TIMING OF MISINFORMATION IMPACTS FALSE MEMORY CONSOLIDATION DURING SLEEP

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Neuroscience - Master of Science

2023

ABSTRACT

The impact of sleep on the consolidation of veridical memory is well-established, but its effect on false memory remains unclear. Two experiments were conducted using the misinformation paradigm to investigate how sleep affects false memory. Participants completed three experimental phases – encoding, misinformation, and test. We manipulated the delay interval between encoding and test (Wake and Sleep) and the timing of misinformation (Pre-retention Interval and Post-retention Interval). Both experiments followed a similar general procedure, with one primary difference. In Experiment 1, participants were warned, prior to the test, that they had been exposed to misinformation. In Experiment 2, participants were not warned about the misinformation. In Experiment 1, there was lower false memory in the sleep group when misinformation was presented after a retention interval, compared to when the misinformation was presented prior to the retention interval. The Sleep group also outperformed the Wake group on correct recognition. In Experiment 2, false recognition of suggested items was higher when misinformation was presented after the retention interval for both delay conditions, Sleep and Wake. Correct recognition was similar for all groups. These findings suggest that sleep-dependent consolidation processes can reduce false memory, but only when conflicting information is encountered after a period of sleep and when participants are aware of the manipulation. It is therefore possible that awareness is an essential factor in preventing false memory. This research has important implication for theories of memory consolidation as well as applied implications for the criminal justice system, as inaccurate recollection has a profound effect on eyewitness testimony.

I would like to dedicate this thesis to my entire family who has consistently provided their unconditional support. Especially, my parents, Norma and Julio, who put in years of hard work so that I could be where I am today.

ACKNOWELDGEMENTS

I would like to thank the MARC program at Northeastern Illinois University. Specifically, Dr. Ruth Church, Dr. Joseph Hibdon, Dr. Emina Stojković and Dorina Bizhga. The guidance of the MARC program put me on the right path at a time when I had little direction.

I would like to thank Dr. Shannon Saszik, my first mentor in research. You taught me that to be a researcher one must be curious, patient, creative and open-minded. I carried this knowledge into graduate school and will continue to apply it whenever possible.

Thank you, Dr. Kimberly Fenn, for your incredible mentorship during my time at Michigan State. I have grown both as a researcher and as a person during these past two years, and it is thanks to your support and guidance.

Elle, Bridgette, and Erin - thank you for your help and kindness as I integrated into the Sleep and Learning Lab.

Thank you to all of the amazing undergraduate research assistants at the Sleep and Learning Lab who made this study possible.

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INTRODUCTION

Although it is commonly assumed that memory is accurate, in reality, memory is prone to distortion (LaVoie & Malmstrom, 1998; Loftus, 1996; Schacter et al., 1996). Memories are not exact reproductions of past events and, therefore, memory is susceptible to influence from previous memories or outside influences (Loftus, Miller, & Burns, 1978; Okado & Stark, 2003; Roediger & McDermott, 1995). Suggestions from friends or family, for example, can distort memories and lead people to have an inaccurate recollection of a memory or cause people to place themselves in novel situations that they never actually experienced (Loftus, 1996; Loftus & Pickrell, 1995; Okado & Stark, 2003), these inaccurate memories are referred to as false memories. While the effects of sleep on false memory remain ambiguous, studies have shown that sleep has a positive effect on veridical memory. Recent work indicates that declarative memory, which falls under the category of veridical memory, is more accurate after a retention interval which includes sleep, rather than after a retention interval which contains waking activity (Ellenbogen, Hulbert, Stickgold, Dinges, & Thompson-Schill, 2006; Fenn & Hambrick, 2012; Gais, Lucas, & Born, 2006; Plihal & Born, 1997). Through sleep, declarative memories can become more thoroughly integrated with other stored information (Paller & Voss, 2004). Further, declarative memory is enhanced when sleep follows within a few hours of learning, independent of time of day (Gais et al., 2006). While the benefit of sleep on declarative memory has been well-established, it is not entirely clear whether sleep protects against false memory or increases false memory.

Although it is not entirely understood how false memories form, there are theories which try to explain the phenomenon. Previous studies have suggested that false memory is a result of spreading activation, which assumes that memory is organized in such a way that concepts which

are related to each other are linked together and activation of one of these concepts spreads and activated related concepts (Collins & Loftus, 1975; Whittlesea, Masson, & Hughes, 2005). The incorporation of new information into existing knowledge is fundamental for the consolidation of new memories (Tamminen, Lambon Ralph, & Lewis, 2013), however, it is possible that this same process is responsible for the formation of false memories. Another possible explanation for false memories is the fuzzy-trace theory, which proposes that our memories are stored separately as verbatim (exact) and gist (general) representations of an experience (Reyna & Lloyd, 1997). According to this theory, accurate memories rely on both verbatim and gist memory representations, while false memories are primarily supported by gist representations when verbatim representations are weakened by interference (Payne, Elie, Blackwell, & Neuschatz, 1996; Reyna & Lloyd, 1997). Essentially, false memories can occur when the general idea or meaning of an experience is remembered, but the specific details are forgotten or muddled (Brainerd & Reyna, 2002).

Undesrtanding the potential mechanisms of false memory as well as how sleep affects memory in general can help us predict how sleep may affect false memory. Research pertaining to sleep and veridical memory provides evidence that memory reactivation takes place at the hippocampus and related medial temporal lobe structures during sleep and that active memory consolidation mainly occurs during non-REM sleep (Wagner, Gais, Haider, Verleger, & Born, 2004). In one particular study, participants were asked to memorize the location of different pairs of cards before sleep, and during encoding, they were presented a distinct odor (Rasch, Büchel, Gais, & Born, 2007). When the same odor was presented during slow wave sleep, memory of the card locations was significantly improved, however, this same effect was not observed when the odor was presented during REM sleep or when participants were awake during re-exposure

(Rasch et al., 2007). Further, neuroimaging through fMRI showed that exposure to the odor during slow wave sleep increased activation of the left hippocampus, more so than during wakefulness (Rasch et al., 2007). In a rodent study, consolidation of hippocampus-dependent memories of a spatial maze was impaired when slow wave sleep was suprressed (Girardeau, Benchenane, Wiener, Buzsáki, & Zugaro, 2009). The importance of non-REM sleep for memory consolidation is additionaly supported by improved performance on a novel word recall task when sleep spindle count, a marker of non-REM sleep, is higher during sleep (Andrillon et al., 2011; Tamminen et al., 2010).

Despite evidence that sleep plays a crucial role in consolidating declarative memory through active consolidation (Born & Wilhelm, 2012; Rasch & Born, 2013; van der Helm, Gujar, Nishida, & Walker, 2011), there is still ongoing debate regarding the nature of this consolidation benefit. Sleep is considered by some as the optimal state for consolidation of memories (Inostroza & Born, 2013; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010) while others argue that sleep may aid memory by slowing down the decay process (Bailes, Caldwell, Wamsley, & Tucker, 2020) or by reinforcing encoding and retrieval (Newbury & Monaghan, 2019). There is research which suggests that the prevailing effect of sleep on declarative memory is protection against memory loss (Fenn & Hambrick, 2013), indicating that the consolidating beenfit of sleep may be a combination of several mechanisms. Evidence that sleep can protect declarative memories from associative interference could suggest that this protection reduces the likelihood of false memories (Diekelmann, Landolt, Lahl, Born, & Wagner, 2008; Ellenbogen et al., 2006). Sleep could reduce false memories because it provides an interval of reduced interference, while being awake and engaged in day-to-day activities involves memory

processing and naturally increases interference (Fenn, Gallo, Margoliash, Roediger, & Nusbaum, 2009; Wixted, 2004).

Our current understanding of the effect of sleep on false memory has relied almost exclusively on the Deese, Roediger and McDermott (DRM) task. The DRM task is a tool for measuring false memories using semantically associated words lists (Payne et al., 2009; Roediger & McDermott, 1995). Studies utilizing the DRM paradigm have found that participants are susceptible to mistakenly recalling or recognizing critical lures, words that were not studied but are semantically related to the studied words, an indication of false memory (Heit, Brockdorff, & Lamberts, 2004; Roediger & McDermott, 1995).

A consensus result has not been reached in studies utilizing the DRM paradigm to investigate the impact of sleep on false memory. In studies where false memory was measured through recall, a period of sleep increased false memory compared to an equivalent interval of daytime wakefulness (Diekelmann, Born, & Wagner, 2010; Payne et al., 2009). In contrast, when false memory was measured through recognition, there was lower false memory of critical lures after a period of sleep compared to an equivalent period of wakefulness (Fenn et al., 2009; Lo, Sim, & Chee, 2014). The contrasting results suggest that the effect of sleep on false memory in the DRM paradigm depends on the way in which false memory is tested.

Given the equivocal results on false memory and sleep using the DRM, we opted to use a misinformation paradigm. In a typical misinformation study, participants witness an event and are later exposed to deliberately misleading information about what they just saw (Frenda, Nichols, & Loftus, 2011; Loftus et al., 1978). The study typically ends with a memory test, where participants may inadvertently incorporate elements from the misleading information (Frenda et al., 2011). Recent studies looking at the effect of sleep on false memory utilizing a

misinformation paradigm have produced inconsistent results. In one study participants were found to have increased false memory when they slept compared to participants who had remained awake during the day (Calvillo, Parong, Peralta, Ocampo, & Van Gundy, 2016) while a separate study found that sleep had no effect on false memory (van Rijn, Carter, McMurtrie, Willner, & Blagrove, 2017). In both studies, misinformation was only presented after a retention interval. Thus, whether the timing of misinformation, with respect to sleep, affects memory distortion remains largely unexplored.

In two experiments, we used a misinformation paradigm to investigate whether sleep affects the consolidation of false memories. We also assessed the extent to which the timing of misinformation, with respect to sleep, affects this consolidation. In our misinformation paradigm, all participants watched a video of a mock crime, received misinformation pertaining to the video, and then completed a recognition test after a delay interval that included either sleep or waking activity. The misinformation was encountered either before the start of the retention interval or after the retention interval, depending on condition. Both experiments contained a similar procedure, the main difference between the two was that in the first experiment, all participants were warned before the recognition test that they had been exposed to misinformation. This was done to assess if a post-misinformation warning, which has had limited success in reducing false memory (Loftus, 2005), is more effective if presented after sleep. Our hypothesis was that, regardless of warning, the effect of sleep on false memory would depend on when participants received misinformation. We predicted that participants who received misinformation further from encoding and closer to the recognition test would exhibit higher false memory than those who received misinformation directly after encoding. With respect to

sleep, we predicted that if misinformation was received after the retention interval, those who slept during the interval will have lower false memory than those who remained awake.

EXPERIMENT 1

Methods

Participants

We recruited 343 native English-speaking undergraduate students from Michigan State University with no history of a memory or sleep disorders. Participants were excluded if they napped during a waking interval (N = 84), had incomplete data (N = 21), consumed drugs or alcohol prior to the study (N = 26), or for being non-native English speakers (N = 12). Our final sample consisted of 200 participants (142 female), who were 18 - 47 years old (M = 19.68, SD = 2.43). Participants received course credit for participation. The study was approved by Michigan State University's IRB and informed consent was obtained from all participants.

Design

The experiment consisted of three phases – encoding, misinformation, and test (*Figure 1)*. Participants were assigned to one of four conditions in a between-subjects design. We manipulated two variables, delay condition and timing of misinformation.

All participants in the experimental groups completed the encoding and test phases in two separate sessions that were approximately 12 hours apart. There were two delay conditions, Sleep and Wake. Participants in the Wake group completed the first session in the morning (between 8:00-10:00) and the second session in the evening (between 20:00-22:00), after a waking day. Participants in the Sleep group completed the first session in the evening (20:00-22:00) and completed the second session the following morning (8:00-10:00), after a night of sleep.

The timing of misinformation was manipulated such that participants either received misinformation right after encoding (Pre-retention Interval misinformation), or before taking the

recognition test (Post-retention Interval misinformation). Delay condition groups (Sleep and Wake) were divided such that half in each group received misinformation before the retention interval and half received misinformation after the retention interval.

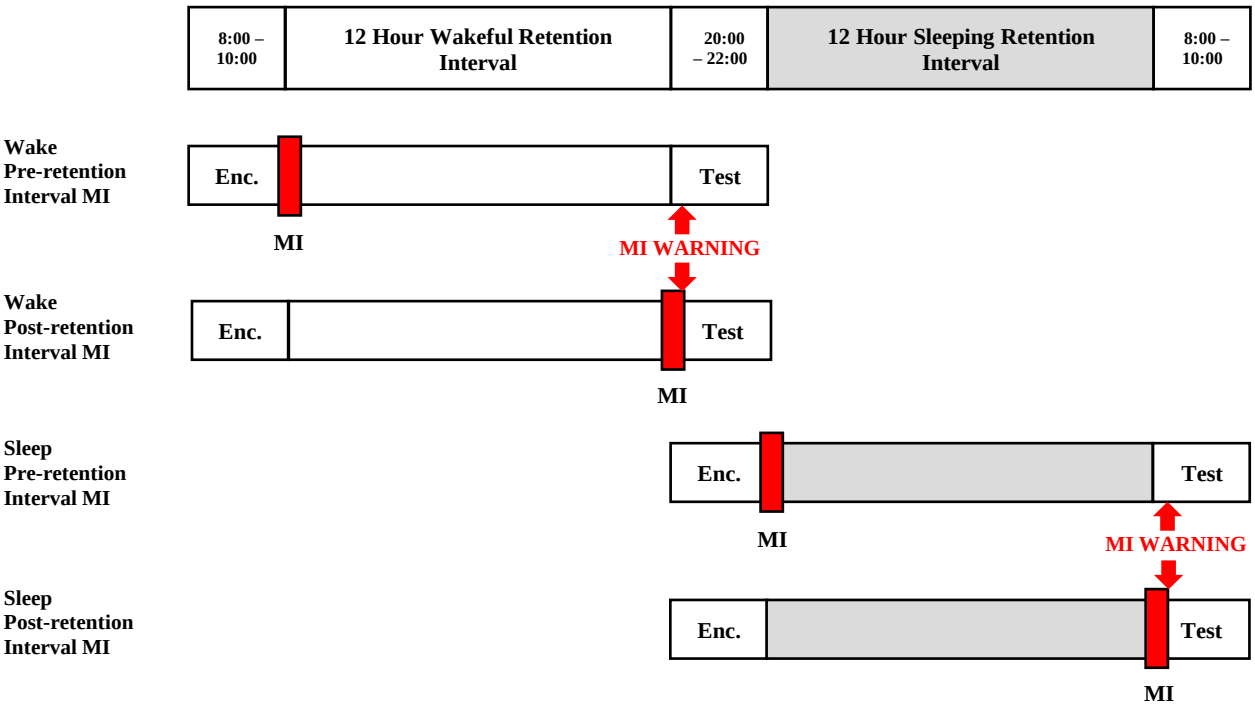

Figure 1. Schematic representation of the progression of each phase for the four experimental groups for Experiment 1. Participants in the Wake condition completed the encoding phase (Enc.) between 8:00 – 10:00 and participants in the Sleep condition completed encoding between 20:00 – 22:00. The red bars represent exposure to misinformation (MI) which began after the encoding phase for all groups and before the retention interval for the Pre-retention Interval MI groups and following the retention interval but before the recognition test for the Post-retention Interval MI group. All participants were warned about being exposed to misinformation after the retention interval but before the recognition test as represented by the MI WARNING text in red. Participants in both Wake conditions remained awake during their retention interval and participants in both Sleep conditions went home to sleep during their retention interval. Wake participants completed the test (Test) between 20:00 – 22:00 and Sleep participants completed the test between 8:00 – 10:00.

The control group completed all phases of the experiment in one session. Half of the participants in the control group completed the experiment in the morning and half completed it

in the evening. these groups were designed to ensure there were no diurnal or circadian effects on performance.

Materials

Mock Crime Video (Encoding Phase): Participants watched a five-minute video of a mock robbery and police chase (*Figure 2)*. In the video, a man enters a house and steals multiple items. He leaves the house and joins his accomplice in a car. A neighbor calls the police about the robbery, and the police chase the thieves and apprehend them.

Figure 2. Screenshots of the mock crime video which all participants watched during the encoding phase of the experiment.

Misinformation Phase: During the misinformation phase, participants were given a questionnaire with 24 open-ended questions pertaining to the Mock Crime Video. Within the open-ended questions, some of the questions contained misinformation (a detail that was not present in the actual film). Most of the information in the questions occurred in the film but there were six

pieces of misinformation in the questions. The questions progressed chronologically through the video from questions 1-12 and then again for questions 13-24. That is, questions 1 and 13 asked about similar information at the very start of the video and questions 12 and 24 asked about information at the very end of the video. In the first 12 questions, the misinformation was introduced or simply included in the question. For example, participants read, "At the beginning of the scene, a young man dressed in jeans, a t-shirt, and **gloves** entered the house. Did he appear to be in a rush when he entered?". In this example, the misinformation, that the thief was wearing gloves, is present in the question but not specifically addressed by the question. In the second half of this phase (questions 13-24), the questions specifically asked about the misinformation. For example, participants read, "At the beginning of the film clip, the young man who entered the house was dressed in jeans, a t-shirt and **gloves**. What color were the **gloves**?" (see Appendix A for full list of misinformation questions).

Recognition Test: During the test phase, participants were presented with 38 items that may or may not have appeared in the film and were asked to indicate whether they recognized the items from the film. There were three types of items present on the questionnaire: Suggested items ("The thief wore gloves"), correct items ("The thief carried a bag" (*Figure 2*)), and unrelated lures that were not present in the film or in the misinformation phase ("The driver had a moustache"). Items were presented individually on a computer screen, in random order. There was no time limit imposed on the test (see Appendix B for full recognition test).

Stanford Sleepiness Scale: The Stanford Sleepiness Scale (SSS; Hoddes, Dement, & Zarcone, 1972) measures subjective sleepiness on a seven-point scale, from one "Feeling active, vital, alert, or wide awake" to seven "No longer fighting sleep, sleep onset soon; having dream-like thoughts", with higher values indicating greater feelings of sleepiness.

Operation Span Task: The Operation Span Task (OSPAN; Unsworth, Heitz, Schrock, & Engle, 2005) measures working memory capacity. On each trial, participants see a simple math problem and a possible answer and must indicate whether the answer is "true" or "false". After they solve the math problem, they receive a letter to remember. The sequence continues until the participants are prompted to recall the letters in the order in which they saw them. Participants complete a total of 15 trials varying in set size, ranging from three to seven letters.

Sleep Diary: The sleep diary asked participants to track their sleep for the five days up to and including the date of their study. Participants were asked what time they went to bed, how long it took them to fall asleep, what time they got out of bed in the morning, how many times they woke up during their sleep and the approximate time they spent awake, and how many times they napped each day and the total time asleep during those naps.

Procedure

In session 1, participants were told that the experiment was investigating how different kinds of movies can affect critical thinking skills and that they should pay close attention to the video since they would be asked questions pertaining to the video after its conclusion. They then completed the SSS, watched the mock crime video, and completed the OSPAN task (to reduce rehearsal). Once participants completed the OSPAN, participants in the Pre-retention Interval misinformation conditions completed the misinformation phase while participants in the Post-retention Interval misinformation conditions were dismissed from the lab until the next session.

During the retention interval, participants either stayed awake during the day (Wake) or went home to sleep in their habitual sleeping environment (Sleep). When participants returned to the lab for session 2, they first completed the SSS.

Before the recognition test, all participants were warned about the misinformation

manipulation (*Figure 1)*. We explained that some information that appeared in the questions did not actually appear in the film and were designed to trick their memory. Specifically, we verbally read the following (words in bold were emphasized):

"You will be given items, details, or events that may or may not have appeared in the video. Please read each one and try to decide whether or not you remember seeing (or hearing) this information in the video. This may sound like an easy task, but during the experiment, we tried to trick you. In the questions you just answered, we mentioned information that was ***not*** *present in the movie. Much of the information that appeared in the questions* ***did*** *appear in the movie, but some of it did not. This means that some items will have been present in the movie only, some items will have been present in the movie and the questions, and some items will have been present in the questions only. Your job is to try to remember the movie and on each trial, we want you to answer based only on your memory for the movie."*

Participants in the Pre-retention Interval misinformation condition were given the warning followed by the recognition test; participants in the Post-interval misinformation condition completed the misinformation phase and then were given the warning and the recognition test. Finally, participants in both conditions completed a demographic questionnaire and were debriefed before leaving the laboratory.

Control groups completed all tasks in the same order as the experimental groups; the only difference was that all were completed in the same session. They were given the same instructions as the experimental groups when they arrived for the study. They completed the SSS, watched the mock crime video, and then completed OSPAN. They then completed the misinformation phase and SSS, and were then read the misinformation warning, and completed the recognition test. Following the recognition test, participants completed a demographic questionnaire, and were debriefed.

Data Analysis

Two-way ANOVAs were used to compare the effects of Condition (Sleep or Wake) and Timing of Misinformation (Pre-retention Interval misinformation or Post-retention Interval

misinformation). Where significant interactions occurred, unpaired t-tests were used to further clarify these significant results.

Results

Correct Recognition

There was a significant main effect of Condition, $F(1,156) = 4.84$, $p = 0.029$, $\eta_p^2 = 0.030$. Participants who slept during the retention interval had higher correct recognition than participants who remained awake. There was no significant main effect of Timing of Misinformation, $F(1,156) = 1.984$, $p = 0.161$, $\eta_p^2 = 0.013$ and no significant interaction between the factors, $F(1,156) = 1.116$, $p = 0.292$, $\eta_p^2 = 0.007$.

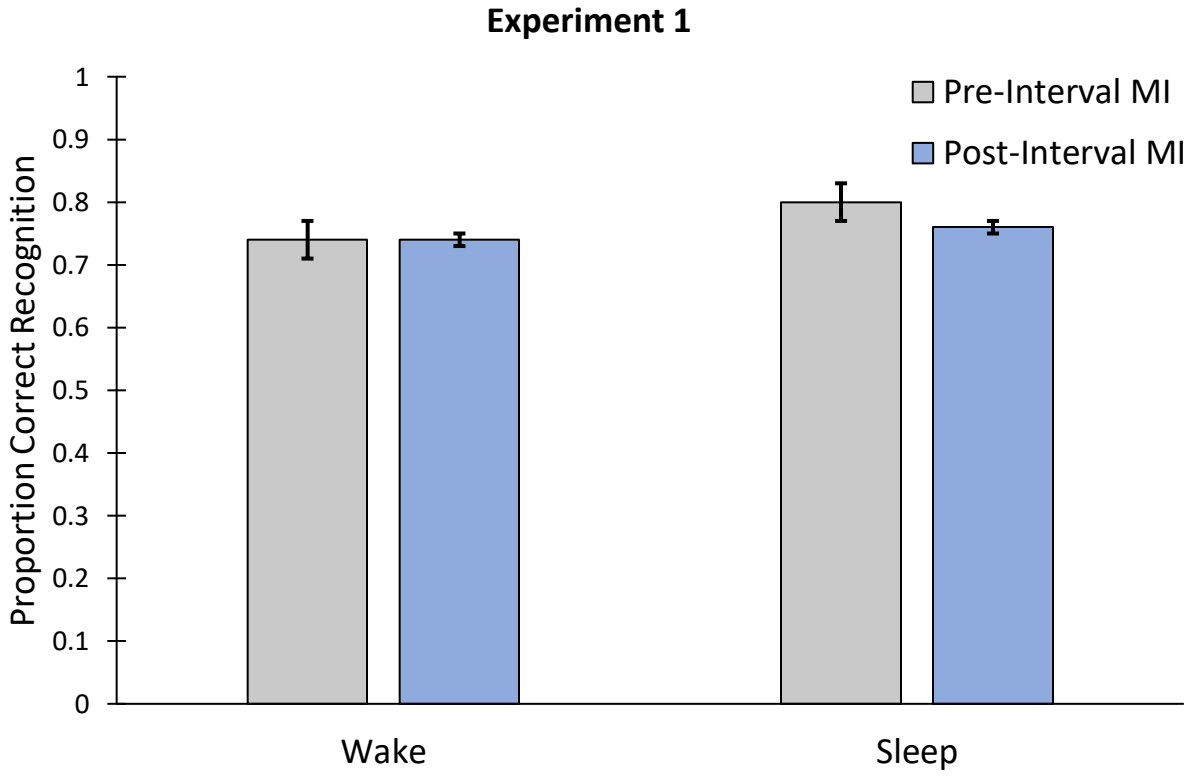

Figure 3. Average proportion of items correctly recognized from the film on the recognition test for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

False Recognition of Suggested Items

There was no significant main effect of Condition, F (1,156) = 0.051, p = 0.821, or Timing of Misinformation, F (1,156) = 3.806, p = 0.053 on false recognition of suggested items. There was, however, a significant interaction between the factors, F(1, 156) = 4.942, p = 0.028, η_p^2 = 0.031.

A main effects analyses revealed that participants in the Sleep condition who were given misinformation *before* the retention interval falsely recognized more suggested items than participants in the Sleep condition who received misinformation *after* the retention interval, t(78) = 2.993, $p < 0.01$. Timing of misinformation did not affect false recognition rates in the Wake condition, t(78) = - 0.190, p = 0.850.

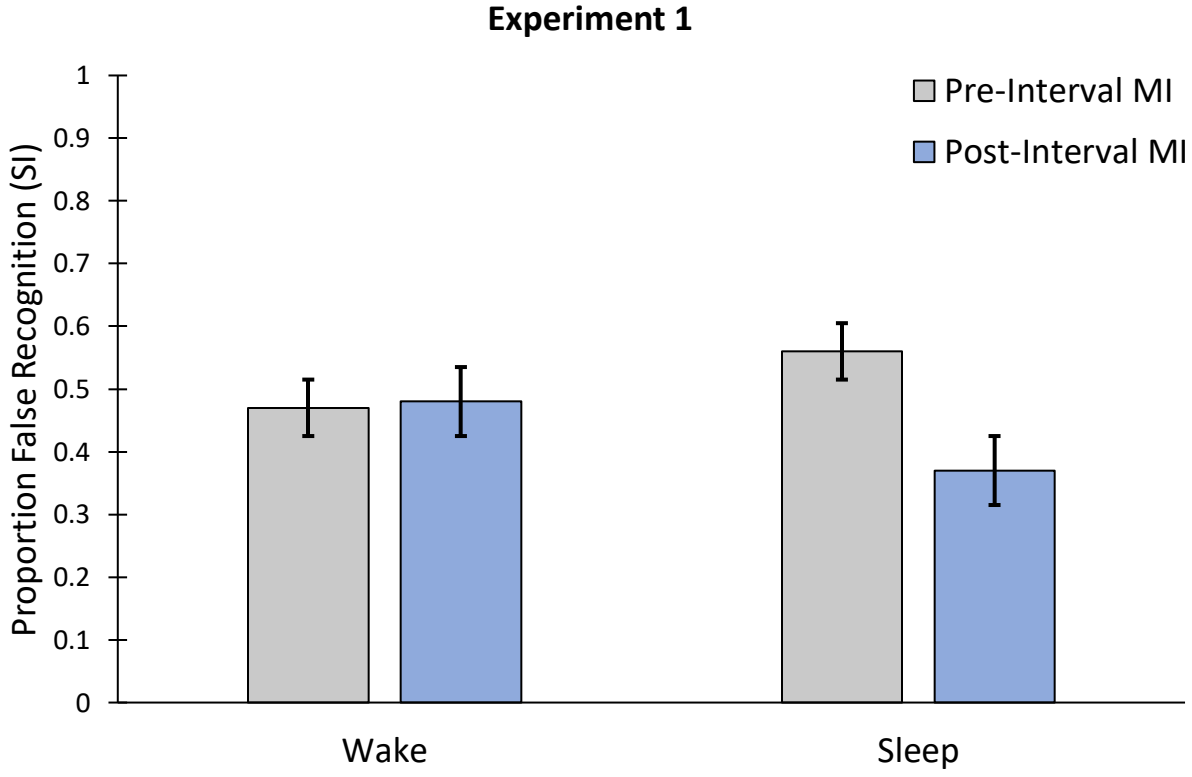

Figure 4. Average proportion of suggested items falsely recognized as being from the film for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

False Recognition of Unrelated Lures

There was a main effect of Condition, F (1,156) = 4.067, p = 0.045, η_p^2 = 0.025 on false recognition of unrelated lures; participants in the Sleep condition recognized fewer unrelated lures than those in the Wake condition. There was no significant main effect of Timing of Misinformation, F (1,156) = 3.329, p = 0.070, and the interaction was not significant, F (1,156) = 1.116, p = 0.292.

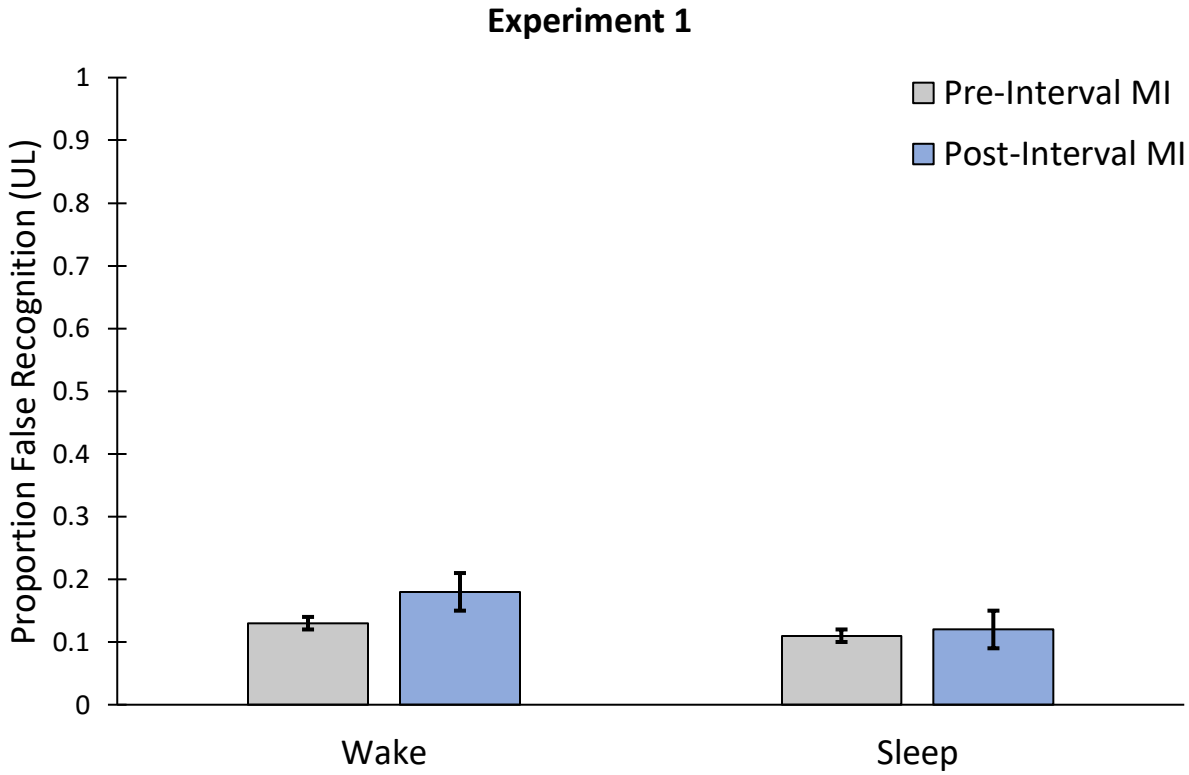

Figure 5. Average proportion of unrelated lures (UL) falsely recognized as being from the film on the recognition test for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

Control Groups

We compared the morning and evening control groups to ensure that none of our effects were due to circadian or diurnal variation. We assessed correct recognition, false recognition of suggested items, and false recognition of unrelated lures using Independent Samples t-tests, with time (AM/PM) as our factor. There was no significant effect of time on correct recognition, $t(38) = 0.150$, $p = 0.881$, false recognition of suggested items, $t(38) = 1.506$, $p = 0.140$, or false recognition of unrelated lures, $t(38) = 1.071$, $p = 0.291$, suggesting that our primary results cannot be explained by diurnal or circadian effects.

Discussion

In this experiment we found that false memory is lower when misinformation is encountered following a period of sleep than if it is encountered prior to a period of sleep. All participants received a warning prior to beginning the recognition test which made them aware that they received misleading information. It is unclear whether this benefit of sleep is only present when participants are warned about the manipulation. We therefore designed a second experiment to test if we would see the same results in the absence of a warning about the misinformation manipulation.

For Experiment 2, we also modified the number of times that participants were exposed to each misinformation item in the misinformation phase. In both experiments, participants were exposed to six individual items of misinformation, however, in Experiment 1 participants were exposed to each item twice, while in Experiment 2, participants were exposed to each item of misinformation only once.

EXPERIMENT 2

Methods

Participants

We recruited 394 novel native English-speaking undergraduate students from Michigan State University with no history of a memory or sleep disorders and who did not regularly use prescription or over-the-counter sleep aids at the time of the experiment. Participants were excluded if they napped during a waking interval (N = 23) or had incomplete data (N = 58). Our final sample consisted of 313 participants (206 female, 103 male, 4 non-binary) who were 18 - 24 years old (M = 19.26, SD = 1.26). Participants were compensated with course credit and informed consent was obtained from all participants.

Design

The design for Experiment 2 was nearly identical to Experiment 1 (*Figure 1)* except that participants did not receive a misinformation warning at any point and participants were only exposed to each item of misinformation once.

Materials

Mock Crime Video (Encoding Phase): The mock crime video used in this experiment was the same as the one used in Experiment 1 (*Figure 3*).

Misinformation Phase: During the misinformation phase, participants were given a questionnaire with 13 open-ended questions pertaining to the Mock Crime Video. Within the open-ended questions, some of the questions contained misinformation (a detail that was not present in the actual film). For example, “Meanwhile, the driver was sitting in the car **smoking a cigarette** while he waited. What kind of hat was he wearing?” The misinformation in this example is that the driver was smoking a cigarette, however, that is not the piece of information which is being

directly addressed in the question. Participants were exposed to each item of misinformation (n = 6) once through the open-ended questions. The questions were presented in chronological order according to the order of events in the video (see Appendix C for full list of misinformation questions).

Recognition Test: The recognition test used in Experiment 2 followed a similar format as the recognition test used in Experiment 1 (see Appendix D for full recognition test).

Stanford Sleepiness Scale: The SSS administered was the same for Experiment 1 and Experiment 2.

Positive and Negative Affect Schedule: The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) is made up of two scales, one which measures positive affect and the other which measures negative affect. Participants rate each item which describes a different feeling or emotion on a 5-point Likert scale. Participants are asked to rate each item based on what extent they feel that way that moment where one represents "very slightly or not at all" and five represents "extremely". Out of the 10 items, five of the items measure positive affect while the other five items measure negative affect.

Cognitive Reflection Test: The Cognitive Reflection Test (CRT; Frederick, 2005) is a three-item test that measures impulsive responding. The three questions are in an open-ended response format (see Appendix E for CRT questions).

Dissociative Experience Scale: The Dissociative Experience Scale (DES, Bernstein & Putnam, 1986) measures dissociative experiences through a 28 items self-report questionnaire (see Appendix F for DES questionnaire).

Sleep Diary: Participants in both Experiments completed the same sleep diary.

Procedure

The procedure for Experiment 2 was similar to the procedure for Experiment 1. At the start of the first session, participants completed both the SSS and PANAS before watching the mock crime video. At the conclusion of the video, participants completed the CRT and DES. Post-retention Interval misinformation participants were then dismissed until the next session. Pre-retention Interval misinformation participants completed the misinformation phase before being dismissed.

Participants either stayed awake during the day (Wake) or went home to sleep in their habitual sleeping environment (Sleep) during the retention interval. When participants returned to the lab for session 2, they first completed the SSS and PANAS. Participants in the Pre-retention Interval misinformation condition were then given the recognition test; participants in the Post-interval misinformation condition completed the misinformation phase and then the recognition test. There was no warning given to participants at any point. Following the recognition test, participants in both conditions completed a demographic questionnaire and were debriefed about the study.

Control group participants completed all of the phases in one session. They completed the SSS and PANAS, watched the mock crime video, and completed the CRT and DES. They then completed the misinformation phase, SSS and PANAS, and the recognition test. Finally, all participants completed the demographic questionnaire and were debriefed.

Data Analysis

Two-way ANOVAs were used to compare the effects of Condition (Sleep or Wake) and Timing of MI (Pre-retention Interval MI or Post-retention Interval MI).

Results

Correct Recognition

There was no significant effect of Condition, $F(1,190)= 0.650$, $p = 0.421$, $\eta_p^2 = 0.003$, or Timing of Misinformation, $F(1,190) = 0.524$, $p = 0.470$, $\eta_p^2 = 0.003$ on correct recognition. There was also no significant interaction between the two factors, $F(1,190)= 0.669$, $p = 0.415$, $\eta_p^2 =0.004$.

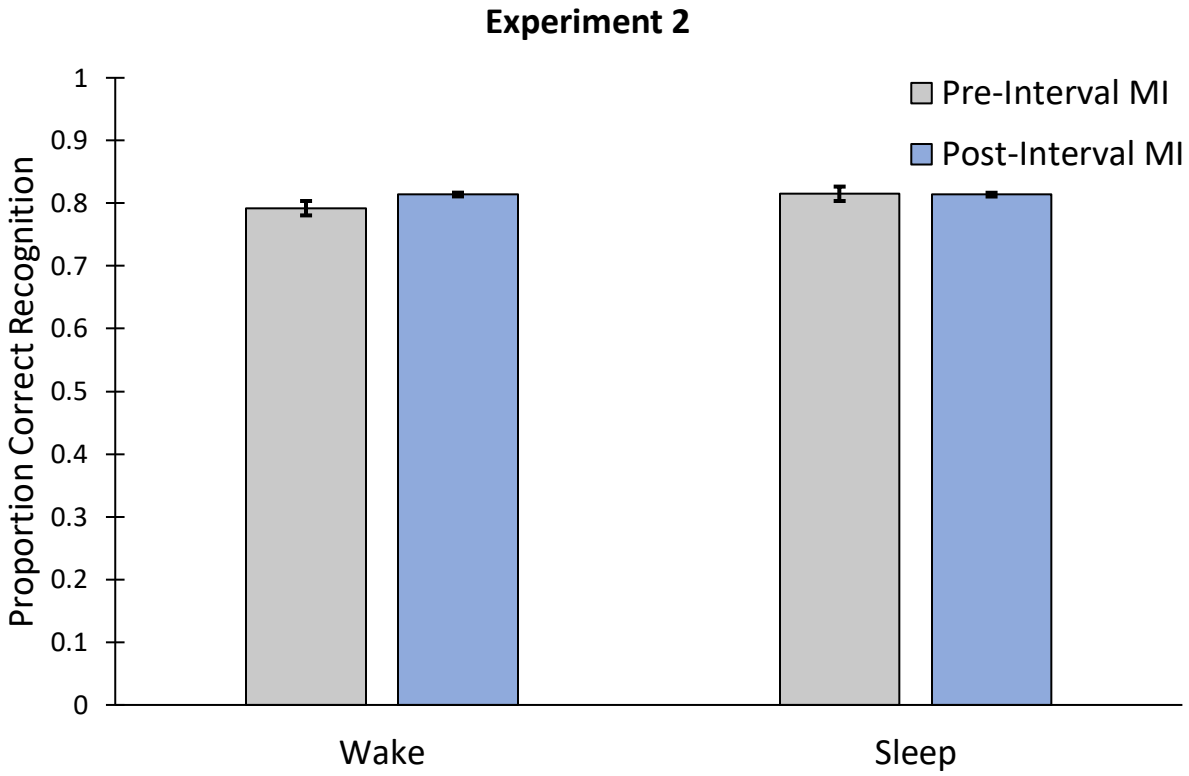

Figure 6. Average proportion of items correctly recognized from the film on the recognition test for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

False Recognition of Suggested Items

There was no significant main effect of Condition, $F(1,190)= 0.581$, $p = 0.447$, $\eta_p^2 = 0.003$ on false recognition of suggested items but there was a significant main effect of Timing

of MI, $F(1,190) = 18.627$, $p = < 0.001$, $\eta_p^2 = 0.089$. Participants who received MI after the retention interval falsely recognized more suggested items than participants who received MI before the retention interval. There was no significant interaction between the factors, $F(1,190) = 5.68$, $p = 0.018$, $\eta_p^2 = 0.029$.

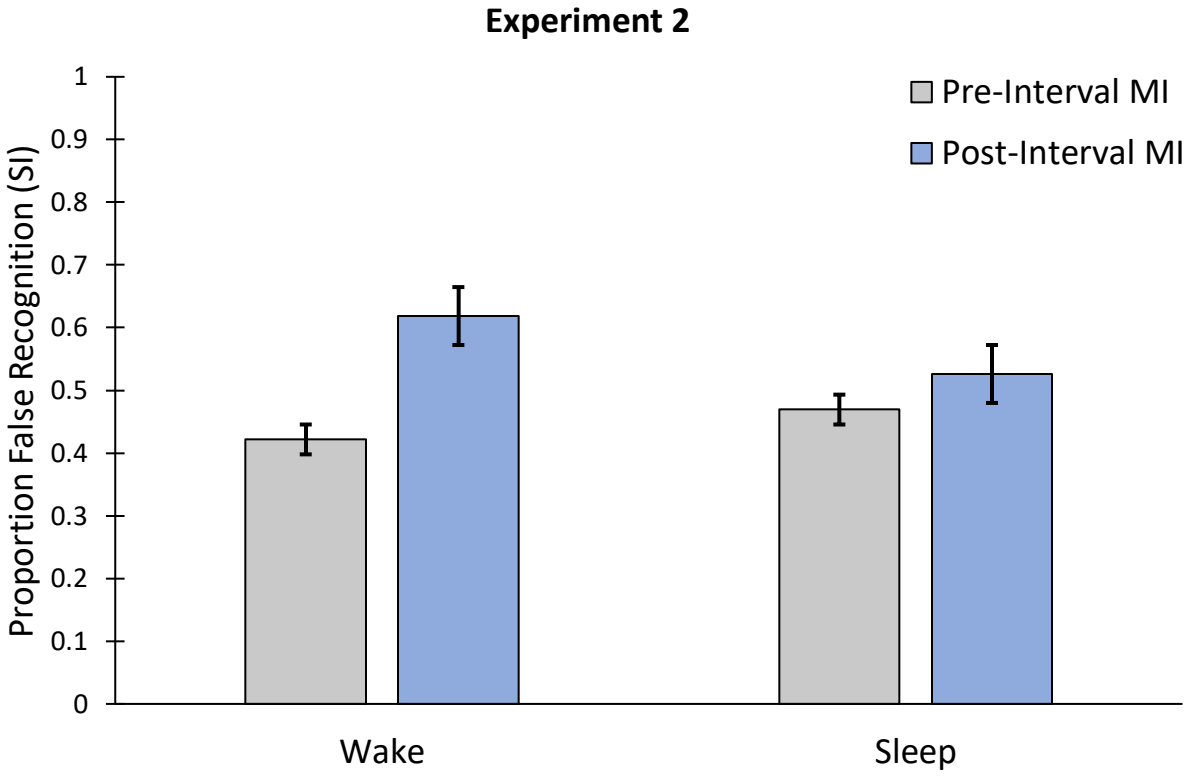

Figure 7. Average proportion of suggested items (SI) falsely recognized as being from the film on the recognition test for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

False Recognition of Unrelated Lures

There was no significant main effect of Condition, $F\ (1,190) = 0.358$, $p = 0.55$, $\eta_p^2 = 0.002$ or Timing of MI, $F\ (1,190) = 2.217$, $p = 0.142$, $\eta_p^2 = 0.011$ on false recognition of

unrelated lures. There was also no significant interaction between the factors, F (1,190) = 2.221, p = 0.138, η_p^2 = 0.012.

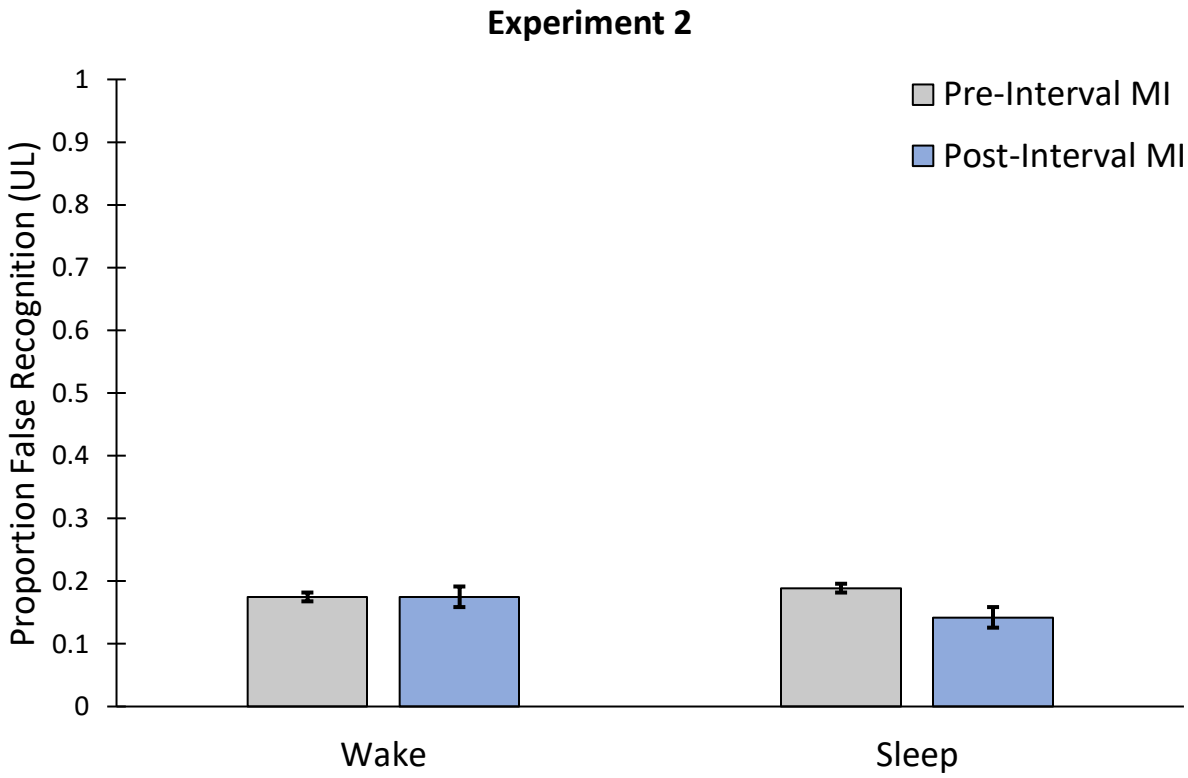

Figure 8. Average proportion of unrelated lures (UL) falsely recognized as being from the film on the recognition test for the Wake condition (left bars) and the Sleep condition (right bars) when misinformation (MI) was encountered prior to the retention interval (grey bars) and after the retention interval (blue bars). Error bars represent the standard error of the mean.

Control Groups

We compared the morning and evening control groups to ensure that none of our effects were due to circadian or diurnal variation and assessed correct recognition, false recognition of suggested items, and false recognition of unrelated lures using Independent Samples t-tests.

There was no significant effect of time on correct recognition, $t(117) = 0.299$, $p = 0.766$, or false recognition of suggested items, $t(117) = 0.550$, $p = 0.583$. There was, however, a significant difference in false recognition of unrelated lures between the morning and evening control groups, $t(117) = 2.276$, $p = 0.025$. Participants in the evening control group falsely recognized more unrelated lures than participants in the morning control group.

Discussion

In Experiment 2, we found that the timing of misinformation affected false memory, replicating prior work (Chan, O'Donnell, & Manley, 2022; Frost, 2000), whereas the delay condition did not. Regardless of whether the retention interval included a period of sleep or wakeful activity, misinformation was encountered 12-hours after encoding, false memory was higher. This result was different than what was observed in Experiment 1, where we found that misinformation received after a retention interval with sleep reduced false memory.

GENERAL DISCUSSION

The aim of this study was to assess the effect of sleep on the consolidation of false memory, based on when misinformation was presented. In the first experiment, participants received a warning before the recognition test letting them know that they had been exposed to misinformation. In the second experiment, participants were not made aware of the manipulation. When participants did not receive a warning, a parallel effect was not observed. False memory was higher when participants received misinformation following the retention interval, for both Wake and Sleep groups. The results from these experiments suggest that when people are given a warning, they may be better able to monitor their own memory and avoid false memory than they would if they were to answer spontaneously. This benefit, however, only emerges in instances when misinformation is encountered after a period of sleep.

Our findings from Experiment 1, in which participants were given a warning, had some consistencies with previous studies where participants were informed about being exposed to misinformation. In previous studies where false memory was measured utilizing the DRM task, false memories were suppressed when participants were warned about critical lures on the recognition test (Carmichael & Gutchess, 2016; Neuschatz, Benoit, & Payne, 2003). Here, we showed that in a misinformation study, the warning is effective in reducing false memory, but only when it is preceded by a period of sleep. In general, it seems that when individuals are made aware in some way about having been exposed to misinformation, false memories are less likely, even if it is not in the form of an explicit warning. Participants who take part in misinformation studies where they are debriefed at the end are less likely to develop false memories when they participate in a subsequent misinformation study than those who are participating in one for the first time (Murphy, Loftus, Grady, Levine, & Greene, 2020).

The results from our first experiment supports the theory that memory consolidation occurs during sleep through the reactivation of recently encoded information. When participants in the sleep group received misinformation during the encoding phase, it is possible that sleep may have integrated the false information into their long-term memory resulting in higher false memory (Payne et al., 2009; Schacter, Guerin, & St Jacques, 2011). This is further supported by participants in the sleep group exhibiting lower false memory when the misinformation occurred after sleep. Our results from this experiment could also be indicative of how sleep acts as protection against memory distortion through interference. When misinformation is encountered after the retention interval, sleep could potentially provide protection from interference, while not sleeping before receiving misinformation, may make memory more susceptible to distortion from interference (Schönauer, Pawlizki, Köck, & Gais, 2014; Sheth, Varghese, & Truong, 2012).

In Experiment 2, we found that when participants did not receive a warning, those who received misinformation after the retention interval had higher false memory in both the Wake and Sleep group. This is consistent with research which indicates that false memory is higher when misinformation is encountered closer to a recognition or recall task (Seamon et al., 2002; Thapar & McDermott, 2001). In Experiment 1, the timing of misinformation did not influence false memory in the Wake group, however, for the Sleep group, false memory was reduced when misinformation was presented after sleep. This was despite participants in Experiment 1 being exposed to each item of misinformation twice, while participants in Experiment 2 were only exposed to each item once. Together, the results from both experiments suggest that while misinformation is more likely to distort memory when it is presented closer to encoding, misinformation awareness is most effective against false memory formation when directly preceded by sleep and exposure to misinformation in that order. Prior research utilizing a

misinformation paradigm indicates that when participants answer quickly, they are more likely to falsely recognize and item than if they were to take their time (Heit et al., 2004). This is relevant to our study if we assume that earlier processing during a recognition task is relatively automatic and later processing is more deliberate (Dodson & Hege, 2005; Heit et al., 2004). Under this assumption, our results could be indicative of a reduction in false memory when individuals are more cautious with their answers due to their awareness of misinformation. Conversely, individuals who are not aware of the misinformation and were exposed to misinformation after the retention interval may answer spontaneously consistent with the misinformation. A significant decrease in false memory with the misinformation warning was only found when participants received misinformation after an interval of sleep. These results suggest that just being aware of misinformation is not enough to reduce false memory. We speculate that when misinformation is presented before an interval of sleep, that information is more likely to consolidate with memory and, therefore, awareness of misinformation is no longer as effective at reducing false memory.

Limitations

While the current study provides insight into how sleep affects false memory, there were also limitations. Our participant pool consisted of Michigan State University students with an average participant age of under 20. A previous study showed that sleep increased false memory in young adults, ages 18-23, while it decreased false memory in older adults, ages 57-77 (Huan, Xu, Wang, & Yu, 2022). It is possible that would see different results if our participants were older. However, while very young children and the elderly are more susceptible to the misinformation effect, adolescents and adults are generally equally vulnerable (Frenda et al., 2011; Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010).

Another limitation was that we could not control how long participants in the Sleep groups slept during their retention interval. Post-learning reductions of false memory are associated with longer periods of slow-wave activity during sleep (Lo, Sim, & Chee, 2014) and it is possible that false recognition of suggested items could have been influenced by both quality and quantity of sleep.

Future Directions

To better understand how awareness of misinformation can reduce false memory, a future study may incorporate a group where participants receive the warning between encoding and the start of the retention interval. Previous studies have found that a warning immediately following encoding could result in decreased false memory due to increased strategic monitoring for misinformation items (Huff, Bodner, & Fawcett, 2015; Murphy et al., 2020). Here, a warning was only presented following the retention interval and preceding the recognition test. A study in which participants are warned about being exposed to misinformation before the retention interval would provide further clarification on how awareness of misinformation affects false memory. Based on the previous research and our current results, we predict that participants would be better able to avoid false recognition during the testing phase when the warning is presented closer to when they are exposed to misinformation and when the retention interval contains a period of sleep. In a study where the warning is provided after encoding and before the retention interval, we speculate that participants who receive the misinformation before sleep will be most successful at suppressing false memories.

In our study, both experiments utilized a 12-hour retention interval which contained either sleep or wake. Sleep shortly after encoding information improves veridical memory of that information when the recognition test is 24 hours away from the time of encoding (Gais et al.,

2006; Payne et al., 2012). It is not as clear how a 24-hour retention period, either before or after receiving misinformation, would affect false memory and how sleep would influence the result. Current research utilizing the DRM suggests that false memory is less likely than veridical memory to dimmish after a lengthy retention interval (Seamon et al., 2002). To our knowledge, it remains unclear whether this same result would be seen in a study using the misinformation paradigm. A future study with a similar design but longer or shorter retention intervals could give us insight as to how false memory progresses in comparison to correct memory.

Apart from the misinformation warning, the main difference between Experiment 1 and Experiment 2 was the number of times participants were exposed to each item of misinformation. While we found that sleep reduced false memory of post-retention interval misinformation with the presence of a warning, participants in Experiment 1 had been exposed to each item of misinformation twice. In a future study, we would like to replicate the misinformation phase and recognition test conditions from Experiment 1 and eliminate the warning to verify that it was awareness of misinformation which reduced false memory and not another factor, such as overexposure to the misinformation items. However, we predict that we would see a similar result in this potential study as we saw in Experiment 2, where participants were only exposed to each misinformation item once.

CONCLUSION

In summary, our study applied the misinformation paradigm in two separate experiments to demonstrate how timing of exposure to misinformation can affect the development of false memories. We hypothesized that false memory would be higher when misinformation was encountered before the retention interval. We found this to be true whether the retention interval contained sleep or wakeful activity in the absence of a warning. misinformation presented closer to the test and further from encoding increased false memory, except when individuals are given a warning following a period of sleep. We speculate that this is because the warning motivated individuals to better monitor their memory rather than answering spontaneously, however, this benefit only emerged when the warning was preceded by sleep and misinformation was presented after the retention interval because sleep was able to consolidate the encoded information but not the misinformation which was presented after sleep. While sleep can protect against false memory, this result is contingent on awareness and timing of misinformation and sleep.

Our results also have real world applications in relation to eyewitness interrogation practices. Our study used a misinformation paradigm with a mock-crime video, which is more applicable to a real-world situation than the DRM (Nichols & Loftus, 2019). In a non-laboratory setting, coercive or biased interviewing can increase the incidence of false accusations made by eyewitnesses of a crime (Loney & Cutler, 2016). Our results would suggest that if eyewitness encounter misinformation related to the witnessed crime closer to when they must provide some information about the event, the likelihood of false memory is higher. However, sleep before exposure to the misinformation and awareness about the likelihood of encountering misinformation can help protect against these false memories. The results of our study may bring

awareness to how misinformation can lead to false recollections from eyewitnesses and could assist in developing better procedures for investigating criminal cases that rely on eyewitness testimony.

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APPENDIX A: MISINFORMATION QUESTIONS FOR EXPERIMENT 1

1. At the beginning of the scene, a young man dressed in jeans and a t-shirt entered the house. Did he appear to be in a rush when he entered?
2. The young man then walked into the bedroom, pulled the window shade, and went to the nightstand. Was the nightstand directly next to the bed?
3. After finding some money in the dresser, did the thief continue to look for more items in the drawers?
4. Was the driver, who was sitting in the car smoking a cigarette while he waited, listening to the radio?
5. During this time, the neighbor woman's attention was drawn to an unfamiliar car parked in front of the house next door. Did she write down the license plate number?
6. Later, as he was leaving the house, the thief, putting his hand on the gun at his waist, looked both ways and went out the door. Did he slam the door behind himself?
7. After the thief got into the car, he told the driver to "…get out of here!" Did the driver say that the neighbor had seen them?
8. During the phone call the neighbor made to the police she said, "This is Mrs. Anderson, I'd like to report what I think is a robbery." She said she had gotten part of the license plate number. Did she say it was "HGN4073"?
9. Later was a scene in which two officers sitting in a police cruiser spotted the thief's car. When the officer set down his Coke and said, "Damn if it isn't!" did he suggest they follow the car?
10. In the next scene the police officer told the dispatcher the "vehicle is not stopping…we are in pursuit." Did he seem sure the car would stop?

11. When the police said, “Pull over! You’re under arrest!”, did the thief curse at the driver?
12. The videotape ended as the driver jumped the curb and the thief said, “That’s it, I’m giving this up!” Did the car then screech to a halt?
13. Let’s begin at the start of the scene again. At the beginning of the film clip, the young man who entered the house was dressed in jeans and a t-shirt. What color was the t-shirt?
14. When the young man later entered the bedroom and pulled down the window shade, what condition was the shade in (e.g. worn, new, torn, etc.)?
15. Having taken some money from the dresser, did the thief count the money before putting it into his pocket?
16. Meanwhile, the driver was sitting in the car smoking a cigarette while he waited. Did he hold the cigarette in his right hand or left hand?
17. Was the neighbor working in her garden when her attention was drawn to an unfamiliar vehicle parked next door?
18. Before leaving the house the thief the thief checked the gun at his waist and looked both ways to see if anyone was watching. Where on the thief’s waist was the gun located (e.g. front, side, back)?
19. When the thief got into the car, did he seem angry with the driver for not moving fast enough?
20. When the neighbor called the police she said, “This is Mrs. Anderson, I’d like to report what I think is a robbery.” Did her voice shake when she told the dispatcher her name?
21. Later in the film, two police officers saw the car involved in the burglary. After the officer put down his Coke and said “Damn if it isn’t!”, they called the dispatcher. Was the Coke in a can or a bottle?

22. Soon after, the police officer reported that the “vehicle is not stopping…we are in pursuit.” Did he say he thought the car was stolen?
23. In the pursuit scene, when the police said, “Pull over! You’re under arrest!”, did the thief say, “I knew we’d never get away!”?
24. During the last scene, the driver jumped the curb and the thief said, “That’s it, I’m giving this up!”. Did they end up on the sidewalk when the driver jumped the curb?

APPENDIX B: RECOGNITION TEST ITEMS FOR EXPERIMENT 1

Misinformation

1. The thief pulled a window shade down
2. The driver smoked a cigarette
3. The thief had a gun
4. The neighbor's name was Mrs. Anderson
5. One of the police officers had a Coke
6. The driver jumped a curb with the car
7. The thief wore gloves
8. The thief took a watch
9. There was a barking dog
10. The thief put on his seatbelt
11. The police thought the driver was DWI
12. The police said they would shoot

Correct

13. The thief stole some money
14. There was a nightstand
15. The thief wore a t-shirt
16. A police officer said, "Pull over! You're under arrest!"
17. The thief was slender
18. The neighbor looked out her window
19. The neighbor wore a red shirt
20. The thief said, "It's not worth it for this crap we got out of that place!"

21. The police car was #12

22. The thief carried a bag

23. The police dispatcher was female

24. The thieves drove a Buick

25. There was a camera bag

26. One of the thieves was on parole

27. The neighbor's phone was in the kitchen

Unrelated Lures

28. The dresser had a mirror

29. The thief stole some CDs

30. The neighbor started to cry

31. It was raining

32. The thief broke a window

33. The thief was wearing a hat

34. They passed a farm during the chase

35. The police offer said "Let's get those guys!"

36. The neighbor's phone was red

37. The thief was wearing khakis

38. The driver had a moustache

APPENDIX C: MISNFORMATION QUESTIONS FOR EXPERIMENT 2

1. At the beginning of the scene, a young man dressed in jeans, and a t-shirt, and gloves entered the house. What color was the t-shirt?
2. The young man then walked into the bedroom, pulled the window shade, and went to the nightstand. Did he turn on a light before rummaging through the nightstand?
3. While searching through the nightstand, the thief found some books that he put in his bag. Were the books in the top drawer or the bottom drawer?
4. The thief took a watch and some money from the dresser. Did the thief count the money before putting it into his pocket?
5. While the thief was looking through the dresser, he was standing with his back facing out. What image was on the back of his jean vest?
6. Meanwhile, the driver was sitting in the car smoking a cigarette while he waited. What kind of hat was he wearing?
7. During this time, the neighbor woman's attention was drawn to an unfamiliar car parked in front of the house next door. Did she write down the license plate number?
8. Later, as he was leaving the house the thief looked both ways and went out the door. Did he slam the door behind himself?
9. After the thief got into the car, and put on his seatbelt, he told the driver to "…get out of here!" Did the driver say that the neighbor had seen them?
10. During the phone call the neighbor made to the police she said, "I'd like to report what I think is a robbery." She then reported that they had left in a car that was what color?

11. Later, there was a scene in which two officers sitting in a police cruiser spotted the thief's car. When the officer set down his Coke and said, "Damn if it isn't!" did he suggest they follow the car?
12. When the police said, "Pull over! You're under arrest!", did the thief say, "C'mon man, try to lose him!"?
13. The videotape ended as the driver said, "That's it, I'm giving this up!" What did the thief do?

APPENDIX D: RECOGNITION TEST ITEMS FOR EXPERIMENT 2

Misinformation

1. The thief wore gloves
2. The thief pulled a window shade down.
3. The thief took a watch
4. The driver smoked a cigarette
5. The thief put on his seatbelt
6. One of the police officers had a Coke

Correct

7. The thief wore a t-shirt
8. The thief stole some money
9. There was a nightstand
10. A police officer said, “Pull over! You’re under arrest!”
11. The thief carried a bag
12. The neighbor looked out her window
13. The thief was slender
14. The neighbor wore a red shirt
15. The thief said, “It’s not worth it for this crap we got out of that place!”
16. The police car was #12
17. One of the police officers was wearing sunglasses
18. The thieves drove a Buick
19. There was a camera bag
20. One of the thieves was on parole

21. The neighbor's phone was in the kitchen

22. The dresser had a mirror

Unrelated Lures

23. The thief had a gun

24. The neighbor's name was Mrs. Anderson

25. The driver jumped a curb with the car

26. There was a barking dog

27. The police thought the driver was DWI

28. The police said they would shoot

29. The thief stole some records

30. The neighbor started to cry

31. It was raining

32. The thief broke a window

33. The police dispatcher's hair was in a ponytail

34. They passed a farm during the chase

35. The police officer said, "Let's get those guys!"

36. The neighbor's phone was black

37. The thief was wearing khakis

38. The driver had a moustache

APPENDIX E: COGNITIVE REFLECTION TASK

1. A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? _____ cents?
2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? _____ minutes?
3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? _____days?

APPENDIX F: DISSACIOATIVE EXPERIENCE SCALE

1. Some people have the experience of driving a car and suddenly realizing that they don't remember what has happened during all or part of the trip. Select a number to show what percentage of time this happens to you.
2. Some people find that sometimes they are listening to someone talk and they suddenly realize that they did not hear part or all of what was just said. Select a number to show what percentage of time this happens to you.
3. Some people have the experience of finding themselves in a place and having no idea how they got there. Select a number to show what percentage of time this happens to you.
4. Some people have the experience of finding themselves dressed in clothes that they don't remember putting on. Select a number to show what percentage of time this happens to you.
5. Some people have the experience of finding new things among their belongings that they do not remember buying. Select a number to show what percentage of time this happens to you.
6. Some people sometimes find that they are approached by people that they do not know who call them by another name or insist that they have met them before. Select a number to show what percentage of time this happens to you.
7. Some people sometimes have the experience of feeling as though they are standing next to themselves or watching themselves do something and they actually see themselves as if they were looking at another person. Select a number to show what percentage of time this happens to you.

8. Some people are told that they sometimes do not recognize friends or family members. Select a number to show what percentage of time this happens to you.
9. Some people find that they have no memory for important events in their lives (for example wedding or graduation). Select a number to show what percentage of time this happens to you.
10. Some people have the experience of being accused of lying when they do not think that they have lied. Select a number to show what percentage of time this happens to you.
11. Some people have the experience of looking in a mirror and not recognizing themselves. Select a number to show what percentage of time this happens to you.
12. Some people have the experience of feeling that other people, objects, and the world around them are not real. Select a number to show what percentage of time this happens to you.
13. Some people sometimes have the experience of feeling that that their body does not belong to them. Select a number to show what percentage of time this happens to you.
14. Some people have the experience of sometimes remembering a past event so vividly that they feel as if they were reliving the event. Select a number to show what percentage of time this happens to you.
15. Some people have the experience of not being sure whether things that they remember happening really did happen or whether they just dreamed them. Select a number to show what percentage of time this happens to you.
16. Some people have the experience of being in a familiar place but finding it strange and unfamiliar. Select a number to show what percentage of time this happens to you.

17. Some people find that when they are watching television or a movie they become so absorbed in the story that they are unaware of other events happening around them. Select a number to show what percentage of time this happens to you.
18. Some people sometimes find that they become so involved in a fantasy or daydream that it feels as though it were really happening to them. Select a number to show what percentage of time this happens to you.
19. Some people find that they are sometimes able to ignore pain. Select a number to show what percentage of time this happens to you.
20. Some people find that they sometimes sit staring into space, thinking of nothing, and are not aware of the passage of time. Select a number to show what percentage of time this happens to you.
21. Some people sometimes find that when they are alone they talk out loud to themselves. Select a number to show what percentage of time this happens to you.
22. Some people find that in one situation they may act so differently compared with another situation that they feel almost as if they were two different people. Select a number to show what percentage of time this happens to you.
23. Some people sometimes find that in certain situations they are able to do things with amazing ease and spontaneity that would usually e difficult for them (for example sports, work, social situations, etc.). Select a number to show what percentage of time this happens to you.
24. Some people sometimes find that they cannot remember if they have done something or have just thought about doing that thing (for example not knowing whether they have just

mailed a letter or have just thought about mailing it). Select a number to show what percentage of time this happens to you.

25. Some people sometimes find evidence that they have done things that they do not remember doing. Select a number to show what percentage of time this happens to you.
26. Some people sometimes find writings, drawings, or notes among their belongings that they must have done but cannot remember doing. Select a number to show what percentage of time this happens to you.
27. Some people sometimes find that they hear voices inside their head that tell them to do things or comment on things that they are doing. Select a number to show what percentage of time this happens to you.
28. Some people sometimes feel that they are looking at the world through a fog so that people and objects appear far away or unclear. Select a number to show what percentage of time this happens to you.