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The role of REM sleep in the processing of emotional memories: Evidence from behavior and event-related potentials

S. Groch, I. Wilhelm, S. Diekelmann, J. Born *

Department of Neuroendocrinology, University of Luebeck, Ratzeburger Allee 160, 23538 Luebeck, Germany
Institute of Medical Psychology and Behavioral Neurobiology, University of Tuebingen, Otfried Mueller-Strasse 25, 72076 Tuebingen, Germany

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ABSTRACT

Emotional memories are vividly remembered for the long-term. Rapid eye movement (REM) sleep has been repeatedly proposed to support the superior retention of emotional memories. However, its exact contribution and, specifically, whether its effect is mainly on the consolidation of the contents or the processing of the affective component of emotional memories is not clear. Here, we investigated the effects of sleep rich in slow wave sleep (SWS) or REM sleep on the consolidation of emotional pictures and the accompanying changes in affective tone, using event-related potentials (ERPs) together with subjective ratings of valence and arousal. Sixteen healthy, young men learned 50 negative and 50 neutral pictures before 3-h retention sleep intervals that were filled with either SWS-rich early or REM sleep-rich late nocturnal sleep. In accordance with our hypothesis, recognition was better for emotional pictures than neutral pictures after REM compared to SWS-rich sleep. This emotional enhancement after REM-rich sleep expressed itself in an increased late positive potential of the ERP over the frontal cortex 300–500 ms after stimulus onset for correctly classified old emotional pictures compared with new emotional and neutral pictures. Valence and arousal ratings of emotional pictures were not differentially affected by REM or SWS-rich sleep after learning. Our results corroborate that REM sleep contributes to the consolidation of emotional contents in memory, but suggest that the affective tone is preserved rather than reduced by the processing of emotional memories during REM sleep.

1. Introduction

Emotional contents are well known to be remembered better than neutral contents (McGaugh, 2000). An emotional event elicits a response that includes subjective feelings, behaviors indicating approach or avoidance (like facial expressions), and various physiological responses, all of which to a certain extent can reoccur during later remembering (Lang, 1995; Schelling et al., 2003). The two components of an emotional memory, i.e. the memory information about the experienced event and the affective component, develop over time, sometimes with different dynamics. Dating back to Sigmund Freud's clinical observations (Freud, 1900), a long standing tradition developed proposing that dream sleep as well as the physiologically more accurately defined stage of rapid eye movement (REM) sleep is involved in the emotional processing of memories, possibly exerting a cathartic influence on exuberant emotions. Along this line, a recent model proposed that REM sleep, on the one hand, plays an important role in maintaining the content of an emotional event in memory and, on the other hand, simultaneously reduces its associated affective tag (Van der Helm & Walker, 2009; Walker, 2009). As an underlying mechanism it was proposed that during REM sleep emotional representations involving the amygdala are reactivated in the absence of noradrenergic activity which mediates the arousal during encoding of an emotional event. However, empirical evidence for this concept is surprisingly scarce.

There is indeed a growing number of studies indicating that REM sleep facilitates the consolidation of emotional memories. However, most of these studies disregarded that aspects of memory content and emotionality may be differentially influenced. Thus, the amount of post-learning REM sleep was revealed to be positively correlated with retention of emotional memories (Nishida, Pearsall, Buckner, & Walker, 2009). In a comparison of effects of early nocturnal retention periods of sleep with predominant slow wave sleep (SWS) and late REM-rich periods of retention sleep, late REM-rich sleep improved retention of emotional with reference to neutral stories distinctly more than early SWS-rich sleep (Wagner, Gais, & Born, 2001). The enhancing effect of REM-rich sleep on the retention of emotional stories was also significant in comparison with the effects of a corresponding wake retention interval.

* Corresponding author at: Institute of Medical Psychology and Behavioral Neurobiology, University of Tuebingen, Otfried Mueller-Strasse 25, 72076 Tuebingen, Germany. Fax: +49 7071 29 25016.
E-mail address: jan.born@uni-tuebingen.de (J. Born).

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So far, only a few studies directly addressed the issue of sleep-associated changes in the affective responses to aversive emotional and neutral pictures with rather inconsistent findings (Baran, Pace-Schott, Ericson, & Spencer, 2012; Van der Helm et al., 2011; Wagner, Fischer, & Born, 2002). Wagner et al. (2002) used the approach of splitting the night into early SWS-rich and late REM-rich periods of retention sleep, and affective responses were assessed by subjective ratings of the pictures' valence (i.e. positive to negative) and arousal (i.e. degree of excitement). Surprisingly, REM-rich retention periods of sleep distinctly increased, rather than decreased, the valence (i.e. rated aversiveness) of the emotional pictures seen before the sleep interval in comparison with new emotional pictures not seen before. The enhancing effect on subjectively experienced aversiveness was even more pronounced after a full night of sleep. These findings basically agree with a recent study (Baran et al., 2012) where affective ratings of emotional pictures were relatively reduced after the wake rather than sleep retention interval. Of note, because in these studies the picture stimuli were also rated before retention sleep, knowledge of this first rating may have confounded the critical rating response after retention sleep. Also, ratings were only affected on the valence dimension, whereas arousal ratings, which are commonly assumed to reflect better the affective tone, remained uninfluenced by sleep in those studies.

However, the findings regarding subjective ratings are clearly at variance with a proposed reducing effect of REM sleep on the affective tone of emotional memory (Walker, 2009) which is also suggested by a recent report of reduced amygdala activation in response to familiar negative pictures when encoding was followed by sleep (van der Helm et al., 2011). Yet, functional magnetic resonance imaging of amygdala activity in other studies did not confirm this picture, revealing that post-acquisition sleep can increase activity in the extended amygdala at recognition of emotionally aversive pictures (Payne & Kensinger, 2011; Sterpenich et al., 2009).

Overall, it remains an unresolved question whether REM sleep enhances or reduces the affective tone of an emotional memory, and there is indeed no investigation yet, going beyond behavioral measures, that targets the combined role of REM sleep on the consolidation of the content and simultaneous processing of the affective tone of an emotional memory. Event-related potentials (ERPs) and especially the late positive potentials (LPPs) of the ERP have been proven sensitive to the effects of memory accuracy as well as to the affective tone of a memory (Schupp, Flaisch, Stockburger, & Junghöfer, 2006). The LPP refers to a complex of overlapping positive potential components in the latency range between 300–800 ms after stimulus onset. LPPs are sensitive to enhancing influences of attention and emotionality, thereby facilitating encoding at learning as well as recognition at retrieval (Cacioppo, Crites, Berntson, & Coles, 1993; Diedrich, Naumann, Maier, & Becker, 1997; Johnston, Miller, & Burleson, 1986; Schupp et al., 2000). In particular, frontal positivity 300–500 ms post-stimulus has been linked to memory accuracy, as it was consistently found to increase with accuracy of familiarity-based item memory recognition (Rugg et al., 1998; Woroch & Gonsalves, 2010; Yu & Rugg, 2010). On the other hand, ERP positivity peaking 300–600 ms post-stimulus over posterior brain sites was consistently found to be enhanced in response to emotional pictures in comparison with neutral pictures (Codispoti, Ferrari, & Bradley, 2007; Krug, Plihal, Fehm, & Born, 2000; Pollatos, Kirsch, & Schandry, 2005; Schupp et al., 2000). Arousal, evoked by emotional pictures, covaried with ERP positivity with largest effects over posterior sites during a late time window of 500–800 ms post-stimulus (Dolcos & Cabeza, 2002; Pollatos et al., 2005; Rozenkrants, Olofsson, & Polich, 2008).

In the present study we combined behavioral measurements of memory and subjective ratings of valence and arousal with ERP recordings to dissociate effects of post-learning REM sleep vs. SWS on the consolidation of the emotional content of a memory and the processing of its affective tone. Subjects memorized neutral and negative emotional pictures taken from the International Affective Picture System (IAPS) before 4-h retention periods filled with 3 h of either early SWS-rich or late REM sleep-rich nocturnal sleep. Recognition memory as well as affective ratings was assessed after the sleep periods. ERPs were recorded during both learning and recognition testing. If REM sleep supports specifically the consolidation of the contents of emotional memories, then post-encoding REM sleep, in comparison with SWS, should enhance later recognition of the aversive pictures together with frontal ERP positivity 300–500 ms post-stimulus onset in response to these pictures. If REM sleep in parallel reduces the affective tone, subjectively rated emotional arousal should be decreased after REM-rich periods of sleep and this should be accompanied by a relative decrease in posterior ERP positivity 500–800 ms post-stimulus onset.

2. Materials and methods

2.1. Participants

Sixteen native German speaking healthy men (mean age: 22.06 years, range 20–26 years) were recruited at the University of Luebeck. All were non-smokers, free of medication and had no history of neurological, psychiatric or endocrine disorders. Participants had followed a normal sleep-wake rhythm (i.e. no shift work, usual sleep time from 2300–0700 h) for at least four weeks before the experiments. Prior to the experiments, subjects were accustomed to sleeping under laboratory conditions during an adaptation night, including wearing EEG caps (Easy Cap GmbH, Herrsching, Germany) with electrodes for polysomnographic recordings. On experimental days participants were required to get up at 0700 h and not to consume caffeine or alcohol. The study was approved by the ethics committee of the University of Luebeck and all participants gave written informed consent prior to participation.

2.2. Design and procedure

Fig. 1A illustrates the study design. The study was conducted according to a within-subject cross-over design with the order of conditions ('early sleep' vs. 'late sleep') balanced across subjects, and an interval of at least two weeks between the subject's two conditions. Subjects reported to the lab at 2100 h for the early night condition and at 2200 h for the late night condition. Each condition started with the attachment of electrodes. For the early sleep condition, subjects learned the pictures (2200–2230 h) immediately before an early 4-h retention interval including 3 h of SWS-rich sleep, and were then tested on recognition memory of the pictures. For the late sleep condition, subjects first slept for about 3 h (starting 2300 h) before the learning phase took place 0300–0330 h. Then, they slept for another 3 h filled with REM-rich sleep, before recognition memory was tested in the morning (0715–0800 h), after a retention interval of 4 h in total. Thus, the retention intervals in the two experimental conditions were characterized by either high amounts of SWS (early sleep) or high amounts of REM sleep (late sleep). Lights-off for the early sleep interval was at 2300 h, and at 0330 h for the late sleep interval, with the start of the 3-h sleep period determined by the first signs of sleep stage 2 for more than 1 min. Subjects were awakened from sleep stage 1 or 2 after 3 h of sleep, and subsequent learning or retrieval testing was timed 45 min thereafter to allow subjects to recover from sleep inertia.