, in the control condition, 41/50 awakenings took place either during a REM sleep epoch or within 60 s of its termination. The remaining nine awakenings took place during a NREM epoch that was less than 10 min in length; most of these occurred during the third REM/NREM cycle. In the REMD condition, 54/58 awakenings took place either during a REM sleep epoch or within 60 s of its termination. The remaining four awakenings took place during a NREM epoch that was less than 5 min in length.

Using an index of REMD% (see later section), the awakening procedure was found to have failed for three REMD subjects (REMD% ≤ 12.4%) and was too effective for one control subject (REMD% = 24.1%). Another control subject had excessive REM rebound (REMD% = −223.9%) due to a severe first night effect. These five subjects were dropped from further analysis. The remaining 17 REMD (11 women, mean age 26.4 ± 4.3 years) and 18 control (12 women, mean age 23.7 ± 4.4 years) subjects were further differentiated into groups that were high and low in REM%; they were divided into high-REM%N2 (n = 20) and low-REM%N2 (n = 15) groups based upon the mean value of REM% on night 2 (18.2%). The latter value provided a clearer separation of groups than did either REMD% or the group median. High- and low-REM%N2 groups did not differ in age ($F_{1,33}$ = 0.53, P = 0.473) or sex ratio (χ^2_{35} = 1.786, P = 0.181) and were used for subsequent group comparisons.

Dream collection

Each subject was awakened by an 80-dB, 500-Hz, 0.5-s tone, after which the lights were switched on and they were told by intercom: 'Please describe the very last thing that was going through your mind before you were awakened'. When the report was completed, they were asked: 'Is there anything else that you can remember?'. Subjects then responded verbally to two questions about the dream's emotional valence (0 = no emotions; 1 = negative to 9 = positive) and emotional arousal (1 = not at all intense to 9 = extremely intense). If a dream contained both positive and negative emotions, they were asked to rate the most intense emotion experienced. Subjects then rated their dreams with an emotions list modified from the Differential Emotions Scale (Izard, 1989) to assess the intensity of 11 different emotions on a scale of 1–5 (1 = very little or not at all; 5 = very much): alert, happy, surprised, sad, angry, disgusted, arrogant, scared, shy and guilty. Confused was added as an exploratory item but not analyzed further here. Subjects were kept awake for a minimum of 10 min, regardless of whether mentation was recalled. On these rare occasions, technicians simulated typical technical adjustments and interacted with subjects. All responses were recorded on DVD for later transcription.

Emotion-induction task

Pictures from the International Affective Picture System (IAPS) (Center for the Study of Emotion and Attention, CSEA-NIMH, 2005) were selected using normative ratings of valence and arousal provided in the instruction manual. Seventy-two pictures were selected from eight categories, including four rated as neutral, i.e. household objects (n = 8), neutral human faces (n = 10), exterior (n = 13) and interior scenes ($n = 5$), and four rated as unpleasant, i.e. animals attacking ($n = 5$), humans attacking ($n = 20$), victims ($n = 4$) and accidents ($n = 7$). According to female and male normative ratings (Lang *et al.*, 2005), the valence of the 36 neutral pictures varied between 4.06 and 5.93 (mean 5.01 ± 1.30) (1 = unpleasant to 9 = pleasant) and the arousal pictures varied between 2.00 and 3.95 (mean 3.09 ± 2.05) (1 = not at all intense to 9 = extremely intense). Valence of the 36 unpleasant pictures varied between 1.63 and 4.00 (mean 2.75 ± 1.66) and the arousal pictures varied between 5.66 and 7.35 (mean 6.31 ± 2.15).

Prior to the task, subjects were given instructions drawn from the instruction manual (Lang *et al.*, 2005), translated into French and adapted for the present study. Subjects were instructed to view each picture while it was on the screen and told how to rate each block of 12 pictures using the SAM system. Subjects were first told that the task lasted 20 min, that they would be viewing different pictures projected on the screen, and that they would be rating the pictures at six different times during the experiment for how they made them feel while viewing them. They were instructed to rate each block of 12 pictures using the SAM scales (for complete instructions, see Lang *et al.*, 2005) and that their ratings of each block should reflect their immediate personal experience of them. They were also told that they should view each picture for the entire time it is projected on the screen and that they should make their ratings on the two dimensions of the SAM as quickly as possible to be ready for the next block of pictures. Finally, they were asked to keep in mind that there were no right or wrong answers.

Pictures were shown with SuperLab Pro v.4.0.1 software (Cedrus Corporation, San Pedro, CA, USA) on a 15-inch color LCD monitor situated in the subject's bedroom. Presentation was based on the Smith, Bradley and Lang (Smith *et al.*, 2005) methodology and adapted for the present study. First, three neutral practice pictures were viewed and rated. Then, a series of three blocks of 12 neutral pictures was presented followed by a series of three blocks of 12 negative pictures. Each picture was presented for 6 s with an inter-picture interval of 1.5 s. Blocks were followed by 10-s intervals for SAM administration and the two series by a 5-min interval. Subjects were instructed to stay calm and still during these intervals. The SAM was thus completed a total of six times. The task lasted 20 min, including instructions and all ratings. The order of picture presentation within each series was randomized across subjects, but the same order was used for the evening and morning presentations.

Electrophysiological recording and monitoring took place throughout the task. During picture presentations, physiological measures (corrugator EMG, skin conductance, heart rate, startle-related orbicularis oculi EMG) were acquired while startle probes (50 ms, 90-dB bursts) were administered over headphones 12 times in total in a manner identical for each subject, i.e. 3 s after picture onset during the second and the 11th picture of both the negative and neutral blocks of pictures. These results are not presented here.

Mean values over the three blocks of negative and neutral pictures were computed for valence and arousal ratings for the evening and morning sessions. We expected that morning reactions to the stimuli would be both less intense and more positive; thus, $EA_{arousal}$ was calculated as 'evening minus morning' arousal ratings and $EA_{valence}$ was calculated as 'morning minus evening' valence ratings. For both measures, then, high values denote high adaptation and low values denote low adaptation.

Polysomnography and dream affect ratings

Sleep tracings were scored by two experienced polysomnography technicians using standard criteria (Rechtschaffen and Kales, 1968). Inter-rater reliability, computed as the percent of epochs identically classified by both technicians, was 90%. From the scored records, in-house software was used to calculate REM% [(number of min of REM/total sleep time) × 100]. From this variable a REM deprivation measure REMD% was calculated for each subject:

$$\frac{\text{REM\%N1} - \text{REM\%N2}}{\text{REM\%N1}} \times 100.$$

From subjects' dream emotion valence ratings, dreams were separated into three categories: negative dreams (valence ≤4), neutral dreams (valence = 5) and positive dreams (valence ≥6). Mean scores for each item of the emotions list were computed separately for dreams from REM periods 3–8 and the morning REM period at final wake-up. Ratings for 'confused' were excluded because this exploratory item was not part of the original Izard (1989) scale. A negative emotion intensity (NEI) score for each dream report was calculated as the average of intensity ratings (1–5) for all emotion items except confused, alert and surprised; the item 'happy' was reverse keyed and included in this average. Whole-night NEI was calculated for each subject as the average of NEI scores for dreams from REM periods 3–8 and the morning REM period.

Statistical tests

Success of REM deprivation was examined with a 2 × 2 anova using groups (REMD and control) as a between-group factor, nights (N1 and N2) as a repeated measure and REM% as the dependent measure; *t*-tests were used to interpret interaction effects.

Emotional adaptation scores for groups high and low in REM%N2 were compared using a one-way anova with groups (high-REM%N2 and low-REM%N2) as the between-group factor. Finally, correlations between EA measures and REM%N2 measures were calculated for the whole group and for subjects high and low in the REM%N2 measure.

Relationships between EA measures and dream emotions were assessed globally by comparing high- and low-EA groups on the whole-night and per-REM period NEI measures using one-way anovas. A possible carry-over effect interpretation –

according to which dream recall could affect morning cognition or mood (Lavie and Sutter, 1975; Nielsen *et al.*, 1989) – was examined with Pearson correlations between per-REM period NEI measures and morning valence and intensity ratings (adjusted $P = 0.05/5 = 0.01$). More specific relationships for emotion types were assessed using MANOVAS with groups (high-EA and low-EA) as the between-group factor and averages of each of the 10 emotion intensity scores for dreams from REM periods 3–6 as multiple dependent variables. For this analysis, total N was reduced to 38 because one subject failed to complete the emotions list. Seven subjects with extremely high *z*-scores were identified as univariate outliers on the following variables: sad, angry, disgusted, arrogant, scared, shy and guilty and were replaced by scores at the $z = 3.29$ limit. Assumptions of normality, linearity and multicolinearity were all satisfactory and correlations between dependent variables were moderate (Tabachnick and Fidell, 2001). Because the assumption of homogeneity of variance–covariance was not met (Box's mean 2.27, $P < 0.001$), the more robust Pillai's criterion was chosen for significance testing. Univariate effects were subsequently examined using a Bonferroni adjustment at $P = 0.005$ (0.05/10 comparisons). Dose–response relationships were assessed by calculating correlations between EA measures and both NEI (adjusted $P < 0.01$) and the 10 dream emotion items (adjusted $P < 0.005$). All analyses were performed with SPSS 11.5 (SPSS Inc., Chicago, IL, USA).

RESULTS

REM sleep deprivation

No differences were found between REMD (range 1–6; mean 3.4 ± 1.5) and control (range 1–5; mean 2.8 ± 1.1; $t_{33} = 1.3$, $P = 0.193$) groups in mean number of REM awakenings. Nor were there differences in REM% on night 1 or in stage 2, stages 3 + 4, sleep latency or REM sleep latency on either night 1 or 2 (see Table 1). As shown in Fig. 1, success of the REMD procedure was indicated by a groups × nights (N1 and N2) interaction for REM% ($F_{1,33} = 48.72$, $P < 0.001$). The REMD group decreased in REM% from N1 to N2 ($t_{16} = 8.30$, $P < 0.001$), whereas the control group did not ($t_{17} = -1.60$, P = NS). Group differences in total sleep time and sleep efficiency (both $P < 0.001$) showed similar interactions and are attributable to the selective deprivation of REM sleep for the REMD group.

Effect of REM deprivation on emotional adaptation

Two values missing for morning ratings of SAM valence and arousal were replaced by subject-wise mean values. As shown in Table 2, negative pictures altered emotional state as expected; unpleasant pictures were rated as more negative than neutral pictures both in the evening ($t_{39} = 11.09$, $P < 0.001$) and in the morning ($t_{39} = 9.74$, $P < 0.001$). Negative pictures were also evaluated as more arousing than neutral pictures in the evening ($t_{39} = -5.20$, $P < 0.001$) and in the morning ($t_{39} = -5.49$, $P < 0.001$).

Groups high and low in REM%N2 did not differ in number of awakenings ($F_{1,33} = 0.11$, $P = 0.741$), number of awakenings with dream recall ($F_{1,33} = 0.22$, $P = 0.641$), number of dreams with emotions ($F_{1,33} = 2.30$, $P = 0.139$) or number of dreams with negative, neutral or positive emotions (all $P > 0.30$). They also did not differ in the mean ratings of neutral and negative pictures, either on valence and arousal scales (all $P > 0.125$). However, as shown in Fig. 2, the high-REM%N2 group had significantly lower $EA_{arousal}$ scores to negative pictures than did the low-REM%N2 group ($F_{1,33} = 4.18$, $P = 0.049$). They did not differ on $EA_{valence}$ scores to negative pictures or on EA scores to neutral pictures

Table 1 Polysomnographic sleep measures (mean ± SD) for control and REM deprivation (REMD) groups

	Control (n = 18)	*REMD (n = 17)*	*t*	*d.f.*
Sleep efficiency (%) night 1	91.99 ± 7.49	92.36 ± 6.24	0.15	33
Sleep efficiency (%) night 2	86.06 ± 3.74	80.59 ± 6.47	−3.08*	33
Sleep latency night 1	20.37 ± 24.45	11.69 ± 8.84	−1.38	33
Sleep latency night 2	13.69 ± 15.92	12.12 ± 11.25	−0.34	33
REM sleep latency night 1	93.20 ± 33.37	95.20 ± 31.39	0.18	33
REM sleep latency night 2	86.41 ± 21.14	80.73 ± 36.23	−0.57	33
Total sleep time (min) night 1	419.15 ± 83.95	410.22 ± 62.35	−0.36	33
Total sleep time (min) night 2	427.93 ± 63.17	369.02 ± 45.18	−3.19*	30.8
Stage 2 sleep time (min) night 1	190.61 ± 44.26	182.16 ± 50.22	−0.53	33
Stage 2 sleep time (min) night 2	186.89 ± 30.28	175.20 ± 29.03	−1.17	33
Stages 3 + 4 sleep time (min) night 1	105.44 ± 24.57	98.43 ± 38.83	−0.63	26.8
Stages 3 + 4 sleep time (min) night 2	105.22 ± 24.25	96.06 ± 28.65	−1.02	33
REM sleep time (min) night 1	89.22 ± 40.93	92.65 ± 26.27	0.29	33
REM sleep time (min) night 2	95.20 ± 29.70	52.76 ± 17.97	−5.08***	33
REMD (min)	−22.66 ± 46.38	42.63 ± 15.80	5.64***	21.1
REM sleep time (%) night 1	20.28 ± 7.05	22.47 ± 4.98	1.06	33
REM sleep time (%) night 2	21.87 ± 5.08	14.28 ± 4.44	−4.70***	33
REMD (%)	−15.02 ± 28.15	36.57 ± 15.90	6.72***	27.1

Values are given as mean ± SD. ***$P < 0.001$, *$P < 0.05$.

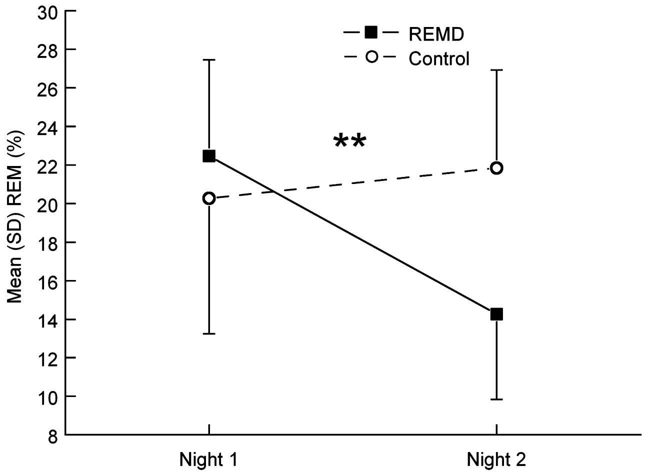

Figure 1. Rapid eye movement (REM)% for baseline (night 1) and REM deprivation (REMD; night 2) recordings. REM sleep was significantly reduced from night 1 to night 2 for the REMD group but not for the control group. **Interaction effect, $P < 0.00001$.

Table 2 Valence and arousal ratings (mean ± SD) of neutral and negative pictures for all subjects ($n = 40$)

	Neutral pictures	*Negative pictures*	*t(39)*
Valence			
Evening	5.90 ± 1.26	3.23 ± 1.39	11.09***
Morning	5.81 ± 1.05	3.86 ± 1.50	9.74***
Arousal			
Evening	3.73 ± 1.50	5.21 ± 1.96	−5.20***
Morning	2.88 ± 1.44	4.22 ± 2.01	−5.49***

Values are given as mean ± SD. ***$P < 0.001$.

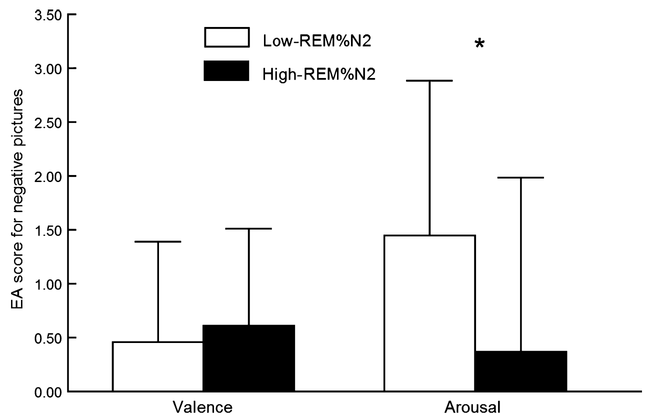

Figure 2. Mean (+SD) emotional adaptation (EA) scores on $EA_{valence}$ and $EA_{arousal}$ for the high- and low-rapid eye movement (REM)%N2 groups. Low-REM%N2 subjects showed higher $EA_{arousal}$ scores (greater cross-night decrease in arousal) than did high-REM%N2 subjects. *$P < 0.05$.

(all $P > 0.391$) however. The difference for $EA_{arousal}$ was apparently not due to the observed difference in sleep efficiency because an ANCOVA with *sleep efficiency N2* as covariate did not eliminate the effect ($F_{1,32} = 4.52$, $P = 0.041$). Finally, the difference was not attributable to the fact that low-REM%N2 subjects tended to have, on average, earlier awakening times as reflected in a measure of *mean time from sleep onset to each awakening N2* (mean 370.6 ± 55.6 min) than did high-REM%N2 subjects (mean 396.1 ± 38.1 min; $F_{1,32} = 2.55$, $P = 0.120$) because an ANCOVA with this measure as a covariate also did not eliminate the effect ($F_{1,31} = 4.25$, $P = 0.048$).

No significant correlations were observed between REM%N2 and $EA_{valence}$ or $EA_{arousal}$ to negative pictures for the total sample ($r_{35} = 0.012$, $P = 0.95$, $r_{35} = -0.202$, $P = 0.24$), the high REM%N2 group ($r_{35} = -0.131$, $P = 0.58$, $r_{35} = 0.333$, $P = 0.15$) or the low REM%N2 group ($r_{35} = -0.051$, $P = 0.86$, $r_{35} = -0.172$, $P = 0.54$).

Association of dream emotions with emotional adaptation

Analyses of dream emotions included 39 subjects (26 women, 13 men; mean age 25.3 ± 4.4); one was excluded for failing to report dream mentation on the experimental night. Subjects were split into high-EA and low-EA groups using median $EA_{valence}$ (low-EA < 0.67, $n = 19$; high-EA ≥ 0.67, $n = 20$) and median $EA_{arousal}$ (low-EA < 1.00, $n = 17$; high-EA ≥ 1.00, $n = 22$) scores for the negative pictures because median values provided much clearer separations of the distributions than did mean values.

A total of 122 REM awakenings were performed; 114 (93.4%) were accompanied by dream mentation. Among the recalled dreams, 95.6% ($n = 109$) contained emotions; 35.8% ($n = 39$) of these were rated as negative, 26.6% ($n = 29$) as neutral and 37.6% ($n = 41$) as positive. Low- and high-EA groups did not differ in the number of dreams reported, the number of dreams containing emotions and the number of dreams containing positive or negative emotions (all $P > 0.05$). However, marginally more dreams were evaluated as neutral by the high- versus low-$EA_{arousal}$ group ($t_{12} = -2.13$, $P = 0.054$) but not by the high- versus low-$EA_{valence}$ group ($P = 0.243$).

As shown in Fig. 3, a group main effect for whole-night NEI ($F_{1,36} = 9.09$, $P = 0.005$) indicated that negative dream emotion was lower for the high-$EA_{valence}$ group (mean 1.37 ± 0.11) than for the low-$EA_{valence}$ group (mean 1.64 ± 0.38). An analysis of the $EA_{valence}$ difference by REM period indicated that the effect was robust for the morning REM period (mean 1.28 ± 0.17 versus 1.67 ± 0.39; $F_{1,36} = 16.59$, $P = 0.0002$) but also present for the third REM period (mean 1.39 ± 0.19 versus 1.71 ± 0.47; $F_{1,25} = 5.41$, $P = 0.028$). In both cases, subjects who had the lowest intensities of negative emotions in dreams also showed the highest morning decreases in negativity ratings (Fig. 3). Differences were not obtained for REM periods 4–6 (all $P > 0.13$). Moreover, no differences were found for $EA_{arousal}$.

A multivariate analysis for the ensemble of dream emotions confirmed and clarified this effect, demonstrating lower emotion intensity ratings for high- than for low-$EA_{valence}$

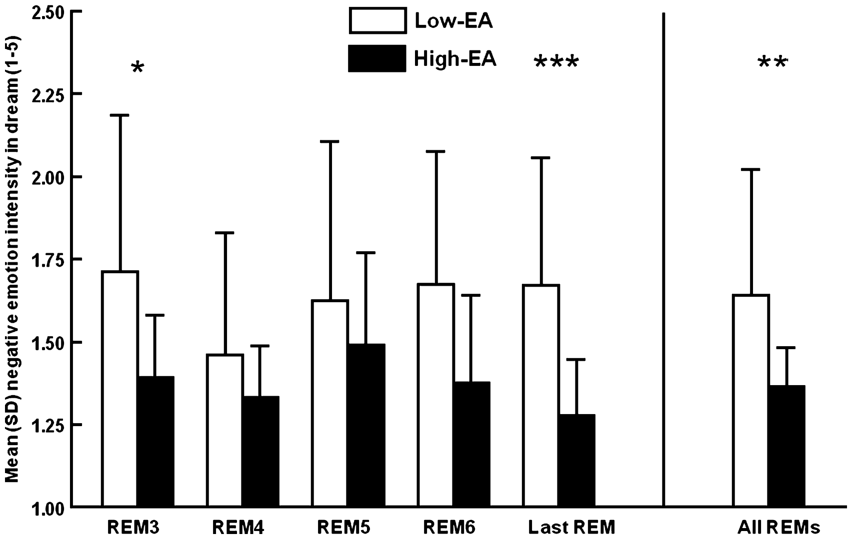

Figure 3. Mean (± SD) negative emotional intensity (NEI) scores for dreams by subjects above (high-EA) and below (low-EA) the median on the emotional adaptation-valence ($EA_{valence}$) measure. Well-adapted subjects (high-EA), who showed the largest evening-to-morning decrease in picture negativity ratings, had lower mean NEI and lower NEI for dreams from the third and last rapid eye movement (REM) periods. $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$.

Table 3 Mean intensities of 10 dream emotions (± SD) for low- and high-emotional adaptation ($EA_{valence}$) groups

	Low-EA (n = 19)	*High-EA (n = 19)*	*F*	*P*[†]
Alert	3.32 ± 0.74	2.76 ± 0.77	5.339	0.027
Happy	2.78 ± 1.23	2.70 ± 0.58	0.073	0.789
Surprised	2.39 ± 0.98	1.98 ± 0.69	2.196	0.147
Sad	**1.81 ± 0.89**	**1.08 ± 0.15**	**12.636**	**0.001**
Angry	1.43 ± 0.58	1.14 ± 0.25	3.849	0.058
Disgusted	1.25 ± 0.54	1.04 ± 0.15	2.428	0.128
Arrogant	1.37 ± 0.63	1.09 ± 0.19	3.568	0.067
Scared	1.41 ± 0.57	1.14 ± 0.27	3.598	0.066
Shy	1.33 ± 0.46	1.05 ± 0.16	6.036	0.019
Guilty	1.31 ± 0.60	1.07 ± 0.19	2.717	0.108

[†]Error-adjusted $P < 0.005$, two-tailed significant comparisons in bold.

groups (Pillai's trace 0.44, $F_{10,27} = 2.13$, $P = 0.058$, partial $\eta^2 = 0.44$). As shown in Table 3, the only significant univariate effect consisted of lower sadness ratings ($F_{1,36} = 12.64$, $P = 0.001$, $\eta^2 = 0.26$) for the high-$EA_{valence}$ group, although the latter also tended to rate both shyness ($F_{1,36} = 6.04$, $P = 0.019$, $\eta^2 = 0.14$) and alertness ($F_{1,36} = 5.34$, $P = 0.027$, $\eta^2 = 0.13$) as lower than did the low-$EA_{valence}$ group. Thus, subjects whose intervening dreams contained lower ratings of sadness, shyness and alertness gave less negative morning (versus evening) evaluations of negative pictures. To exclude the possibility that this association was due to socially desirable responding to both picture valence and dream emotion intensity, univariate analyses were repeated with Lie scale scores from the Eysenck Personality Inventory as a covariate; the effects persisted (sadness: $F_{2,35} = 7.38$, $P = 0.010$, $\eta^2 = 0.17$; shyness: $F_{2,35} = 3.83$, $P = 0.058$, $\eta^2 = 0.10$; alertness: $F_{2,35} = 5.79$, $P = 0.022$, $\eta^2 = 0.14$). When Lie, Neuroticism and Depression scale scores were all covaried, the effects were still evident (sadness: $F_{4,32} = 7.58$, $P = 0.010$, $\eta^2 = 0.19$; shyness: $F_{4,32} = 3.95$, $P = 0.056$, $\eta^2 = 0.11$; alertness: $F_{4,32} = 5.48$, $P = 0.026$, $\eta^2 = 0.15$).

Closer examination of dreams from REM periods across the night revealed that the group difference for sadness paralleled that for NEI, i.e. was robust for the morning REM period ($t_{19.5} = 3.01$, $P = 0.007$), present for REM period 3 ($t_{12} = 2.38$, $P = 0.035$), marginal for REM period 4 ($t_{15} = 2.06$, $P = 0.052$) and absent for REM periods 5 ($t_{22} = 1.44$, $P = 0.165$) and 6 ($t_{11} = 1.11$, $P = 0.290$). With correction for multiple comparisons, only the morning REM period effect remains statistically reliable.

No multivariate or univariate differences were found for the high- and low-$EA_{arousal}$ group comparisons (Pillai's trace 0.16, $F_{10,27} = 0.51$, $P = 0.870$).

Correlational analyses revealed that, although $EA_{valence}$ was only marginally associated with whole-night dream NEI ($r_{38} = -0.294$, $P = 0.073$), it was associated exclusively with dream NEI for the morning REM period ($r_{38} = -0.414$, $P = 0.010$; all other $P > 0.15$). The higher the NEI of the morning dream, the lower the difference between the morning and evening negative picture ratings. Analysis of the same correlations by subgroup did not reveal any significant relationships (all $P > 0.15$). Analyses of $EA_{arousal}$ correlations produced only trends (all $P > 0.025$) which did not survive error rate correction ($0.05/5 = 0.01$).

To assess the possibility that an emotional 'carry-over' effect explains the latter result, a correlation between the morning REM period dream NEI and morning valence ratings of negative pictures was conducted. A significant negative correlation ($r_{38} = -0.441$, $P = 0.006$) revealed that, as NEI ratings of the morning dreams increased, valence ratings of the morning pictures became more negative. No correlations for other REM periods exceeded the adjusted threshold of $P < 0.01$, although a similar correlation was obtained for the dream NEI of REM period 3 ($r_{27} = -0.424$, $P = 0.027$). This, and the finding that no correlations were found between dream NEI (an intensity measure) and morning ratings of negative picture intensity (all $P > 0.10$), cast some doubt on the carry-over effect interpretation.

Finally, to determine if the task of rating pictures in the evening influenced subsequent dreams, correlations were calculated between evening valence/arousal ratings and NEI scores for the dreams of subsequent REM periods. For the entire sample, no correlations exceeded the adjusted *P*-value of 0.01 (all $P > 0.15$). Similarly, for the low-$EA_{valence}$ group, no correlations exceeded the adjusted *P*-value, although a trend was seen between evening valence ratings and dream NEI for the morning REM period ($r_{19} = -0.426$, $P = 0.069$); more negative picture ratings were associated with more negative morning dreams. For the high-$EA_{valence}$ group, trends were found for correlations between evening ratings of both valence ($r_{19} = -0.470$, $P = 0.042$) and arousal ($r_{19} = 0.453$, $P = 0.052$) and the whole-night dream NEI measure, while a significant correlation was found for arousal ratings and REM period 3 dream NEI ($r_{14} = 0.659$, $P = 0.010$). In this case, evening ratings that were negative and intense were both associated with intensely negative dream emotions.

DISCUSSION

The REMD and negative emotions induction procedures were successful, in that REMD subjects displayed less REM sleep than did control subjects, and the presentation of unpleasant pictures led to more negative and more arousing ratings at both time points than did the presentation of neutral pictures. However, the first hypothesis that REMD would impair adaptation to negative pictures was not supported. In fact, an opposite relationship was suggested in that subjects who had relatively little REM sleep on the deprivation night had better adaptation scores than those who had relatively more REM sleep. This finding fails to support the hypothesis that REM sleep enables EA and is, rather, consistent with the finding (Wagner *et al*., 2002) that negative ratings of IAPS pictures are increased following sleep that is predominantly REM rather than NREM in nature. The latter authors found an association with picture valence rather than with arousal, but nonetheless also conclude that their findings do not support a 'cathartic' function for REM sleep. Rather, they suggest that REM sleep enhances 'aversive reactivity' to negative pictures.

Our results might seem to parallel the well-known finding (Vogel *et al*., 1975) that REMD temporarily alleviates dysphoric symptoms in depressed patients. This and other evidence of abnormal REM sleep during depression, such as increased REM density in the first REM period, have led to the suggestion (Cartwright *et al*., 1998b) that mood improvements after sleep deprivation are due to the elimination of some or all of depressed subjects' dysfunctional REM sleep. However, the fact that our subjects were screened for depressive symptoms (BDI scores < clinical threshold of 14) limits such a conclusion for our results. Nonetheless, it remains possible that task-induced negative mood, although mild, is nevertheless REM sensitive and responds favorably to REMD by a similar mechanism. Further study would be needed to determine if this effect is temporary as it is with depressed subjects.

Other evidence linking dreaming to an evening-to-morning emotional change also did not support our expectations. High-$EA_{valence}$ subjects tended to rate their negative dream emotions as less intense overall and to rate dream sadness, in particular, as less intense than did low-$EA_{valence}$ subjects, even though the groups' dream emotions did not differ in other respects. These findings nevertheless implicate dreamed emotions in cross-night mood improvements as has been shown in several studies (Cartwright, 1991, 2005; Kramer and Roth, 1973, 1980). The latter effects were largely attributable to the presence of dreamed characters (Nielsen and Lara-Carrasco, 2007) and the mood changes were either in unhappiness or depression more generally. Our own analyses also indicated that the dream emotion most closely related to the evening-to-morning shift is sadness, although trends were also seen for shyness and alertness.

The correlational nature of the latter finding leaves open the possibility that picture valence ratings and dream emotion intensity ratings were both biased by a third factor, such as social desirability or affective disorder. However, the fact that a similar correlation was not seen for $EA_{arousal}$ ratings – which more closely resemble dream emotion intensity ratings than do $EA_{valence}$ ratings – argues against this interpretation. Moreover, the observed correlation between dream emotions and $EA_{valence}$ ratings survived statistical control of social desirability and other personality measures. In the light of these considerations, attempted replication of this finding within an experimental design seems warranted.

The possibility that morning ratings of negative pictures were influenced by the 'carry-over' of dream emotions into the morning rating task was supported to some extent. Ratings of NEI for the morning dream, especially sadness, correlated almost exclusively with morning valence ratings and (therefore) the $EA_{valence}$ score. Note, however, that similar, albeit, marginal correlations were also observed for the dream negativity ratings of REM period 3 – and for sadness intensity ratings of REM periods 3 and 4 – and no correlations were observed between dream emotion intensity and the more similar $EA_{arousal}$ score. These findings, together with the fact that the REM sleep carry-over effect is generally considered to last in the order of minutes (Dinges, 1990; Nielsen *et al*., 1989; Stickgold *et al*., 1999), rather than the hour that elapsed between final dream report and the morning rating task in the present study, tend to cast doubt on the carry-over explanation. At the very least, the findings suggest that the nature and duration of emotional carry-over effects deserves additional study.

Our group difference in sadness displayed a cross-night change, i.e. was apparent for REM period 3, less evident for REM period 4, absent for REM periods 5 and 6 and then apparent again for the morning REM period. This pattern may constitute an instance of 'progressive-sequential' dreaming that others have linked to EA (for review, see Kramer, 2007). Alternatively, it may indicate that dream-mediated EA is influenced by either circadian or sleep homeostatic processes. In the light of evidence that dreams from the first REM period of the night are preferentially involved in emotion regulation (Cartwright *et al*., 1998a,b), it is possible that we would have observed even larger effects if we had assessed dreams from REM periods 1 and 2 of the experimental night. Future research should clearly take this into account.

Correlational analyses also provided some evidence that the presleep picture rating task influenced subsequent dreams, but that this influence was different for subjects who scored high and low in the adaptation measure. Negative emotional intensity of the dreams of subjects with high adaptation scores correlated with both negative valence and negative arousal ratings of the negative pictures viewed prior to sleep. This was particularly true of dream negativity for the earlier dreams of REM period 3. Subjects with low adaptation scores did not show this pattern of correlations, but showed a trend implicating dreams from the morning REM period.

In conclusion, the present results do not support the hypothesis of a straightforward EA function for REM sleep. Rather, they replicate other work indicating that REM sleep enhances reactivity to emotionally negative stimuli. They also suggest that REM deprivation decreases the intensity of negative emotions and they link a decreased intensity of dream emotions (sadness in particular) to a cross-night improvement in ratings of picture valence. The results are consistent with the notion that REM sleep and dreaming processes are implicated in two different dimensions of emotional processing: the REM sleep measure was associated with EA differences on the arousal dimension whereas dream emotions were associated with EA differences on the valence dimension. Kramer and colleagues (Kramer and Roth, 1973, 1980) have drawn a similar conclusion from their findings that sleep and dream measures correlate with different cross-night mood-change measures. Thus, it may be that REM sleep and dreaming processes act independently on different features of emotion in facilitating cross-night processing of negative stimuli.

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