pii: sp-00734-15 http://dx.doi.org/10.5665/sleep.6310

SLEEP AND TRAUMA

Effects of Sleep after Experimental Trauma on Intrusive Emotional Memories

Birgit Kleim, PhD[1,2]; Julia Wysokowsky, MSc[1]; Nuria Schmid, MSc[1]; Erich Seifritz, MD[2]; Björn Rasch, PhD[3]

[1]Department of Experimental Psychopathology and Psychotherapy, University of Zurich, Switzerland; [2]Department of Psychiatry, Psychotherapy and Psychosomatics, Psychiatric Hospital, University of Zurich; [3]Division of Biopsychology, Department of Psychology, University of Fribourg, Switzerland

Study Objectives: To investigate sleep's effect in the immediate aftermath of experiencing an analog trauma in the laboratory on reducing intrusive emotional memory formation.

Methods: Sixty-five healthy women were exposed to an experimental laboratory trauma. They viewed a neutral and a trauma film in the laboratory and were randomly allocated to either a group that slept following film viewing or a group that remained awake. Sleep was recorded with electroencephalogram in a subgroup of participants in the sleep group. All participants recorded intrusive memories in the week following the film.

Results: The sleep group experienced fewer and less distressing intrusive trauma memories compared to the wake group. These effects were particularly evident toward the end of the week. Duration spent in stage N2 as opposed to light N1 sleep, a higher number of fast parietal sleep spindles and a lower rapid eye movement sleep density predicted intrusion frequency.

Conclusions: Our results have clinical implications and set the ground for early-intervention sleep studies following trauma and prevention of chronic posttrauma disorders.

Keywords: emotional memory, intrusion, memory consolidation, PTSD, sleep, trauma

Citation: Kleim B, Wysokowsky J, Schmid N, Seifritz E, Rasch B. Effects of sleep after experimental trauma on intrusive emotional memories. *SLEEP* 2016;39(12):2125–2132.

Significance

Sleep post analogue trauma was associated with fewer and less distressing intrusive trauma memories. Sleep characteristics, such as N2 sleep and sleep spindles were associated with intrusive memory frequency. Sleep early after trauma may be protective and play an important role in early intervention in facilitating adaptation to trauma.

INTRODUCTION

Sleep's role in the context of experiencing trauma has been a topic of debate that is of central importance to understanding the development of intrusive emotional memories post-trauma.[1] Reexperiencing such spontaneous and emotion-laden trauma memories is a core feature of posttraumatic stress disorder (PTSD), one of the most frequent psychiatric problems following trauma. Such intrusions comprise mostly sensory impressions and emotional responses from the trauma, and are fragmented and disconnected from contextual information,[2] possibly lacking proper integration into hippocampal-cortical memory networks due to extreme arousal at encoding.[3] Over the past decade, successful psychotherapy interventions have been developed that aim to change or weaken the intrusiveness of trauma memories and enhance integration of the trauma memory into survivors' existing network of autobiographical memories. This can be achieved, for example, by imaginal and *in vivo* exposure and by incorporating updated information into the memory.[4,5] Although early pharmacological interventions to depotentiate traumatic memories are currently the subject of active research,[6] integrative memory processes occurring during sleep might have a high potential for trauma memory modulation in the early aftermath of trauma. There are currently two contrasting views regarding sleep's role on trauma memory formation and the development of PTSD. On the one hand, it has been proposed that, via offline consolidation processes, sleep may selectively enhance emotional trauma memories and thus exacerbate intrusive memories and PTSD symptoms.[7,8] On the other hand, sleep may contribute to memory integration and affective depotentiation, hence leading to fewer intrusive trauma memories and decreased PTSD symptoms.[9]

It is now well established that sleep is involved in the consolidation of memories, including emotional memories.[9,10] During nonrapid eye movement (NREM) sleep, recently encoded memories are spontaneously reactivated and gradually integrated into cortical networks of preexisting long-term memories in a process of active system consolidation.[11] The integration of memories during sleep probably relies on an interleaved hippocampal reactivation of new and associated old memories and occurs in a fine-tuned interaction with cortical slow oscillations (< 1 Hz) and thalamocortical fast-spindle activity (13–15 Hz).[12]

Remarkably, several studies suggest that emotional memories are preferentially reactivated and consolidated during sleep,[12–14] leading some authors to suggest that sleep deprivation and sleep disturbances shortly after trauma might have a protective effect. It is argued that sleep deprivation may hamper memory strengthening that may otherwise occur during sleep.[13] In a recent experimental study,[8] sleep deprivation after watching a trauma film indeed reduced intrusive memories on the initial 2 days postfilm. Based on these findings, the authors suggested that sleep deprivation may prevent sleep-dependent memory enhancement by disrupting trauma memory consolidation. However, the effect of sleep was only seen on the first 2 days and was no longer present throughout the remaining study period. That is, no negative effects of sleep were found on affective distress of intrusive memories. Over time, the effect of sleep appeared to reverse in that on days 5–6, the sleep group experienced fewer intrusive memories, although this effect was not significant. A closer look at how the effect of sleep on intrusive memories unfolds over time thus seems warranted.

In contrast with the notion that sleep deprivation following trauma is beneficial, disturbed sleep has been shown to

contribute to PTSD symptoms and is regarded as a risk factor for PTSD development.[15–17] In line with these findings, sleep after emotional learning has been shown to depotentiate affective tone of emotional memories, in spite of strengthening their content.[18] Given the assumption that memory integration promotes voluntary retrieval while simultaneously inhibiting involuntary retrieval of trauma memories, the beneficial role of NREM sleep on memory integration should prevent the formation of intrusive traumatic memories, which has not yet been directly examined.

Here we investigate the effect of sleep after exposure to a traumatic event on formation of intrusive memories in a laboratory study in healthy young females. Based on the aforementioned studies, it was hypothesized that sleep's effect was protective.[9,12–14,19] We also sought to relate sleep stages and candidate indices of sleep assessed via electroencephalography (EEG) (stage 1 and 2 sleep, slow wave sleep, rapid eye movement [REM] sleep, REM density, sleep spindle density) to later intrusive memories.

METHODS

Subjects

Participants were 71 healthy young females, with a mean age of 24 y, standard deviation (SD) = 3.13. Recruitment was restricted to female subjects as the type of trauma (interpersonal violence with a female survivor, for example) is likely to exert differential effects on male and females that would be difficult to control in a mixed sample. Participants were screened to ensure that they or any close relatives or friends had not been exposed to any interpersonal trauma. We also excluded those who reported any psychiatric problems, such as anxiety or depression. These exclusion criteria were assessed over the phone via questions derived from standardized questionnaires, such as the Beck Depression Inventory and Beck Anxiety Inventory. Of 84 subjects recruited via newspaper ads, 10 did not meet these exclusion criteria and were excluded, and 3 chose not to participate or did not attend the laboratory session. Six participants had to be excluded: four participants did not fill in the intrusion diary, one participant in the sleep group did not sleep, and one participant experienced the neutral film as traumatizing due to a prior personal life event that had remained undisclosed during initial screening. Data from 65 subjects were included in the analyses, 32 in the sleep and 33 in the wake condition. Subjects received 50 Swiss francs (approximately US $55) as compensation for their participation.

Procedure

The local ethics review board at the University of Zurich approved the study. Participation included three appointments: an initial screening session to assess eligibility over the phone, the laboratory session during which participants filled in questionnaires and viewed the films, and an assessment at the laboratory 7 days later to return the intrusion diary, discuss entries, and fill in some more questionnaires, see Figure 1. After complete description of the study to participants, written informed consent was obtained. Participants then completed a brief screening in order to assess whether they fulfilled diagnostic criteria for depression or anxiety disorder. Laboratory sessions took place in a temperature-controlled, sound-attenuated, and darkened room at the university. Participants were randomly assigned to the sleep or wake groups. The sleep group slept at home after film viewing. In a subgroup of participants (n = 18), sleep was additionally polysomnographically recorded using a mobile recording device (see following paragraphs). Participants in the wake group viewed the movies either in the morning, i.e., in the hours between 09:00 and 11:00 and stayed awake for at least 8 h afterward (daytime wake) or in the evening and were sleep deprived during the night. Participants in the sleep group viewed the movies in the evening, i.e., in the hours between 18:00 and 21:00, and slept following film viewing. Because the results were highly comparable between these two conditions, data were collapsed across the day-wake and sleep deprivation conditions.

Trauma and Neutral Films

The trauma film consisted of a 12-min scene from the film "Irreversible", directed by Gaspar Noe. It comprised a fictional scene depicting physical and sexual violence and was played on a 19-inch monitor in a darkened laboratory room. Participants viewed both films individually, without presence of the experimenter in the room. They were asked to pay full attention to the film without diverting attention away and were later asked to rate gaze aversion during film viewing. Participants were informed on the study advertisement, telephone screening, and informed consent process that the video contained graphic material that some individuals may find disturbing and that they were free to withdraw from the study at any time without penalty. The neutral film was a film of equal length containing a scene from a National Geographic compilation of blue whales. Participants each viewed a trauma as well as a neutral film, in randomized order.

Following film viewing, participants were asked to rate themselves, using the widely used measure of self-reported fear, the Subjective Units of Distress Scale (SUDS)[20] as to how distressed they felt. The SUDS was a 100-point scale on which participants rated their level of distress. In addition, participants filled in questionnaires and were introduced to their personal intrusion diary.

One-Week Intrusion Diary

Participants kept a pen-and-paper intrusion diary over 7 days following the laboratory session. The diary was prepared and explained to them and they were asked to briefly describe in writing each intrusive memory relating to the film at the time of occurrence (or as soon as possible). They were educated about intrusive memories and asked to note each intrusive memory, including content, vividness, distress, and intrusiveness characteristics for each memory they experienced during this time. They also recorded memory characteristics, i.e., vividness and distress for each of the memories, on a scale of 0 to 100 (not at all vivid/distressing to extremely vivid/distressing).

Follow-up Assessment

Patients returned to the laboratory 1 w later to discuss their diary and complete some additional questionnaires.

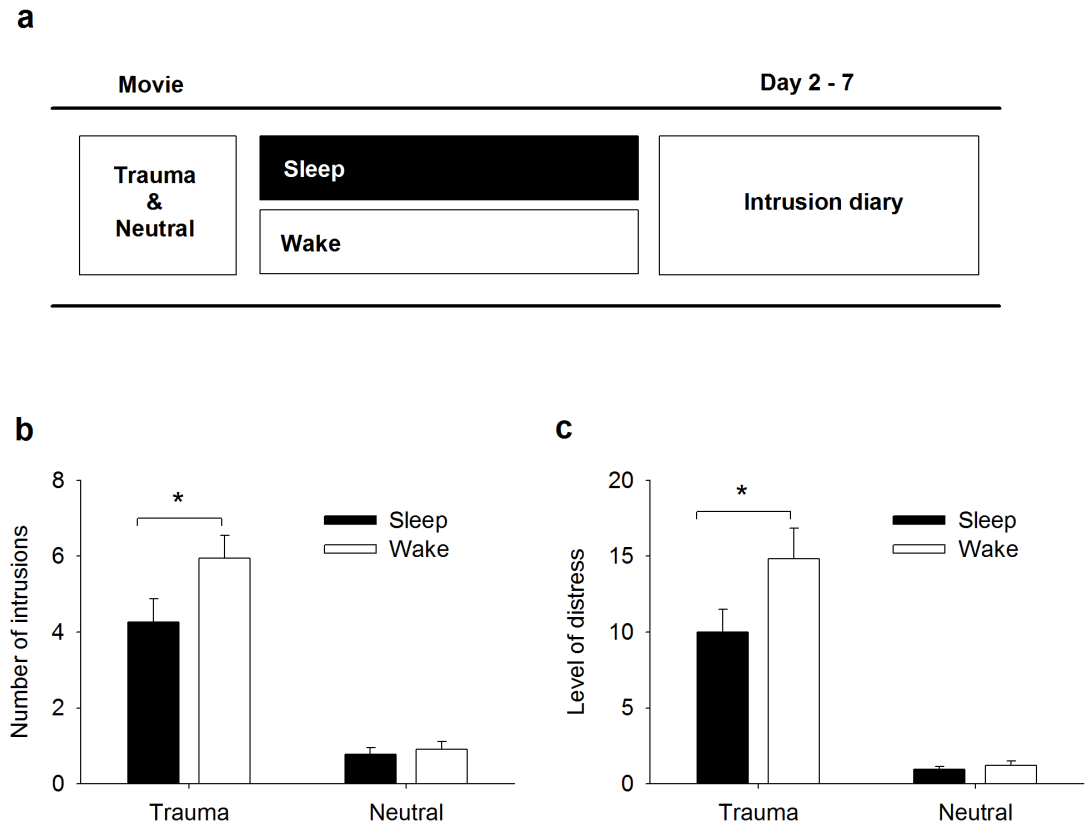

Figure 1—Effects of sleep on intrusive memory frequency. Following exposure to a trauma movie and a neutral movie, participants either slept or remained awake and then recorded intrusive memories of either movie during the following 6 days in an intrusion diary (**a**). Participants who slept report fewer intrusive trauma, but not neutral memories compared to those who remained awake (**b**). Moreover, intrusive trauma memories were less distressing in those who slept compared to those who remained awake, whereas no differences were found for neutral memories (**c**).

Sleep Recordings

Sleep was recorded using a portable EEG machine (SOMNOscreen EEG 10/20, SOMNOmedics, Randersacker, Germany), which participants took to their home. Sleep was recorded in participants' natural environment on two occasions (one initial recording was conducted in order to get participants accustomed to the EEG equipment in the night prior to the laboratory session) on Fz, Cz, Pz, and Oz channels according to the international 10/20 system. The left mastoid was used as reference. In addition, electrooculography, chin electromyography, and electrocardiography were recorded. Sleep parameters and architecture were determined using a validated automatic scoring algorithm[21] according to standard criteria of the American Academy of Sleep Medicine.[22] All polysomnographic recordings were additionally checked by a sleep expert to ensure scoring accuracy and corrected when necessary. In addition, all recordings were examined individually to assess the occurrence of sleep.

Spindle Analysis

Slow (< 13 Hz) and fast spindles (> 13 Hz) were separately identified at the three selected EEG recording sites (Fz, Cz, Pz) during NREM sleep stage 2, based on an algorithm adopted from previous studies.[23] In brief, frequency power was extracted in the frequency bands of interest (10–13 Hz; 13–15 Hz), and the events were counted for which the power signal exceeded a fixed threshold (± 10 muV) for an interval lasting 0.5–3 sec. Spindles were counted separately in each channel during EEG segments free of movement artifacts (maximal electromyography difference < 150 muV). To calculate mean spindle density, mean spindle counts were divided by the number of analyzed 30-sec epochs. The two separate spindle bands were chosen based on previous studies that demonstrated the presence of two types of spindles in humans possibly linked to different aspects of cognitive function, i.e., slow spindles that prevail over the frontal cortex and show greater topographical variability than the fast spindles concentrated over the parietal cortex.[24]

REM Analysis

Average REM density was calculated by dividing the number of 1-sec periods during REM sleep that contained REMs by the total number of 1-sec REM sleep epochs.[25] REMs during REM sleep were detected automatically and were defined as rapid signal changes in the electrooculography channel (> 0.8 mV/s) after movement artefact rejection and application of a 50-msec moving average. Automatic detection was restricted to REM sleep episodes without artefacts.

Table 1—Sociodemographic, clinical and sleep characteristics of sleep versus wake group (n = 65).

Variable	Sleep (n = 32)	Wake (n = 33)	Significance test, P
Age, mean (SD)	24.41 (3.36)	23.21 (2.82)	$F(1, 64) = 2.42$, P = 0.125
Alcohol			χ^2 (2) = 1.27, P = 0.530
Never, n (%)	3 (9.4)	2 (6.2)	
Occasionally, n (%)	28 (87.5)	30 (93.8)	
Daily, n (%)	1 (3.1)	0 (0)	
Smoking			χ^2 (3) = 4.61, P = 0.203
Never, n (%)	21 (65.6)	20 (62.5)	
Occasionally, n (%)	9 (28.1)	7 (21.9)	
1–5 cigarettes per day, n (%)	2 (6.2)	1 (3.1)	
> 5 cigarettes per day, n (%)	0 (0)	4 (12.5)	
Chronotype			χ^2 (4) = 5.12, P = 0.276
Morning type, n (%)	6 (18.8)	11 (34.3)	
Neutral type, n (%)	21 (65.6)	18 (56.2)	
Evening type, n (%)	5 (15.6)	3 (9.3)	
Sleep Quality (PSQ)	4.84 (2.10)	4.91 (1.91)	$F(1, 64) = 0.02$, P = 0.895
Epworth Sleepiness Scale Score	7.47 (3.52)	8.12 (4.17)	$F(1, 63) = 0.46$, P = 0.498
BDI-II Score	4.31 (3.72)	5,13 (3.48)	$F(1, 63) = 0.81$, P = 0.370
BAI Score	14.34 (12.31)	16.28 (11.91)	$F(1, 63) = 0.41$, P = 0.524

BAI, Beck Anxiety Inventory (cut-off for clinical anxiety = 16); BDI, Beck Depression Inventory (cut-off for clinical depression = 18); chronotype was assessed with the Morningness-Eveningness-Questionnaire, D-MEQ; PSQ, Pittsburg Sleep Quality Questionnaire.

Questionnaire Measures

The following self-report questionnaires were administered: chronotype was assessed with the Morningness-Eveningness-Questionnaire,[26] excessive daytime sleepiness was assessed using the Epworth Sleepiness Scale,[27] and sleep quality was assessed using the Pittsburgh Sleep Quality Index.[28] Depressive symptoms were assessed with the Beck Depression Inventory,[29] and anxiety symptoms were assessed with the Beck Anxiety Inventory.[30] A number of other questionnaires were included in the study, assessing mood, affective state, and trait information processing, but these will be reported elsewhere.

Statistical Analysis

Statistical analyses were performed with PASW 21.0 for Macintosh. Group differences in demographic, clinical, and sleep-related variables were analyzed with analyses of variance or chi-square tests. General linear models were calculated to assess the effect of film type (trauma versus neutral) and group (sleep versus wake) on number and distress of intrusive memories recorded during days 2 to 7. For the statistical analyses, data were log-transformed to conform to a normal distribution. We excluded day 1, as these recordings would be markedly different for those who slept right after the film and those who slept later or were sleep deprived, respectively. We also included study group as factor in this analyses, controlling for the two wake conditions (daytime wake vs. sleep deprivation) and the two sleep conditions (with vs. without polysomnography). We investigated daily measures of intrusion frequency and affective distress and tested group differences for these indices for days 1 to 7, as we were interested in investigating how sleep's effect may unfold over consecutive nights. In an explorative analysis, we correlated selected sleep indices with number and distress of intrusive memories. Effect sizes were calculated for significant results.

RESULTS

Descriptives

Sleep and wake groups did not differ in any of the demographic, sleep, or clinical variables; see Table 1.

Effects of Sleep on Intrusive Memories

As predicted, sleep early after viewing the trauma film had a protective effect on the development of intrusive memories. Participants who were awake after film viewing reported on average M_{Wake} = 5.91, SD = 3.46 intrusive memories in total, whereas participants who slept after the movie indicated only M_{Sleep} = 4.28, SD = 3.27 intrusive memories (For study group 1: M_{Wake} = 3.68, SD = 0.60 vs M_{Wake} = 5.10, SD = 0.58, for study group 2: M_{Wake} = 3.42, SD = 0.53, M_{Wake} = 4.36, SD = 0.53). This difference was significant ($F(1,64) = 3.79$, P = 0.019). The reported trauma film memories were similar to intrusive memories commonly seen in PTSD patients, i.e., contained mostly sensory memories, such as seeing the offender's face or eyes staring, seeing how the victims is pressed to the floor, her screams, etc. We observed no difference between the sleep and wake group's intrusive memories of the neutral control film (M_{Sleep} = 0.78, SD = 1.0, vs. M_{Wake} = 0.91, SD = 1.51, $F(1,64) = 0.16$, P = 0.690). A significant interaction between experimental group ("wake vs. sleep") and film type ("trauma" vs. "neutral") confirmed the specificity of the protective effect of sleep on the development of intrusive memories ($F(1, 61) = 4.38$, P = 0.041). Generally, significantly more intrusive trauma memories were reported compared to memories from the neutral film (M_{Trauma} = 5.11, SD = 3.44, $M_{Neutral}$ = 0.85, SD = 1.28, $t(64) = 9.58$, P < 0.001). No significant interactions were observed with wake group type (i.e., daytime wake vs. sleep deprivation) and film type or sleep vs. wake groups (all values of P > 0.217).

Sleep was not only protective in terms of frequency of reexperiencing, but also significantly reduced the affective tone or distress experienced in the context of intrusive memories. Those who slept after the film reported significantly less distressing trauma memories (M_{Sleep} = 9.98, SD = 8.03) as compared to those who remained awake (M_{Wake} = 14.83, SD = 10.02, $F(1,64) = 4.61$, P = 0.036). This difference was not significant for the neutral film (M_{Sleep} = 0.94, SD = 1.37, vs. M_{Wake} = 1.20, SD = 2.66, $F(1,64) = < 1$, P = 0.625). The interaction between these factors was significant ($F(1, 61) = 6.84$, P = 0.011). Generally, participants reported more distress in the context of trauma memories compared to memories from the neutral film (M_{Trauma} = 12.44, SD = 9.35, $M_{Neutral}$ = 1.07, SD = 2.11, $t(64) = 10.38$, P < 0.001). Interactions between film type and study group, as well as between film type, sleep group and study group were not significant (all values of P > 0.107).

Chronotype, indexed by the Morningness-Eveningness-Questionnaire (DMEQ) sumscore, was not significantly related to intrusion frequency, distress, or vividness, all P > 0.60.

Sleep Indices and Intrusive Memories

Participants in the subgroup of those whose sleep was recorded with EEG (n = 18) slept an average of 7 h, SD = 0.81, with a mean sleep latency of 16 min, SD = 15.85. On average, participants spent 28 min in sleep stage 1, 3.6 h, SD = 45.4 min, in sleep stage 2, with an average of 83 min of slow wave sleep, SD = 27.13 and 87 min of REM sleep, SD = 30.99 min. An exploratory analysis of the contribution of candidate sleep parameters to the development of intrusive reexperiencing showed that more stage 2 sleep and a higher density of parietal fast sleep spindles (13–15 Hz) was related to fewer trauma film intrusions ($r = -0.56$ and $r = -0.48$, both P < 0.05, see Figure 2). In contrast, increased time spent awake after sleep onset and in stage 1 sleep predicted a higher number of intrusions ($r = +0.47$ and $r = +0.51$, respectively, both P ≤ 0.05, see Table 2). Similarly, higher REM density was related to higher intrusion development (r = +0.48, P = 0.042, see Figure 2). There were no significant correlations between percentage of slow wave sleep or REM sleep, or total sleep duration with intrusive reexperiencing, all P > 0.294, see Table 2).

Table 2—Correlations between sleep parameters and intrusive trauma memory frequency (n = 18).

Sleep Parameter	Intrusive Trauma Memory	P
Total sleep duration	+0.16	0.518
WASO, in %	+0.47	0.050
Stage 1 sleep, in %	+0.51	0.029
Stage 2 sleep, in %	−0.56	0.016
Slow wave sleep, in %	+0.23	0.359
REM sleep, in %	−0.26	0.295
REM density	+0.48	0.042
Parietal fast spindle density (13–15 Hz, Pz)	−0.48	0.044
Frontal slow spindle density (11–13 Hz, Fz)	−0.35	0.160

REM, rapid eye movement; WASO, wake after sleep onset.

DISCUSSION

Here we show that sleep may play a key role in memory integration following exposure to trauma. Our results indicate that sleep in the early aftermath of trauma exposure in the laboratory, compared to staying awake, reduced the amount and emotional distress of subsequent intrusive trauma memories. This effect was specific to the trauma film memories, as no difference emerged for memories from the neutral film. The effect developed over time: the groups initially experienced similar number of intrusions, but intrusion count significantly declined in the sleep group for days 3, 6, and 7, see Figure 3. There were similar effects for affective distress of intrusive memories, which was also significantly reduced in the sleep group for days 3, 4, 6, and 7, as depicted in Figure 3. In addition, longer duration spent in NREM sleep stage N2, parietal fast sleep spindle density as well as decreased REM density emerged as critical physiological parameters during sleep that predicted a reduction in intrusive reexperiencing.

Exposure to trauma requires an integration of a distressing and emotionally charged experience into one's autobiographical memory base. In trauma survivors afflicted with PTSD, the traumatic experience is predominantly laid down in memory in a disorganized and fragmented fashion that is not well integrated into its context in time, place, subsequent and previous information, and other autobiographical memories.[31] This lack of integration may underlie the intrusive and distressing nature of traumatic memories, and may be due to an improper and nonadaptive overconsolidation of traumatic experiences. In contrast, during sleep, consolidation of memories is highly adaptive and fosters the proper integration of memories into its appropriate context. Particularly during NREM sleep, newly learned information is spontaneously reactivated in an interleaved and selective fashion with related old memories in a so-called "hippocampal-neocortical dialogue", [32] benefiting the integration and reorganization of relevant new memories with respect to already existing experiences.[33] The sleep-related reactivation and integration processes occur in a fine-tuned interaction with several oscillatory signals, including hippocampal sharp-wave ripples, cortical slow oscillations, and parietal fast spindles.[10] Thus, proper consolidation and integration of memories during sleep should hamper the development of nonintegrated and intrusive traumatic memories. This notion is strengthened by the common observation that sleep disturbances, including insomnia and nightmares, are frequent in the aftermath of trauma and associated with PTSD symptoms.[15,16,34,35] In line with this notion, our results provide the first direct evidence that sleep during this time window has a protective effect on the formation of intrusive trauma memories, as those who slept experienced fewer and less distressing intrusive trauma memories compared to those who remained awake and that the reduction was associated with the density of parietal sleep spindles. The effects of sleep on intrusive memory formation in our study were specific to the emotional trauma memories, and no effects emerged for intrusive memories of the neutral film. This is in line with previous studies

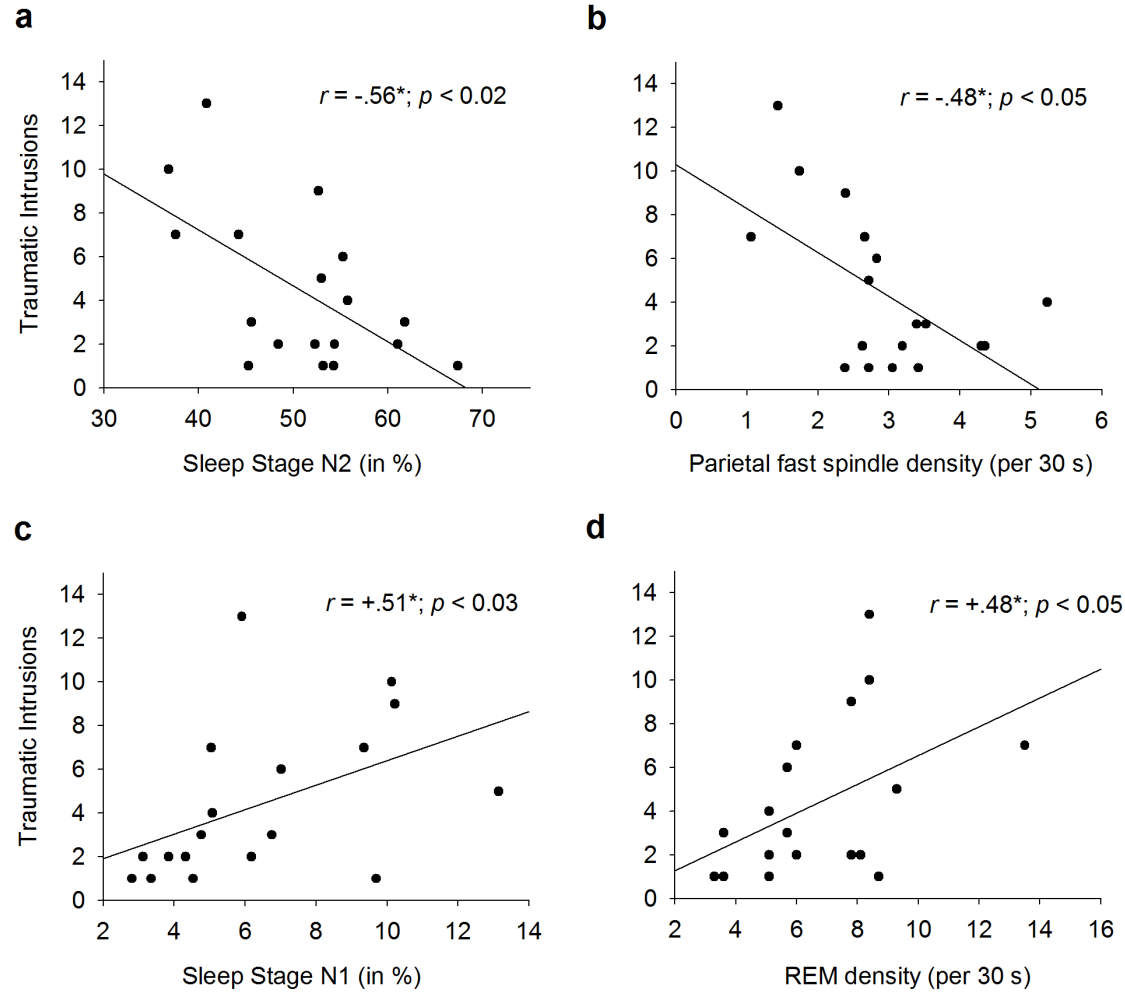

Figure 2—Associations between frequency of trauma film intrusions and sleep parameters. More stage 2 sleep (**a**) and a higher density of parietal fast sleep spindles (13–15 Hz) (**b**) were related to fewer trauma film intrusions. In contrast, increased time spent in stage 1 sleep (**c**) and increased rapid eye movement (REM) density (**d**) was related to more frequent intrusive reexperiencing.

suggesting that emotional memories are tagged and preferentially reactivated and consolidated during sleep.[36]

Our results are in line with studies and theoretical accounts proposing a role of sleep in the affective depotentiation of emotional memories.[9,14,13,18,37] Recent functional magnetic resonance imaging studies show that participants who slept after encoding emotionally aversive pictures showed reduced amygdala activity when exposed to the same pictures later whereas no such depotentiation of amygdala activity was found in the group who remained awake.[18] However, in our study we do not find evidence for a critical role of REM sleep in this process. In contrast, REM density was inversely correlated with the reduction of intrusive memories, and a longer time spent in NREM stage 2 sleep and the density of fast parietal sleep spindles might be more beneficial in this regard. These findings are in support of the notion that the reduction of intrusive memories is related to processes of reactivation and memory integration occurring mainly during NREM sleep.

Some previous studies showed strengthening of emotional memories after consolidation during sleep.[13,18,35,38] On the basis of these results, it has been argued that sleep posttrauma might consolidate and further strengthen negative traumatic memories and that symptoms of sleep disturbance frequently seen in trauma survivors in whom PTSD later develops serve as an evolutionary useful mechanism against the formation of such memories.[37] Kuriyama et al.[37] investigated sleep in the context of fear generalization and found that sleep deprivation reduced fear-associated memories. Most of these studies indexed voluntary recognition memory, such as the study by Wagner et al.,[13] which showed that sleep led to enhanced recall of previously encoded emotional narratives, or the study by Payne and Kensinger,[38] which found enhanced recognition memory for emotional scenes following sleep, indexed by classification of whether individuals had previously seen an image or not. Emotional memory is perceptual, as emotion specifically promotes perceptual memory, most likely by enhanced encoding of perceptual aspects of emotional experiences.[39] Trauma memories are mostly manifest in involuntary intrusive memories, nightmares, or reliving and the current study captured this specific aspect of the memory. Here we investigated this involuntary, largely perceptual and key part of the emotional memory, rather than its voluntary and conceptual parts, as

some of the previous studies did, and show a beneficial effect of sleep on the involuntary, perceptual part of the memory in the form of decreased intrusive reexperiencing. In our view, strengthening and integration of trauma memories may hinder the development of intrusive involuntary traumatic memories. Sleep strengthens the integration and later voluntary recall of emotional memories (in their proper context) due to an adaptive consolidation processes, thereby reducing the development of nonadaptive and nonintegrated intrusive trauma memories, which we indexed here.

Porcheret and colleagues investigated *involuntary* intrusive memories following sleep versus sleep deprivation in the context of experimental trauma.[8] Sleep deprivation had a protective role for intrusive memory formation, but this effect was specific to the first day for the questionnaire measure and the first 2 days for the diary measure. The protective effect was transient in that intrusion frequency did no longer differ between the groups for the later two segments of the week. The protective effect of sleep in our study was not found immediately, i.e., 1–2 days following analog trauma exposure and sleep, and it is well possible that the opposite effect, i.e., an immediately protective effect of sleep deprivation, is present.[1] In fact, affective distress of intrusive memories was higher (although this was not significant) in the sleep group on day 1. During the following segments of the week, however, the sleep group experienced significantly fewer intrusions than the wake group, an effect that may well be present in the study by Porcheret et al., albeit nonsignificant. Evidence for distinct time-dependent sleep-related memory processes has recently been reported,[40] suggesting a differentiation between initial hippocampus-dependent memory buffering effects and later consolidation intervals during delayed sleep over continuous nights. EEG measures and polysomnography were not included in the study by Porcheret et al. in either of the experimental groups, however, so that it remains unclear which aspects of sleep may have exerted an effect on intrusive memories in the group that slept. More studies are needed to gain insight into the neurobiological mechanisms of sleep-dependent learning to understand the precise processes that underlie the development of intrusive memories.

The current study is not without limitations. First, we included healthy female participants and thus cannot generalize our results to male populations. Second, our study was conducted in the laboratory and future studies are needed to confirm this effect in naturalistic studies, as the experimental, analog nature of the video stimuli differ in many ways from an actual traumatic memory. Third, although we asked participants to refrain from using stimulants including coffee, energy drinks, etc., prior to taking part in the study, we did not index sleep or sleep hygiene prior to the experiment in a detailed way other than our assessment of general sleep using the standardized self-report measures mentioned previously. Additionally, sleep as well as memory encoding is likely to have been influenced by other variables, such as gonadal hormones as well as menstrual cycle phase, which we did not index in the current study. Fourth, we implemented sleep within the first hours post- trauma in the laboratory, but the optimal timing of sleep during this initial posttrauma period still needs to be determined. Future studies must replicate and further investigate the association between specific sleep stages and indices of the sleep architecture, such as spindle and REM density, in the modulation of emotional trauma memories.

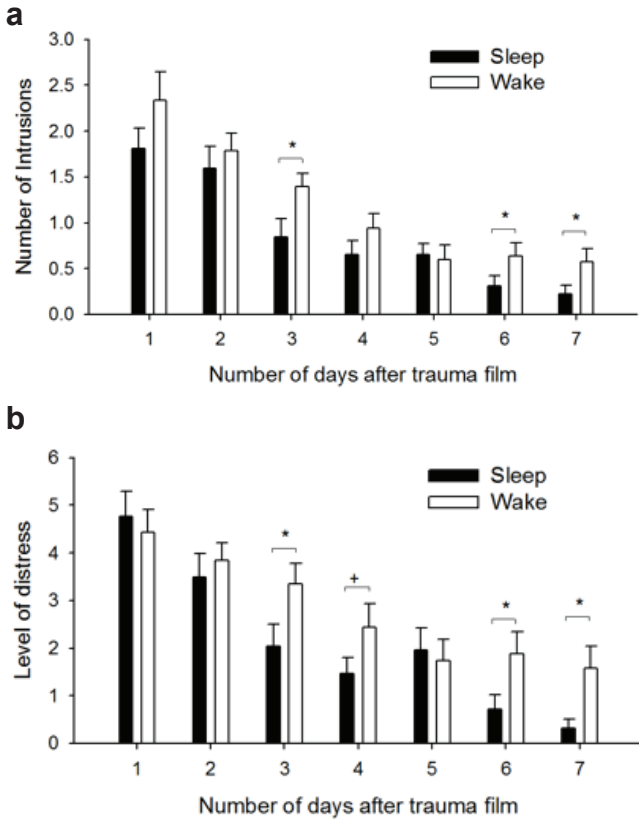

Figure 3—Day-by-day profile of intrusive memories depicting mean number of intrusive memories on days 1 to 7 (**a**), and mean distress of intrusive memories (range 0–10) (**b**), including standard errors of the mean (SEM). The sleep group experienced significantly fewer intrusive memories (days 3, 6, and 7), but not during the first 2-day period, indicating possible initiation of a process of memory reconsolidation that continues over several nights. Intrusive memories were also significantly less affectively charged for days 3, 4, 6, and 7.

Our results suggest that sleep in the early aftermath of trauma may protect individuals from the development of intrusive memories, possibly by improved sleep-dependent consolidation and integration of traumatic memories into neocortical long-term memory. Our results have clinical implications and set the stage for early intervention sleep studies following trauma and the prevention of PTSD. If replicated, our results suggest sleep as a viable intervention in the early aftermath of trauma that may help decrease the frequency intrusive memories, the afflicted emotional distress and thus reduce the burden of PTSD on individual survivors and society. Given the current debate about early intervention for PTSD and the need to identify effective treatment strategies that can be applied in the early aftermath of trauma,[5] the current findings are timely and suggest sleep as a novel, non-pharmacological intervention for recent trauma survivors at risk for chronic PTSD.

REFERENCES

1. Pace-Schott EF. Analog flashbacks. Sleep 2015;38:997–9.
2. Brewin C.R. The nature and significance of memory disturbance in posttraumatic stress disorder. Annu Rev Clin Psychol 2011;7:203–27.
3. Pitman RK, Shalev AY, Orr SP. Posttraumatic stress disorder: Emotion, conditioning, and memory. Cogn Neurosci 2000;2:1133–47.
4. Ehlers A, Clark DM, Hackmann A, McManus F, Fennell M. Cognitive therapy for post-traumatic stress disorder: Development and evaluation, Behav Res Ther 2005;43:413–31.
5. Kearns MC, Ressler KJ, Zatzick D, Rothbaum BO. Early interventions for PTSD: a review. Depress Anxiety 2012;29:833–42.
6. Hruska B, Cullen PK, Delahanty DL. Pharmacological modulation of acute trauma memories to prevent PTSD: considerations from a developmental perspective. Neurobiol Learn Mem 2014;112:122–9.
7. Holland P, Lewis PA. Emotional memory: selective enhancement by sleep. Curr Biol 2007;17:R179–81.
8. Porcheret K, Holmes EA, Goodwin GM, Foster RG, Wulff K. Psychological effect of an analogue traumatic event reduces by sleep deprivation. Sleep 2015;38:1017–25.
9. Goldstein AN, Walker MP. The role of sleep in emotional brain function. Ann Rev Clin Psychol 2014;10:679.
10. Rasch B, Born J. About sleep's role in memory. Physiol Rev 2013;93:681–766.
11. Diekelmann S, Born J. The memory function of sleep. Nat Rev Neurosci 2010;11:114–26.
12. Nishida M, Pearsall J, Buckner RL, Walker MP. REM sleep, prefrontal theta, and the consolidation of human emotional memory. Cereb Cortex 2009;19:1158–66.
13. Wagner U, Hallschmid M, Rasch B, Born J. Brief sleep after learning keeps emotional memories alive for years. Biol Psychiatry 2006;60:788–90.
14. Payne JD, Stickgold R, Swanberg K, Kensinger EA. Sleep preferentially enhances memory for emotional components of scenes. Psychol Sci 2008;19:781–8.
15. Koren D, Arnon I, Lavie P, Klein E. Sleep complaints as early predictors of posttraumatic stress disorder: a 1-year prospective study of injured survivors of motor vehicle accidents. Am J Psychiatry 2002;159:855–7.
16. van Liempt S, van Zuiden M, Westenberg H, Super A, Vermetten E. Impact of impaired sleep on the development of PTSD symptoms in combat veterans: a prospective longitudinal cohort study. Depress Anxiety 2013;30:469–74.
17. Pace-Schott EF, Germain A, Milad MR. Sleep and REM sleep disturbance in the pathophysiology of PTSD: the role of extinction memory. Biol Mood Anxiety Disord 2015;5:3.
18. Van der Helm E, Yao J, Dutt S, Rao V, Saletin JM, Walker MP. REM sleep depotentiates amygdala activity to previous emotional experiences. Curr Biol 2011;21:2029–32.
19. Stickgold R. Of sleep, memories and trauma. Nat Neurosci 2007;10:540–2.
20. Wolpe J, Lazarus A. Behavior Therapy Techniques. Oxford, UK: Pergamon Press, 1966.
21. Anderer P, Gruber G, Parapatics S, Dorffner G. Automatic sleep classification according to Rechtschaffen and Kales. Engineering in Medicine and Biology Society. EMBS 2007. 29th Annual International Conference of the IEEE.
22. Iber C, et al. The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, 1st ed. Westchester, IL: American Academy of Sleep Medicine, 2007.
23. Gais S, Mölle M, Helms K, Born J. Learning-dependent increases in sleep spindle density. J Neurosci 2002;22:6830–4.
24. Zeitlhofer J, Gruber G, Anderer P, Asenbaum S, Schimicek P, Saletu B. Topographic distribution of sleep spindles in young healthy subjects. J Sleep Res 1997;6:149–55.
25. Ficca G, Scavelli S, Fagioli I, Gori S, Murri L, Salzarulo P. Rapid eye movement activity before spontaneous awakening in elderly subjects. J Sleep Res 2004;13:49–53.
26. Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol 1976;4:97–110.
27. Johns MW: Anew Method for measuring daytime sleepiness. Sleep 1991;14:540–54.
28. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research, Psychiatry Res 1998;28:193–213.
29. Beck AT, Steer SR. Beck Depression Inventory: Manual. San Antonio, TX, Psychological Corporation, 1987.
30. Beck AT, Steer SR. Beck Anxiety Inventory: Manual. San Antonio, TX, Psychological Corporation, 1993.
31. Brewin CR. Autobiographical memory for trauma: update on four controversies. Memory 2007;15:227–48.
32. Buzsáki G. The hippocampo-neocortical dialogue, Cereb Cortex 1996;6:81–92.
33. Germain A, Buysse DJ, Nofzinger E. Sleep-specific mechanisms underlying posttraumatic stress disorder: integrative review and neurobiological hypotheses. Sleep Med Rev 2008;12:185–95.
34. Mellman TA, Pigeon WR, Nowell PD, Nolan B. Relationships between REM sleep findings and PTSD symptoms during the early aftermath of trauma. J Trauma Stress 2007;20:893–901.
35. Hu P, Stylos-Allan M, Walker MP. Sleep facilitates consolidation of emotional declarative memory. Psychol Sci 2006;17:891–8.
36. Sterpenich V, Albouy G, Boly M, et al. Sleep-related hippocampo-cortical interplay during emotional memory recollection, PLoS Biol 2006;5:e282.
37. Kuriyama K, Soshi T, Kim Y. Sleep deprivation facilitates extinction of implicit fear generalization and physiological response to fear. Biol Psychiatry 2010;68:991–8.
38. Payne JD, Kensinger EA. Sleep leads to changes in the emotional memory trace: evidence from FMRI. J Cogn Neurosci 2011;23:1285–97.
39. Arntz A, de Groot C, Kindt M. Emotional memory is perceptual. J Behav Ther Exper Psychiatry 2005;36:19–34.
40. Schönauer M, Grätsch M, Gais S. Evidence for two distinct sleep-related memory consolidation processes. Cortex 2015;63:68–78.

ACKNOWLEDGMENTS

The authors thank Kate Porcheret and Emily Holmes for fruitful discussions about the intrusive emotional memory diary method, as well as the results of the current paper.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication January, 2016
Submitted in final revised form August, 2016
Accepted for publication September, 2016

Address correspondence to: Birgit Kleim, University of Zurich, Dept. of Experimental Psychopathology and Psychotherapy, Lenggstrasse 31, Zurich 8032, Switzerland; Tel: 0041446342351; Email: b.kleim@psychologie.uzh.ch or Björn Rasch, University of Fribourg, Fribourg, Switzerland; Email: bjoern.rasch@unifr.ch

DISCLOSURE STATEMENT

This was not an industry supported study. The research was funded by the Swiss National Science Foundation, grants PZ00P1_126597 and PZ00P1_150812 awarded to Birgit Kleim. The authors have indicated no financial or other conflicts of interest. This work was performed at the University of Zurich, Zurich, Switzerland.