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Sleep Deprivation and False Memories

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Abstract
Many studies have investigated factors that affect susceptibility to false memories. However, few have investigated the role of sleep deprivation in the formation of false memories, despite overwhelming evidence that sleep deprivation impairs cognitive function. We examined the relationship between self-reported sleep duration and false memories and the effect of 24 hr of total sleep deprivation on susceptibility to false memories. We found that under certain conditions, sleep deprivation can increase the risk of developing false memories. Specifically, sleep deprivation increased false memories in a misinformation task when participants were sleep deprived during event encoding, but did not have a significant effect when the deprivation occurred after event encoding. These experiments are the first to investigate the effect of sleep deprivation on susceptibility to false memories, which can have dire consequences.

Keywords
false memory, sleep deprivation, sleep, misinformation, suggestibility

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Memories are not "recorded" in the brain. Rather, they are reconstructed using information from multiple sources, and they can change following exposure to misleading postevent information or other suggestive influences (for reviews, see Frenda, Nichols, & Loftus, 2011; Lindsay, 2008). Moreover, people sometimes recall entire events and experiences that never happened, and these false memories can be vivid, emotional, and held with great confidence (e.g., McNally et al., 2004; see also Loftus & Ketcham, 1994). Memory errors can have serious consequences: For example, eyewitness misidentifications are thought to be the leading cause of wrongful criminal convictions in the United States (e.g., Garrett, 2011). Many studies have investigated situations that lead to the formation of false memories, but one unexplored question is whether sleep deprivation affects memory suggestibility. Accordingly, we investigated the effect of sleep deprivation on susceptibility to false memories.

False Memories

Early studies showed that suggestive questioning can influence memory reports (e.g., Loftus & Palmer, 1974), and since then, myriad studies have shown that false memories can arise in a number of ways. One common method for studying false memories in the laboratory is the misinformation procedure: Participants encode some stimuli (usually videos or photographs), later see misleading information about the material that they encoded, and finally, take a memory test (e.g., Zhu et al., 2010). Participants frequently incorporate the misleading information into their memories for the original materials. One strength of this approach is that the procedure includes three discrete stages (encoding, misinformation, retrieval at test) that theoretically correspond to stages of a process that unfolds in real-world contexts (e.g., a person witnesses a crime, is later exposed to misleading information, and repeats his or her memory as testimony).

Related studies have shown that people sometimes recall witnessing events that they never saw. Specifically, people sometimes falsely report that they viewed video footage of high-profile news events, even when no such

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footage exists (e.g., Princess Diana's fatal car collision—Ost, Vrij, Costall, & Bull, 2002; see also Crombag, Wagenaar, & van Koppen, 1996; Ost, Granhag, Udell, & Hjelmsäter, 2008). Often, these participants provide detailed memory reports. These findings are in line with research demonstrating that imagined events are sometimes confused as being actual memories (e.g., Garry, Manning, Loftus, & Sherman, 1996; Hyman, Husband, & Billings, 1995). A strength of this approach is the use of actual news events—rich with emotion and real-world significance—as the stimuli.

Finally, a common method for creating false memories in the laboratory is the Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995). In the DRM task, participants learn lists of words (e.g., *bed, rest, awake, tired*) that are semantically associated with a nonpresented word—the critical lure (*sleep*). On subsequent memory tests, participants often recall seeing the nonpresented critical lures. False memories in the DRM task have been described as associative, or gist-based, errors (see Schacter, Guerin, & St. Jacques, 2011). Although the DRM paradigm is widely used in false memory research, its relevance to false memories of events in more naturalistic contexts has been controversial (e.g., Pezdek & Lam, 2007; Wade et al., 2007).

Sleep Deprivation

Sleep deprivation appears to be increasingly prevalent (Schoenborn & Adams 2010), and it impairs performance across a wide range of cognitive tasks. It slows reaction time (Koslowsky & Babkoff, 1992), decreases working memory capacity (Chee & Choo, 2004), interferes with normal learning (Drummond & Brown, 2001), and impairs executive function (Nilsson et al., 2005; for reviews, see Harrison & Horne, 2000, and Thomas et al., 2000). Thus, sleep deprivation might also increase false memory. However, studies investigating sleep deprivation and false memory have shown mixed results. In two experiments, participants studied DRM lists before a night of either sleep or sleep deprivation; testing took place the following day. One study showed higher rates of false recognition in sleep-deprived participants, compared with rested participants (Diekelmann, Landolt, Lahl, Born, & Wagner, 2008), but the subsequent study found no differences in false recall between the groups (Diekelmann, Born, & Wagner, 2010). Finally, in another study, participants learned DRM lists at night and then either slept or were sleep deprived. After a period of recovery sleep, they were tested, and no differences in false recall emerged between the groups (Darsaud et al., 2010).

Thus, the evidence suggesting that sleep deprivation contributes to the formation of false memories is sparse and inconsistent. Furthermore, most of the research on this topic has been conducted using DRM procedures. Virtually no research has investigated whether sleep deprivation increases susceptibility to false memories for richer, real-world stimuli.[1] In the experiments reported here, we capitalized on the multiple methods for creating false memories in the laboratory. In Experiment 1, we tested whether self-reported sleep duration on the night prior to an experiment was associated with false memories of witnessing a news event and with false memories in a misinformation task. In Experiment 2, we manipulated sleep deprivation to examine its effects on the formation of false memories at various stages of a misinformation task.

Experiment 1

Method

Participants. We drew the data set for Experiment 1 from a large, multisession study. One hundred ninety-three undergraduates (mean age = 20.3 years, SD = 3.5; 76% female, 24% male) at the University of California, Irvine, completed a battery of personality measures and cognitive tasks for course credit. Only procedures relevant to the current study are described here.

News event. Participants completed a questionnaire that included a passage describing the plane crash in Shanksville, Pennsylvania, on September 11, 2001, and claiming that video footage of the crash had been widely seen on the news and the Internet (although images of the aftermath were widely available, the crash was not captured on video). The critical item on the questionnaire asked participants whether they had seen "video footage of the plane crashing, taken by one of the witnesses on the ground." Participants responded by selecting "yes" or "no."

Prior to debriefing, research staff conducted short, audio-recorded interviews to probe participants' memory for the footage. Critically, interviewers repeated the suggestion that a video of the crash had been widely seen and asked participants to indicate verbally whether or not they had seen the footage (for details on coding, see the Supplemental Material available online).

Misinformation task

Event encoding. We assembled two sets of photographs from materials developed by Okado and Stark (2005). One set depicted a man breaking into a parked car, and the other depicted a woman encountering a thief who steals her wallet. Each set contained 50 photographs that were presented in a fixed order for 3,500 ms each. Participants were told that they would be shown a series of images and that they would later be asked questions about them.

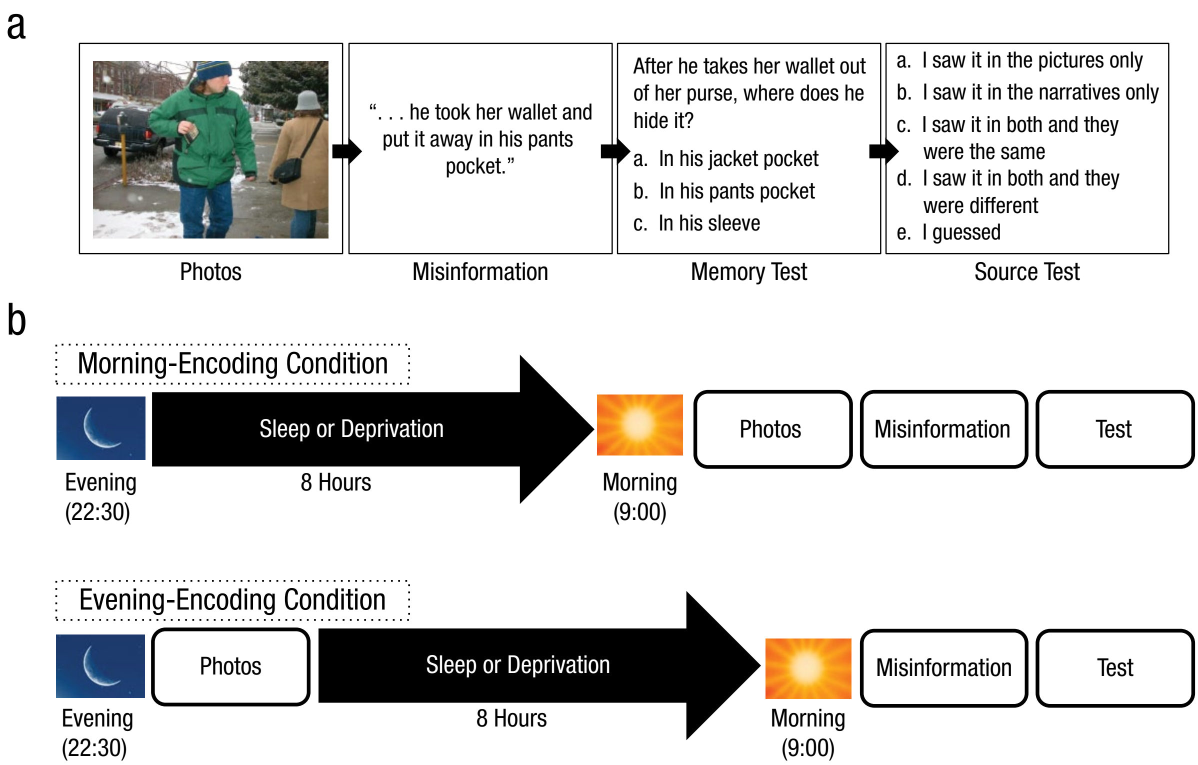

Fig. 1. Experimental procedure and design. The misinformation procedure in Experiments 1 and 2 is illustrated in (a). After viewing two sets of photographs depicting events, participants read narratives that included misinformation about the events. Later, participants took a three-alternative forced-choice test of their memory for the photographs and a source test on which they indicated where they had acquired the information they used to answer each question. In Experiment 2 (b), participants arrived at the lab in the evening to perform the misinformation procedure. Some participants completed the encoding phase (viewing photos) of the procedure in the evening, and others completed it the following morning. Within each encoding condition, some participants remained awake overnight, and others were allowed to sleep for 8 hr.

Misinformation narrative. Approximately 40 min after participants viewed the photographs, they read two text narratives—one for each photo set—that told the stories of the photographs. Each narrative contained three statements that directly contradicted the events shown in the photographs. Therefore, each participant read a total of six pieces of misinformation—three for each photo set—embedded among true information. We created two versions of the study's misinformation phase; for both narratives, each participant received misinformation corresponding to one of two possible sets of questions on the memory test. Participants were instructed to focus on the narratives but were not warned that they might encounter inconsistencies.

Test. Approximately 20 min after participants read the narratives, they took a three-alternative forced-choice test of their memory for the photographs. Each question pertained to a specific detail depicted in one of the photographs (Fig. 1a), and participants were asked to select an answer on the basis of their memory for the photographs. *Critical questions* pertained to information that was presented inaccurately in a narrative; one of the response choices was correct (i.e., consistent with an original photograph), one was consistent with the misinformation (i.e., consistent with an inaccuracy in the narrative), and one was a novel foil (i.e., a possibility not shown in the photographs or mentioned in the narrative). After participants completed the multiple-choice test, they completed a source test in which they viewed each question again and elaborated on their answer choice by indicating where they had acquired the information: "in the pictures only," "in the narratives only," "in both and they were the same," "in both and they were different," or "I guessed." The source test allowed us to assess whether or not the participants remembered seeing misinformation in the original images.

Procedure. In a preliminary session at the lab, participants consented to participation, provided demographic

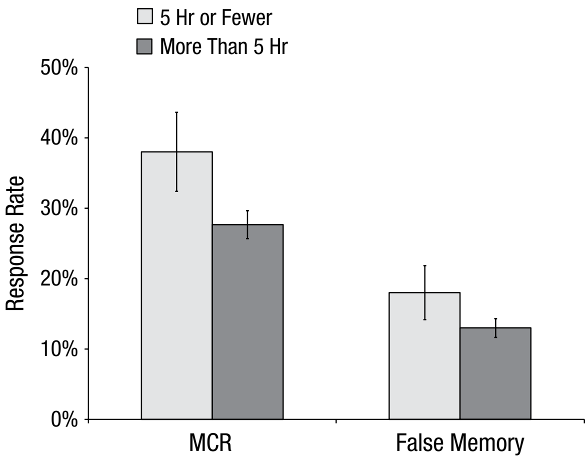

Fig. 2. Results from Experiment 1: mean misinformation-consistent response (MCR) and false memory rates in participants who had slept 5 or fewer hours the night before (restricted-sleep group) and those who had slept more than 5 hr (reference group). Error bars represent ±1 *SEM*.

information, and answered a battery of personality questionnaires (unrelated to the present research). They were also given instructions about how to complete a brief sleep diary each morning for the following week. Each day, they were to report the time they got in bed, the length of time it took them to fall asleep, the time they awoke, the time they got out of bed, and the number and duration of awakenings during the night. Research staff reminded participants to complete their sleep diaries each morning.

Exactly 1 week after the preliminary session, participants returned for the study session. They first saw the two sets of photographs for the misinformation task (i.e., the event-encoding phase). Next, they completed the questionnaire containing the news-event item. Immediately afterward, they completed another questionnaire battery unrelated to the present research. Then, they viewed the misinformation narratives, which were followed by more personality questionnaires. Participants then completed the testing phase of the misinformation task. Finally, they underwent the in-person interview and were debriefed.

Results

In order to assess whether restricted sleep was associated with false memory, we divided participants into two groups on the basis of their self-reported sleep duration on the night prior to the study session. Participants reported an average of 6.8 hr of sleep (SD = 2.0), and 28 participants (15%) reported 5 or fewer hours of sleep. We coded these participants as having restricted sleep.[2] The remaining 165 participants (85%) were used as our reference group. The two groups did not meaningfully differ on any demographic variables (e.g., age, gender, race-ethnicity).

News event. We first compared the two groups' responses to the news-event questionnaire item. Participants in the restricted-sleep group were significantly more likely than participants in the reference group to report that they had seen the video (54% vs. 33%), $\chi^2(1, N = 193) = 4.2$, $p = .04$, $\varphi_c = .15$. However, the groups did not differ when questioned in the follow-up interview: 21% of the restricted-sleep group and 20% of the reference group persisted in their claim that they had seen the video, $\chi^2(1, N = 193) = 0.03$, $p = .86$. Thus, restricted sleep was associated with initial false reports on the questionnaire, but not with false reports in the follow-up interview.

Misinformation task. We first analyzed correct memory by calculating the rate of correct responses to noncritical questions (i.e., questions that were not related to the misinformation given in the misinformation phase). The correct-memory rate did not differ significantly between the restricted-sleep group (M = 87%, SD = 19%) and the reference group (M = 89%, SD = 15%), $t(191) = 0.7$, $p = .5$. The correct-memory rates were rather high, and the null result may have been due to ceiling effects on performance (see the Supplemental Material for additional analyses).

Next, we examined misinformation-consistent response (MCR) rate—participants' tendency to incorporate information from the narratives into their responses to critical questions. The restricted-sleep group incorporated the misinformation into their responses 38% of the time (SD = 30%), whereas the reference group did so only 28% of the time (SD = 25%). This difference narrowly missed significance, $t(191) = 1.9$, $p = .06$, Cohen's $d = 0.27$ (Fig. 2).

Finally, we compared false memory rates between the two groups. We calculated the percentage of critical questions for which participants both chose the misinformation-consistent response on the forced-choice test and reported that they remembered seeing the misinformation in the photographs (i.e., by indicating in the source test that they saw the information "in the pictures only" or "in both [the pictures and the narratives] and they were the same"). The sleep-restricted group selected misinformation-consistent responses and attributed those responses to the photographs 18% of the time (SD = 20%), and the more rested group did so 13% of the time (SD = 17%). This difference was not statistically significant, $t(191) = 1.35$, $p = .18$ (Fig. 2).

Discussion

These findings tentatively suggest that restricted sleep is related to memory suggestibility. However, we did not experimentally manipulate the amount of sleep participants had, and because the entire misinformation procedure was completed following restricted sleep, we were unable to examine when during the formation of false memories restricted sleep had its influence. For example, restricted sleep may have impaired encoding of the event (cf. Yoo, Hu, Gujar, Jolesz, & Walker, 2007), rendering those memories vulnerable to distortion. Alternatively, restricted sleep could have affected processes occurring at the later stages in the misinformation procedure (i.e., retrieval). With this issue in mind, we designed an experiment to measure the effect of 24 hr of total sleep deprivation on susceptibility to false memories. We also manipulated time of encoding: In one condition, all three stages of the misinformation procedure were conducted after sleep deprivation. In another, participants encoded the photographs in a rested state but completed the misinformation and test phases after a period of sleep deprivation.

Experiment 2

Method

Participants. We recruited 104 Michigan State University undergraduates for participation in this study.[3] Participants had a mean age of 19.2 years (SD = 1.3; 54% female, 46% male) and were native English speakers who were not taking any medications that affected sleep. We included only participants who slept regularly (a minimum of 6 hr per night) in the week preceding the experiment. Participants refrained from consuming alcohol or caffeine for 24 hr prior to the experiment; although they slept as usual the night before, they did not take any naps during the 24 hr prior to the experiment.

Design and procedure. The experiment used a 2 × 2 between-subjects design (see Fig. 1b). The independent variables were sleep condition (8 hr sleep or sleep deprivation) and time of encoding (morning or evening). Participants were blind to condition prior to arriving at the lab; they were told that they might sleep or remain awake at the lab and to be prepared for either.

Participants arrived at the lab at 10:30 p.m. and completed measures of mood, sleepiness, and working memory capacity: the Positive and Negative Affective Schedule (PANAS; Watson, Clark, & Tellegen, 1988), the Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), and the Operation Span (OSPAN) task (Turner & Engle, 1989). Immediately after these tasks, participants in the morning-encoding condition were assigned to either sleep or remain awake, and participants in the evening-encoding condition completed the encoding phase of the misinformation procedure and were then assigned to either sleep or remain awake.

Participants assigned to the sleep condition were given from midnight until 8:00 the following morning to sleep, whereas those assigned to the sleep-deprivation condition were kept awake throughout the night. Neither group was allowed to consume caffeine. To ensure that participants in the sleep condition slept on the night of the study, we used polysomnographic recordings, including electroencephalography recordings on the scalp (at F3, F4, C3, C4, O1, O2, with reference electrodes at M1 and M2), electrooculography recordings on both eyes, and electromyography recordings on the chin and legs. We also used electrocardiography to monitor heart rate, thoracic and abdomen belts to monitor respiratory effort, nasal cannulae to monitor respiration, and pulse oximetry to monitor oxygen saturation. Data were collected using Embla N7000 recording systems (Embla ResMed, Denver, CO). Participants in the sleep-deprivation condition were permitted to watch movies, play games, or work on their computers but were not permitted to nap or engage in any physical exercise. Throughout the night, they completed the PANAS and SSS every 2 hr and were offered a small, carbohydrate-rich snack every hour (to reduce the stress associated with sleep deprivation). Two research assistants who napped earlier that day monitored participants continuously throughout the night.

At 8:00 a.m., all participants were given breakfast. At 9:00, all participants completed the PANAS and SSS. The participants in the morning-encoding condition then completed all three stages of the misinformation procedure, as described in Experiment 1, and participants in the evening-encoding condition completed the remaining two phases of the study—misinformation and test.

Results

Memory. For each participant, we calculated a correct-memory score, MCR rate, and false memory rate. We examined the data using 2 × 2 analyses of variance with sleep condition (sleep, sleep deprivation) and time of encoding (morning, evening) as between-subjects factors. For correct memory, we found no main effect of encoding time, $F(1, 99) = 0.79$, $p = .38$. There was a trend for correct-memory scores to be lower for sleep-deprived participants than for rested participants, but the main effect of sleep condition did not reach significance, $F(1, 99) = 3.08$, $p = .08$. There was not a significant interaction between the factors, $F(1, 99) = 0.55$, $p = .46$.

For MCR rates, there were no main effects of either sleep condition, $F(1, 99) = 0.15$, $p = .70$, or encoding time, $F(1, 99) = 1.70$, $p = .20$. However, there was a trend for an interaction between the factors, $F(1, 99) = 3.02$, $p = .09$. In the morning-encoding condition, MCR rates were marginally higher after sleep deprivation than after sleep, but no differences emerged in the evening-encoding condition.

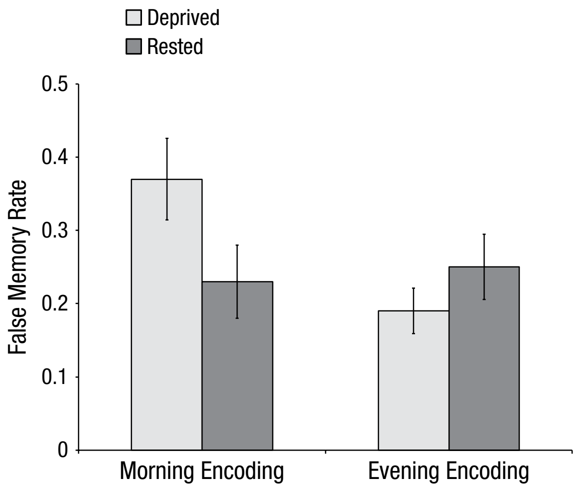

Fig. 3. Results from Experiment 2: mean false memory rates of rested and sleep-deprived participants in the two encoding conditions. Error bars represent ±1 *SEM*.

Next, we compared false memory rates. We found no main effect of sleep condition, $F(1, 99) = 0.54$, $p = .46$, or encoding time, $F(1, 99) = 3.12$, $p = .08$. However, there was a significant interaction between the factors, $F(1, 99) = 4.52$, $p = .04$. Planned comparisons revealed that in the morning-encoding condition, the false memory rate was significantly higher in the sleep-deprived group than in the rested group, $t(51) = 2.01$, $p = .04$ (two-tailed), Cohen's $d = 0.56$. However, in the evening-encoding condition, there was no significant difference in the false memory rate between sleep-deprived and rested participants, $t(52) = 0.98$, $p = .33$ (Fig. 3). (See the Supplemental Material for additional analyses not reported here.)

Mood and sleepiness. We also examined participants' sleepiness and affect. As expected, sleep-deprived participants reported significantly higher morning sleepiness, and lower positive affect, relative to rested participants, *p*s < .001, but there was no association between morning sleepiness and MCR rate, $r(88) = .05$, $p = .62$, or false memory rate, $r(88) = .02$, $p = .83$. Similarly, there was no association between morning positive affect and MCR rate, $r(91) = .03$, $p = .80$, or false memory rate, $r(91) = -.04$, $p = .74$ (see the Supplemental Material for group means and statistics).

Working memory capacity. Finally, we tested whether working memory capacity (measured by the OSPAN task) predicted susceptibility to MCR or false memory. We used two multiple regression analyses, one predicting MCR rate and one predicting false memory rate. For each, we entered sleep condition, encoding time, and OSPAN scores as predictors, followed by interaction terms. We found no main effects of working memory capacity in either model (*p*s > .5) and no interactions (all *p*s > .10). These results suggest that the effects of sleep deprivation and encoding time did not depend on working memory capacity.

Table 1. Mean Duration of Total Sleep Time and Each Sleep Stage for Participants in the Sleep Condition of Experiment 2

Measure	Morning-encoding condition	Evening-encoding condition
Total sleep time (hours)	7.21 (0.46)	7.11 (0.67)
NREM 1 (minutes)	24.6 (13)	28.8 (12)
NREM 2 (minutes)	216.5 (31)	189.1 (41)
NREM 3 (minutes)	106.5 (26)	131.7 (36)
REM (minutes)	85.5 (29)	76.8 (32)

Note: Standard deviations are given in parentheses.

Sleep. All participants slept at least 6 hr on the night of the study. Table 1 presents the mean duration of each sleep stage, separately for the two encoding conditions.[4]

General Discussion

We investigated the effect of reduced sleep and total sleep deprivation on susceptibility to false memories. Experiment 1 provided initial evidence that restricted sleep is associated with increased false memory. Participants who reported 5 or fewer hours of sleep the night before the experiment were more likely to report that they had witnessed a news event that they did not actually see, compared with rested participants. There was also a trend for these participants to incorporate more misleading information into their memory for visual materials. In Experiment 2, the sleep-deprived group showed greater susceptibility to false memories relative to the rested group, but only when participants were sleep deprived during all three stages of the misinformation procedure. When participants encoded the original event in a rested state, there were no discernible differences in false memory between participants who were rested and those who were sleep deprived during misinformation and test.

Why were sleep-deprived participants more likely than rested participants to fall sway to our suggestions in the morning-encoding condition, but not in the evening-encoding condition? One possibility is that sleep deprivation increased false memories by influencing processes related to encoding. Sleep deprivation may have impaired encoding of the original event, thus making memory more vulnerable to intrusions from misleading postevent information. This possibility is also supported by the trend for decreased correct memory after sleep deprivation in the morning-encoding condition and is consistent with previous research showing that sleep deprivation reduces the ability to encode new information (Yoo et al., 2007).

In the evening-encoding condition, memories of the photographs could have been affected by consolidation processes in participants who slept. In other words, sleep-deprived participants in the evening-encoding condition were different from the rested participants in two ways: They were in a state of deprived sleep, and they also did not have an opportunity to consolidate memory for the photographs. Thus, any comparison of rested and sleep-deprived participants in the evening-encoding condition must be interpreted with caution. This issue notwithstanding, it is important to note that we observed a difference in false memory rates between rested and sleep-deprived participants only in the morning-encoding condition, wherein participants could not have consolidated memories of the photographs during sleep.

Our results also suggest that total sleep deprivation may not be necessary to increase false memory. Restricted sleep may also increase the risk of false memories. In Experiment 1, a night of short-duration sleep was associated with a trend toward higher rates of claiming to have seen nonexistent video footage of a news event that occurred many years prior to the experiment. Previous research has suggested that false memories of witnessing news events may emerge when imagined events are confused with actual memories (see Ost et al., 2002; also see Garry et al., 1996; Lindsay, 2008). In the present study, restricted sleep was associated with an increased likelihood of false memories of an event that had long since passed, which suggests that reduced sleep may impair the accuracy of source judgments at retrieval.

On the whole, sleep deprivation appears to increase the risk of false memories. However, sleep deprivation may affect the development of false memories differently depending on the procedure or testing method. In a misinformation procedure, sleep deprivation increased false memory, but only when participants were sleep deprived for all three stages of the procedure (including encoding). For false memories of witnessing news events, sleep restriction may impair source accuracy at retrieval. In the DRM paradigm, there is some evidence that sleep deprivation at retrieval may increase false memory in recognition testing (Diekelmann et al., 2008) but not recall testing (Diekelmann et al., 2010). A key insight emerging from the many approaches to studying false memories is that memory-distortion phenomena are varied and not limited to just one process; rather, there are many ways that false memories can materialize. The present research, taken together with the previous literature, points not only to the increased risk of false memory following restricted sleep and sleep deprivation, but also to the need for a diversity of methodological approaches in the investigation of sleep deprivation and false memory.

Author Contributions

K. M. Fenn, S. J. Frenda, L. Patihis, and E. F. Loftus developed the study concept and contributed to the study design. Testing and data collection were performed by L. Patihis and S. J. Frenda (Experiment 1) and by K. M. Fenn and H. C. Lewis (Experiment 2). S. J. Frenda and L. Patihis performed the data analysis and interpretation under the supervision of K. M. Fenn and E. F. Loftus. S. J. Frenda and K. M. Fenn drafted the manuscript, and all authors provided critical revisions. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. One exception is a unique study (Blagrove, 1996) showing that sleep-deprived participants were more likely than rested participants to yield to leading questions about a story they had read. In that study, however, the sleep-deprived participants were tested at a different circadian time than the rested participants, a serious confound that limits conclusions that can be drawn. Furthermore, it is unclear whether the findings indicate that sleep deprivation increased memory distortion per se or merely increased acquiescence to leading questions.
2. Previous studies have shown that sleep restricted to 4 to 6 hr for several nights can impair cognitive functioning (cf. Axelsson et al., 2008; Dinges et al., 1997; Van Dongen, Maislin, Mullington, & Dinges, 2003). Although some studies have shown that 6 or fewer hours of sleep per night over several nights can cause cognitive deficits (e.g., Van Dongen et al., 2003), we chose a more conservative measure of sleep restriction because we were investigating the effects of only a single night of restricted sleep.
3. One participant had difficulty sleeping in the laboratory and did not complete the experiment.
4. Because of equipment failure or experimenter error, sleep data from 4 participants (1 in the morning-encoding condition and 3 in the evening-encoding condition) could not be analyzed.

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