THE TIMING OF MISINFORMATION MATTERS: SLEEP BOTH INCREASES MEMORY DISTORTION AND PROTECTS AGAINST IT

By

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A THESIS

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

Psychology—Master of Arts

2020

ABSTRACT

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Prior work investigating the effect of sleep on false memory using the Deese-Roediger-McDermott paradigm has yielded equivocal results. Here, we sought to clarify the effect of sleep on false memory using the misinformation paradigm. Participants watched a film of a mock robbery, were given post-event misinformation about the film, and completed a recognition test after a 12-hour retention interval that consisted of waking activity or sleep. We manipulated when participants received misinformation; half received misinformation after watching the film and before the retention interval and half received misinformation after the retention interval, before the test. Thus, for participants who slept, half received misinformation prior to sleep and half received it after a sleep period. Most interesting, we found an interaction between sleep condition and timing of misinformation. In the sleep group, participants who received misinformation before the retention interval showed higher false memory than those who received misinformation after the retention interval. Timing of misinformation did not affect false memory in the wake condition. These results suggest that consolidation processes can have opposite effects on false memory. If conflicting information is presented after sleep, consolidation protects memory from distortion possibly by mitigating interference effects. However, the same consolidation processes may increase distortion if conflicting information is presented prior to sleep possibly by integrating related memories that are available at the time of sleep (i.e. the true event and the conflicting information). This work has implications for theories of memory and applied implications for the criminal justice system.

For all who helped me along the way, with special thanks to my family, Michelle Stepan, Elle Wernette, and Jeewon Oh.

ACKNOWLEDGEMENTS

I would like to thank Kimberly M. Fenn for her guidance on this project and throughout my graduate education. I would also like to thank my committee members, Susan Ravizza and Zach Hambrick for their feedback. Finally, thank you to Bridgette Weiss and Quinn Abate for their help with the data.

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Introduction

It is well established that sleep benefits declarative memory. Memory for word pairs (Gais, Lucas, & Born; Fenn & Hambrick, 2012, 2013), word-context associations (van der Helm, Gujar, Nishida, & Walker, 2011), and short stories (Aly & Moscovitch, 2010) is stronger after a period of sleep than a comparable period of wakefulness. Furthermore, sleep protects memory against proactive interference (Abel & Bäuml, 2014) and retroactive interference (Ellenbogen, Hulbert, Stickgold, Dinges, & Thompson-Schill, 2006) and can even repair memory that has been impaired by retroactive interference (McDevitt, Duggan, & Mednick, 2015). Broadly, these effects are attributed to active consolidation processes that occur during sleep (Marshall & Born, 2007; Inostroza & Born, 2013).

Despite the established effects of sleep on memory for encoded information, it remains unclear how sleep affects false memory. False alarms and wrong answers occur in studies of sleep and memory. However researchers often do not assess these mistakes because the studies are focused on veridical memory, and false alarms are considered mistakes in memory rather than development of false memory. That is, these memory errors would not be considered false memories as they may be guesses, and the methodology is not designed to discern guesses from false memories. Broadly, false memories occur when an individual's memory for an experience does not match the actual event that occurred. In laboratory studies of false memory, two paradigms are often used: the Deese-Roediger-McDermott (DRM) illusory memory paradigm and the misinformation paradigm.

Thus far, the literature investigating the effect of sleep on false memory has relied almost exclusively on the DRM paradigm, with equivocal results. In the DRM paradigm, participants study lists of words (e.g. *bed, rest, awake, tired, dream*) that are all semantically related to the

critical lure (e.g. *sleep)*, which is not presented (Roediger & McDermott, 1995; Deese, 1959). In both recognition and recall tests, participants often report remembering the critical lure even though they never actually encoded the word. Surprisingly, the effect of sleep on false memory in the DRM paradigm seems to depend on the way that memory is tested. When memory is tested using free recall, there is *higher* false memory of critical lures after a period of diurnal sleep than a period of daytime wakefulness (Payne et. al., 2009; Diekelman, Born, & Wagner, 2010; McKeon, Pace-Schott, & Spencer, 2012). In contrast, when memory is tested using a recognition test, there is *lower* false recognition of critical lures after a period of sleep compared to wakefulness (Fenn, Gallo, Margoliash, Roediger, & Nusbaum, 2009; Lo, Sim, & Chee, 2014). Finally, one study using a recognition test found no difference in false memory for critical lures between sleep and wake groups (Diekelmann, Landolt, Lahl, Born, Wagner, 2008).

Given the inconclusive evidence from the DRM paradigm, we chose to investigate the effect of sleep on false memory using the misinformation paradigm, an arguably more ecologically valid way to study false memory (Hyman & Kleinknecht, 1999; Wade et. al., 2007; Pezdek & Lam, 2007). In this paradigm, participants encode an event, receive plausible false information about what occurred in the event, termed post-event misinformation, and are tested on their memory for the event (Frenda, Nichols, & Loftus, 2011). False memories that emerge from misinformation may be additional details about the event that did not actually occur or information that directly contradicts something that happened during an event (see Umanath, Ries, & Huff, 2019 for a discussion of these types of misinformation). Typically, participants attribute some of the post-event misinformation to the actual event, integrating the misinformation with their memory for the original event. This general sequence of events may elicit false memories in an ecologically valid way. In real-life situations when individuals have

an experience and later encounter conflicting information about that experience, false memories can arise through a three-step process: 1.) an individual deems the conflicting information as plausible, 2.) the individual imagines it occurring—creating a memory for the false information, and 3.) the individual misattributes that memory to the true event (Hyman & Kleinknecht, 1999; Wade et. al., 2007). This process leads to altered event memory. Along with simulating real-life memory construction processes, the misinformation paradigm also uses richer stimuli (e.g. a video or series of images that depict an event) than the DRM paradigm which uses word lists. Importantly, recent work has found that there is little to no relationship between false memory in the misinformation paradigm and false memory in the DRM paradigm (Ost et. al., 2013; Calvillo & Parong, 2016; Zhu, Chen, Loftus, Lin, & Dong, 2013). This suggests that false memories in the two paradigms likely arise through different mechanisms and that a failure to find consistent effects of sleep on false memory in the DRM paradigm does not preclude the possibility of more stable results in the misinformation paradigm.

There are several mechanisms that may underlie false memory formation in the misinformation paradigm. False memories may arise through interference (Loftus, Miller, & Burns, 1978) and/or adaptive memory updating processes (Schacter, Guerin, & St. Jacques, 2011). Interference may explain the misinformation effect because misinformation presented after an event may hinder retrieval of memory for the original event and lead to endorsement of the misinformation. In contrast, adaptive memory updating processes may incorporate misinformation into memory for the original event, adding seemingly relevant information to the memory (Schacter, Guerin, & St. Jacques, 2011). Through this process, false memories arise due to a transformed memory for the event.

These two potential mechanisms of false memory formation might be differentially

affected by sleep, based on when the misinformation is encountered. That is, misinformation may be encountered either before a period of sleep or after a period of sleep. Let us first discuss misinformation that is encountered before a period of sleep. If false memories arise through interference, sleep should protect against memory distortion because sleep protects against interference that is presented either before or after sleep (Abel & Bäuml, 2014; Sheth, Varghese, & Truong, 2012; Ellenbogen, Hulbert, Stickgold, Dinges, & Thompson-Schill, 2006). In contrast, if false memories arise through adaptive memory updating processes, sleep might integrate the misinformation into the memory for the original event and increase memory distortion (see Tamminen et. al., 2010 for an investigation of memory integration processes during sleep). If false information is presented after a period of sleep, during which the memory should presumably be consolidated, both theories would predict that there would be relatively low false memory; sleep should protect the memory from interference, and it is unlikely that adaptive memory updating processes would act on the consolidated memory. Thus, the two theories would have similar predictions with regard to the effect of sleep on false memory when misinformation is presented after a period of sleep but would have opposite predictions if the same misinformation is presented before a period of sleep.

Recent work on the effect of sleep on false memory in the misinformation paradigm has found mixed results when misinformation was presented after sleep. One study found that sleep increased false memory and the authors suggested that the result was due to better encoding and memory for the misinformation after sleep. That is, well-rested individuals were better able to remember the post-event information than individuals who had remained awake during the day (Calvillo, Parong, Peralta, Ocampo, & Van Gundy, 2016). Conversely, another study found no effect of sleep on false memory (van Rijn, Carter, McMurtrie, Willner, & Blagrove, 2017). This

study used the Gudjonsson Suggestibility Scale (Gudjonsson, 1987). After listening to a story, participants completed two recall tests of their memory for the story before receiving misinformation (van Rijn, et al., 2017). Sleep may not have had a noticeable impact on false memory because the memory may have been sufficiently strong to avoid distortion after the two tests. A limitation to this work is that the misinformation was always presented after the retention interval. Thus, the question of whether misinformation prior to sleep would affect memory distortion and the question of whether the timing of the misinformation would differentially affect false memory remain unexplored.

In the current study, we used the misinformation paradigm to assess the effect of sleep on memory distortion. We manipulated the presentation time of misinformation, with respect to a retention interval that included sleep or wake. All participants watched a mock crime video, received misinformation about the event, and completed a recognition test after a retention interval containing sleep or wakefulness. Importantly, we manipulated the time at which participants received misinformation: either before or after the retention interval. We predicted that the effect of sleep on false memory would depend on when misinformation was presented. Misinformation presented after sleep would not be integrated into memory and there would be relatively low false memory in the sleep group. Although the two theories discussed above would have opposite predictions when misinformation was presented prior to a sleep period, we predicted that sleep would integrate the misinformation into memory for the original event (Schacter, Guerin, & St. Jacques, 2011), resulting in higher false memory, consistent with the adaptive memory updating theory. Based on prior work (Marshall & Born, 2007; Inostroza & Born, 2013), we also predicted better veridical memory after sleep than wake.

Methods

Participants

We recruited 343 native English-speaking undergraduate students from Michigan State University who had no history of memory or sleep disorders. Several participants were excluded for napping during a waking interval (N = 84), consuming drugs or alcohol prior to the study (N = 26), for being non-native English speakers (N = 12), or having incomplete data (N = 21). Our final sample consisted of 200 (142 Female) participants who were 18 - 47[1] years old (*M* = 19.68, *SD* = 2.43). Participants received course credit for participation and informed consent was obtained from all participants.

Design

This experiment had three phases – encoding, misinformation, and test. Participants in the experimental conditions (Wake and Sleep) completed two sessions that took place approximately 12 hours apart. Participants in the Wake condition completed the encoding phase in the morning (8:00 -10:00) and returned for the test in the evening (20:00 - 22:00), after a waking retention interval. Participants in the Sleep condition completed the encoding phase in the evening (20:00 - 22:00) and returned for the test the following morning (8:00 -10:00), after a retention interval including a night of sleep in their habitual sleeping environment. We also manipulated when participants received misinformation. Half of the participants received misinformation after encoding and before the retention interval (Pre-interval Misinformation). The other half received the misinformation after the retention interval and before the recognition test (Post-interval Misinformation).

In addition to the experimental conditions, we included two control groups to assess

[1] We did not intend on recruiting individuals over 35 but one participant reported being 47. We reanalyzed the data without this participant and all of our primary results remained. The reanalysis is described in the Appendix.

diurnal or circadian effects on performance. Participants in the control conditions completed all three phases of the experiment in one session that occurred either in the morning (8:00-10:00) or evening (20:00-22:00).

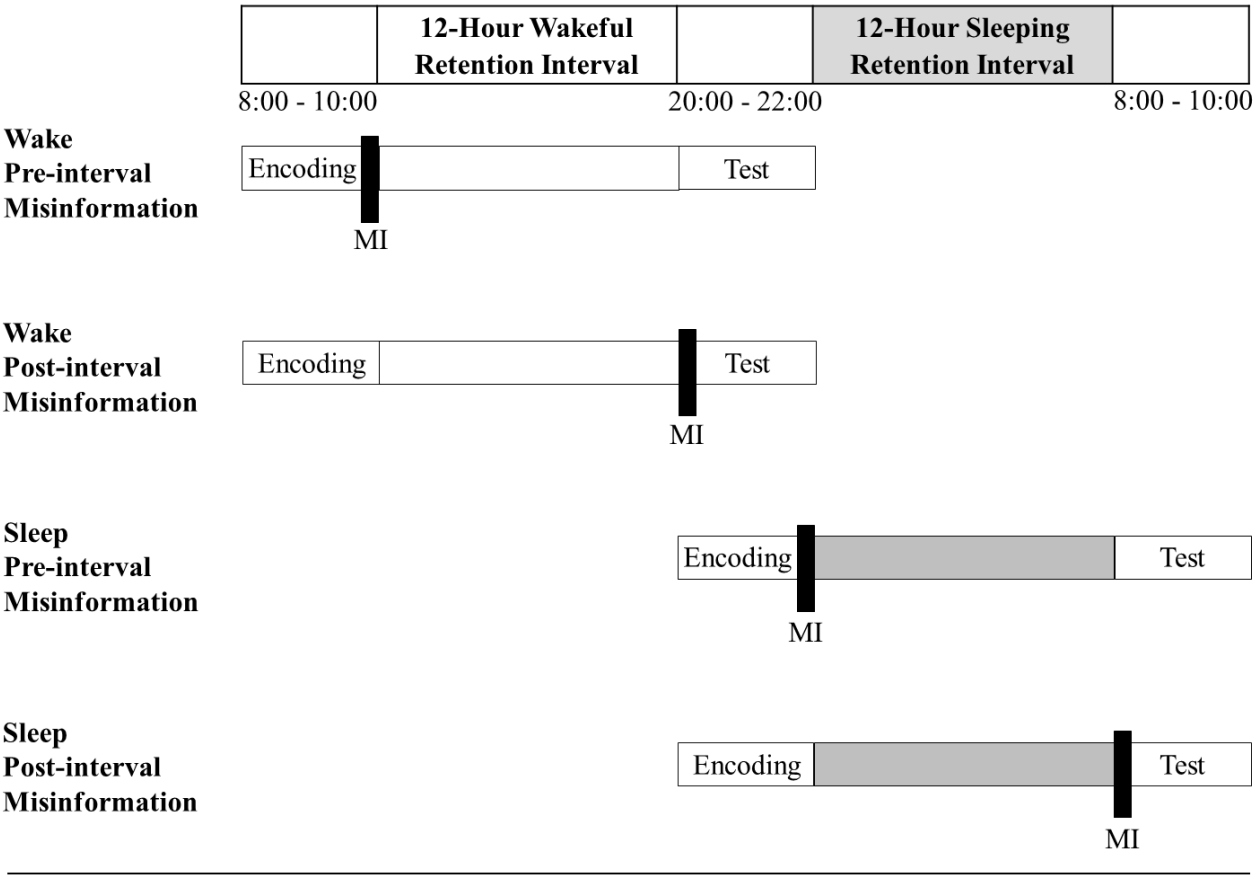

Figure 1. The progression of each phase of the experiment for each experimental condition. Participants in each of the Wake conditions completed the encoding phase at 8:00-10:00, whereas participants in each of the Sleep conditions completed the encoding phase at 20:00-22:00. The misinformation phase, as depicted by the solid black bars, began after the encoding phase and before the retention interval (Pre-interval Misinformation) or after the retention interval and before the test (Post-interval Misinformation). During the retention interval, participants remained awake during the day or went home and slept during the night (solid gray bars). The testing phase for the Wake participants took place at 20:00-22:00, and the testing phase for the Sleep participants took place between at 8:00-10:00.

Materials

Mock Crime Video: Participants watched a five-minute video of a robbery and police chase that has been used successfully in past studies (Chambers & Zaragoza, 2001; Drivdahl & Zaragoza, 2001; Zaragoza & Mitchell, 1996). 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.

Misinformation Phase: The misinformation phase consisted of 24 open-ended questions about the movie. Most of the information in the questions occurred in the film but there were six pieces of misinformation (i.e. details that were not present in the film) 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***[2] *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****?"*

We created two different sets of misinformation (each containing 6 items of misinformation) that were counterbalanced across participants in each condition. We used two

[2] Emphasis added for clarity but did not appear in the actual study materials.

versions of questions to ensure that false memories reflected the effect of misinformation and were not specific to the questions we asked. The italicized and bolded words in the questions below indicate suggested information. These words were not italicized or bolded in the questionnaire given to participants.

Version A.

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 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?***

Version B.

1. 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?
2. The young man then walked into the bedroom and went to the nightstand. Was the nightstand directly next to the bed?
3. After finding a ***watch*** and 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 waiting, listening to the radio?
5. During this time, ***a barking dog*** had drawn the neighbor woman's attention 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 looked both ways and went out the door. Did he slam the door behind himself?
7. 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?
8. During the phone call the neighbor made to the police she said, " 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 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…***driver appears to be DWI***…we are in pursuit." Did he seem sure the car would stop?
11. When the police said, "Pull over or ***we'll shoot*!** You're under arrest!", did the thief curse at the driver?
12. The videotape ended as 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, a t-shirt and ***gloves***. ***What color were the gloves?***

14. When the young man later entered the bedroom, did he turn on a light before rummaging through the nightstand?
15. The thief took *a **watch*** and some money from the dresser. ***Was the watch in the top or bottom drawer of the nightstand?***
16. Meanwhile, the driver was seen sitting in the car waiting. What kind of hat was he wearing?
17. The neighbor was working in her garden when ***a barking dog*** drew her attention to an unfamiliar vehicle parked next door. ***How large was the dog?***
18. Before leaving the house the thief looked both ways to see if anyone was watching. After he got out the door, did he begin to run?
19. When the thief got into the car and ***put on his seatbelt, did he struggle to lock the buckle or did it lock easily?***
20. When the neighbor called 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. (Fill the blank with a color)
21. Later in the film, two police officers saw the car involved in the burglary. After the officer said, "Damn if it isn't!", did they call the dispatcher?
22. Soon after, the police officer reported that the "vehicle is not stopping…***driver appears to be DWI***…we are in pursuit*." **Did the officer sound alarmed when he said the driver was DWI or was he calm?***
23. In the pursuit scene, when the police said, ***"Pull over or we'll shoot!*** You're under arrest!", ***did the officer use the car's PA system to tell the thieves that they would shoot or did he simply yell to the thieves?***
24. During the last scene the thief said, "That's it, I'm giving this up!" What did the driver do?

Misinformation Warning: Before the test, all participants were warned about the misinformation manipulation. We explained that some information that appeared in the questions did not actually appear in the film and was designed to trick their memory. Specifically, we verbally told them 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.*

The warning was designed to encourage participants to critically monitor their memory so that we could gain a greater understanding of the relationship between sleep and memory distortion. We were interested in what participants were *capable* of remembering, not what they spontaneously reported.

Recognition Test: The recognition test consisted of 38 pieces of information and participants were asked to determine whether each piece of information was present in the video or not (see the Appendix for test items). There were three types of information included in the test: 16 correct items that were present in the video, the 6 suggested items that were only present in the misinformation phase, and 16 unrelated lures that were not present in the film or misinformation phase. One unrelated lure needed to be removed from all analyses because it was ambiguous[3] so there were a total of 15 unrelated lures used in the analyses. All participants received the same items but the lures were categorized differently based on which set of misinformation the participant received. That is, 6 of the items were suggested items for participants who received one misinformation set but those same six items were considered unrelated lures for participants who were given the other misinformation set. In addition, four of the correct items were present in both the video and the questions to reduce the likelihood that participants would use a disqualifying recall to reject strategy (Gallo, 2004). That is, simply recognizing that information appeared in the questions was not sufficient for classification because both correct and false information appeared in the questions.

On the list below, items 1 - 16 are the correct items. Of these, items 1 – 4 were present in

[3] The ambiguous item was "The thief was wearing a hat.". In the film, there is a thief who enters the house and an accomplice who waits in the car during the robbery. This item is ambiguous because the thief is not wearing a hat, but the accomplice is wearing a hat. Thus, if participants regarded the accomplice as a thief, they would have recognized this item as being from the film—a correct item. Therefore, this item is ambiguous and could be considered either correct or incorrect, depending on individual interpretation.

the film and the misinformation questions, and questions 5 - 16 were present only in the film. The suggested items for participants who received version A of the misinformation questions were items 17 - 22. The suggested items for version B were items 23 - 28. The suggested items were present only in the misinformation questions. Items 29 - 38 were unrelated lures; these items were not present in the film or misinformation questions. In addition, the suggested items for version B acted as unrelated lures for participants who received version A of the misinformation questions; likewise, the suggested items for version A acted as unrelated lures for participants who received version B of the misinformation questions. Item 33 was removed from analyses because it was ambiguous.

1. The thief stole some money
2. There was a nightstand
3. The thief wore a t-shirt
4. A police officer said, “Pull over! You’re under arrest!”
5. The thief was slender
6. The neighbor looked out her window
7. The neighbor wore a red shirt
8. The thief said, “It’s not worth it for this crap we got out of that place!”
9. The police car was #12
10. The thief carried a bag
11. The police dispatcher was female
12. The thieves drove a Buick
13. There was a camera bag
14. One of the thieves was on parole
15. The neighbor’s phone was in the kitchen
16. The dresser had a mirror
17. The thief pulled a window shade down.
18. The driver smoked a cigarette.
19. The thief had a gun
20. The neighbor’s name was Mrs. Anderson
21. One of the police officers had a Coke
22. The driver jumped a curb with the car
23. The thief wore gloves
24. The thief took a watch
25. There was a barking dog
26. The thief put on his seatbelt
27. The police thought the driver was DWI
28. The police said they would shoot

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 officer 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

Each item was presented individually on a computer screen. Participants first decided whether each item was seen in the video or not seen in the video. Then, for every item that participants identified as being from the video, they were asked to judge their confidence in their response on a seven-point Likert scale ranging from 1 (not at all confident) to 7 (extremely confident). There was no time limit imposed on the test or confidence ratings. Recognition test items and the analyses of confidence ratings can be found in the Appendix.

Stanford Sleepiness Scale: The Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) 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: 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 three to seven letters. The OSPAN score is the total number of letters recalled in the correct order.

Procedure

In session 1, participants completed the Stanford Sleepiness Scale and watched the mock crime video. Before watching the video, participants were told that the experiment was investigating how different kinds of movies affect critical thinking skills. They were also told that after watching the video, they would be asked to answer questions about it, so they should pay close attention. After watching the video, participants completed the Operation Span task to reduce rehearsal. After this task, participants in the Pre-interval Misinformation condition completed the misinformation phase and participants in the Post-interval Misinformation condition left the lab until the next session. During the retention interval, participants either stayed awake during the day (Wake group) or went home to sleep in their habitual sleeping environment (Sleep group).

When participants returned to the lab for session 2, they first completed the Stanford Sleepiness Scale. After this, participants in the Pre-interval Misinformation condition were given the warning and 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. Procedure and materials were approved by the Michigan State University Institutional Review Board.

Results

Table 1. Average proportion of items (SD in parentheses) that participants indicated were present in the video for the experimental conditions.

		N	Correct Items	Suggested Items	Unrelated Lures
Wake	Pre-interval Misinformation	40	.74 (.11)	.47 (.28)	.13 (.10)
	Post-interval Misinformation	40	.74 (.13)	.48 (.31)	.18 (.14)
Sleep	Pre-interval Misinformation	40	.80 (.11)	.56 (.28)	.11 (.11)
	Post-interval Misinformation	40	.76 (.11)	.37 (.29)	.12 (.09)

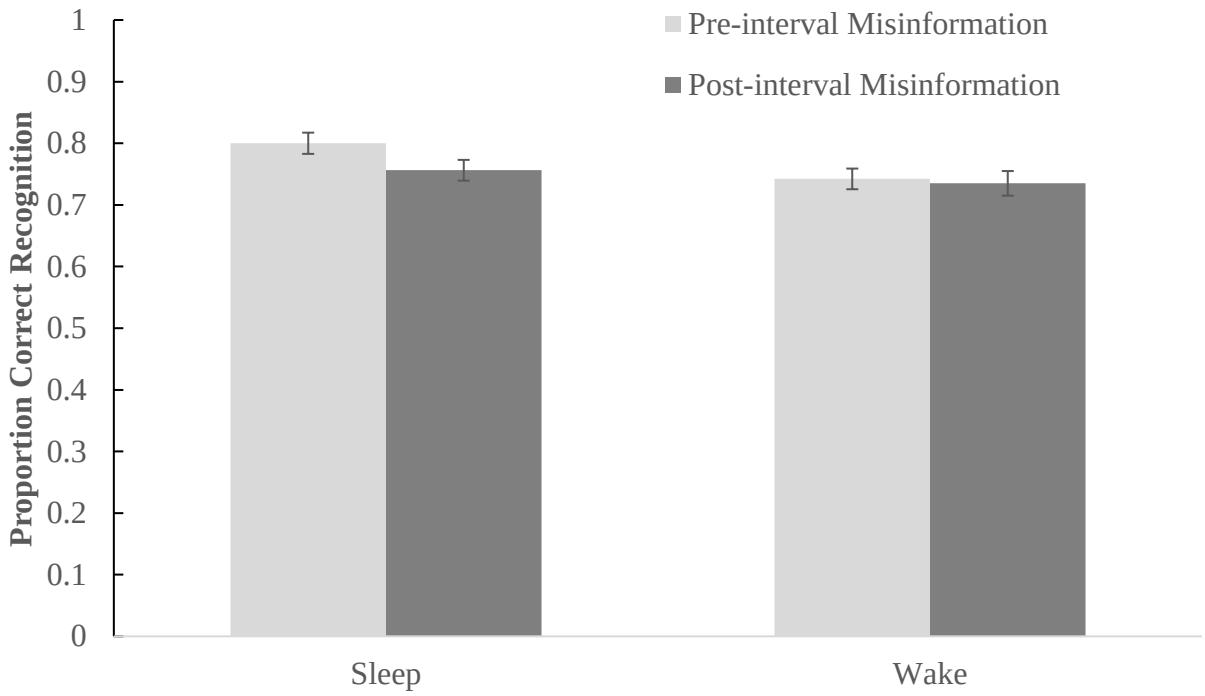

Figure 2. Average proportion of items correctly recognized as "from the film" for each condition. Error bars represent the standard error of the mean.

Correct Recognition

Average correct recognition for each group can be found in Table 1. We ran a two-way ANOVA with Condition (Sleep or Wake) and Timing of Misinformation (Pre-interval or Post-interval) as between-subject factors. There was a significant main effect of Condition, F (1,156)= 4.84, p = 0.029, η_p^2 =0.030. Participants who slept during the retention interval had higher correct recognition than participants who remained awake. There was not a significant main effect of Timing of Misinformation, F (1,156) = 1.984, p = 0.161, η_p^2 = 0.013 or an interaction between the factors, F (1,156) = 1.116, p = 0.292, η_p^2 = 0.007.

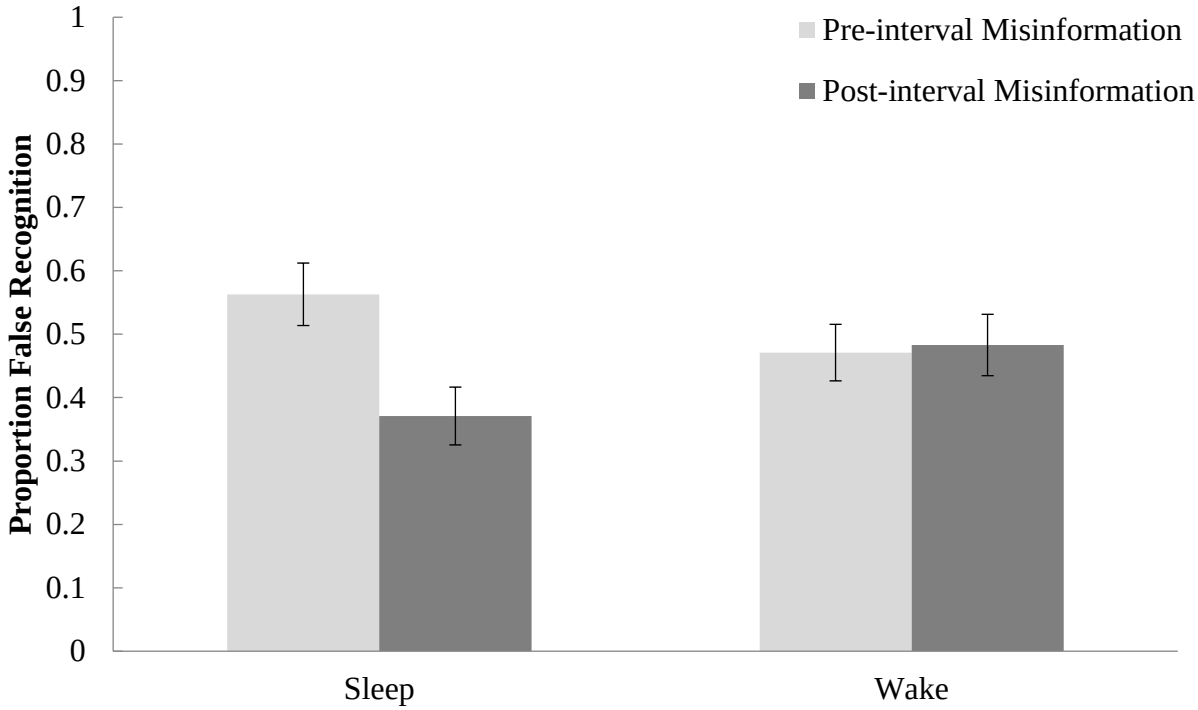

Figure 3. Average proportion of suggested items recognized as "from the film" in each condition. Error bars represent the standard error of the mean.

False Recognition of Suggested Items

We analyzed false recognition of suggested items using a two-way ANOVA with Condition (Sleep or Wake) and Timing of Misinformation (Pre-interval or Post-interval) as between-subject factors. There was not a significant main effect of Condition, F (1,156) = 0.051,

$p = 0.821$ or Timing of Misinformation, F (1,156) = 3.806, $p = 0.053$. There was, however, a significant interaction between the factors, F (1, 156)= 4.942, $p = 0.028$, $\eta_p^2 = 0.031$.

Simple main effects analyses revealed that participants in the Sleep condition who were given misinformation before the delay interval falsely recognized more suggested items than participants in the Sleep condition who received misinformation after the delay, $t(78) = 2.993$, $p = 0.004$. Timing of Misinformation did not affect false recognition rates in the Wake condition, $t(78) = -0.190$, $p = 0.850$.

False Recognition of Unrelated Lures

To assess false recognition of unrelated lures, we entered Condition and Timing of Misinformation as between-subject factors into a two-way ANOVA. There was a main effect of Condition, F (1,156) = 4.067, $p = 0.045$, $\eta_p^2 = 0.025$; participants in the Sleep condition recognized fewer unrelated lures than those in the Wake condition. There was not a 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, $p = 0.292$.

Confidence

Participants rated their confidence for each item on the recognition test that they said was from the film. We calculated average confidence for each item type for each participant. This information is displayed in Table 2.

Confidence for Correct Items. We analyzed confidence for correctly recognized items using a two-way ANOVA with Condition and Timing of Misinformation as between-subject factors. There was a main effect of Condition, $F(1, 156) = 9.023$, $p = 0.003$, such that participants who slept were more confident that they saw the items in the film than people who did not sleep. This effect is consistent with basic recognition performance, reported in the main

document. The main effect of Timing of Misinformation, $F(1, 156) = .782$, $p = 0.378$, and the interaction between Condition and Timing of Misinformation, $F(1, 156) = .095$, $p = 0.758$, were not significant.

Confidence for False Recognition of Suggested items. To compare average confidence ratings for suggested items identified as "from the film" we ran a two-way ANOVA with Condition and Timing of Misinformation as between-subject factors. The main effects of Condition and Timing of misinformation were not significant, $F(1, 144) < 1.349$, $p > 0.247$, and neither was the interaction between the two, $F(1, 144) = 1.524$, $p = 0.219$.

Confidence for Unrelated Lures. Using a two-way ANOVA with Condition and Timing of Misinformation as between-subject factors, we found that the main effects and interaction effect were not significant, $F(1,116) < 0.033$, $p > 0.856$.

Table 2. Average confidence ratings (SD in parentheses) for items identified as "from the film" for each experimental condition.

		N	Correct Items	N	Suggested Items	N	Unrelated Lures
Wake	Pre-interval Misinformation	40	5.92 (.67)	34	4.51 (1.28)	28	3.95 (1.22)
	Post-interval Misinformation	40	5.80 (.76)	36	5.02 (1.40)	32	3.93 (1.24)
Sleep	Pre-interval Misinformation	40	6.18 (.46)	39	4.88 (1.28)	27	3.95 (1.43)
	Post-interval Misinformation	40	6.12 (.52)	35	4.86 (1.14)	33	4.02 (1.34)

Reaction Time

We analyzed reaction times to each item type using a two-way ANOVA with Condition and Timing of Misinformation as between-subject factors. There were no significant differences

in reaction time between groups for either correct items or suggested items, F's ≤ 2.660, p's ≥ 0.105. There were also no main effects of Condition or Timing of Misinformation for unrelated lures, F's ≤ 2.378, p's ≥ 0.125. There was a significant interaction effect, $F(1,156) = 4.037$, $p = 0.046$; the effect of timing of misinformation on reaction times for unrelated lures depended on whether participants slept or stayed awake during the retention interval. Participants in the Wake Pre-interval group spent less time deciding whether the unrelated lures were present in the film than participants in the Wake Post-interval group, $t(78) = 2.450$, $p = 0.017$. The timing of misinformation did not matter for participants who slept during the retention interval, $t(78) = 0.339$, $p = 0.735$. The average reaction times for each group are presented in Table 3.

Table 3. Average reaction times in milliseconds for each experimental and control group, broken by item type. Standard deviations are presented in parentheses.

		N	Correct Items RT	Suggested Items RT	Unrelated Lures RT
Wake	Pre-interval Misinformation	40	3933.13 (1102.68)	3824.72 (926.97)	3445.34 (943.67)
	Post-interval Misinformation	40	4022.06 (1263.59)	4331.57 (1921.67)	4019.48 (1143.07)
Sleep	Pre-interval Misinformation	40	3559.43 (712.30)	3926.42 (1597.37)	3672.68 (1092.89)
	Post-interval Misinformation	40	3994.94 (1141.47)	4241.70 (1749.25)	3597.15 (889.31)
Control	AM	20	4009.35 (929.47)	4127.75 (1330.26)	3623.85 (709.65)
	PM	20	3681.35 (1020.25)	3642.87 (1301.74)	3273.87 (953.14)

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. There was no effect of Time of Day on either correct recognition $t(38) = 0.150$, $p = 0.881$, or false recognition of suggested items $t(38) = 1.506$, $p = 0.140$, or false recognition of unrelated lures $t(38) = 1.071$, $p = 0.291$. Means and standard deviations are presented in Table 4.

Table 4. Average recognition rates (SD in parentheses) for each item type in the control groups.

		N	Correct Items	Suggested Items	Unrelated Lures
Control	AM	20	.77 (.10)	.38 (.28)	.11 (.07)
	PM	20	.77 (.16)	.25 (.28)	.18 (.06)

Table 5. Average OSPAN scores and standard deviations (in parentheses) for the experimental and control groups.

		N	Working Memory (OSPAN Score)
Wake	Pre-interval Misinformation	40	42.37 (16.24)
	Post-interval Misinformation	40	39.98 (18.43)
Sleep	Pre-interval Misinformation	40	41.93 (15.78)
	Post-interval Misinformation	40	43.47 (18.64)
Control	AM	20	47.40 (14.32)
	PM	20	43.80 (15.47)

Working Memory

Working memory capacity is related to false memory; individuals with higher working memory capacity typically show lower false memory (Gerrie & Garry, 2007; Unsworth & Brewer, 2010). We compared performance on the Operation Span task in our experimental groups to ensure that there were no differences based on group, using a two-way ANOVA with

Condition and Timing of Misinformation as between-subject factors. The main effects of Condition and Timing of Misinformation were not significant and neither was the interaction between these factors, F's ≤ 0.520, p's ≥ 0.472. Thus, working memory capacity cannot explain our results.

Sleepiness

We also assessed the potential effect of sleepiness using a repeated measures ANOVA with Session (Session 1 or Session 2) as a within-subject factor and Condition (Sleep or Wake) and Timing of Misinformation (Pre-interval or Post-interval) as between-subject factors. There were no main effects of Session, Condition, or Timing of Misinformation, F's ≤ 1.640, p's ≥ 0.202. Importantly, there was not a three-way interaction between Session, Condition, and Timing of Misinformation, $F(1,153) = 0.040$, $p = 0.841$. Average sleepiness values are reported in Table 6.

Table 6. Average sleepiness and standard deviations (in parentheses) for the experimental and control groups.

		N	Session 1	N	Session 2
Wake	Pre-interval Misinformation	40	3.15 (1.03)	38	2.76 (.97)
	Post-interval Misinformation	40	3.13 (.99)	40	2.77 (1.14)
Sleep	Pre-interval Misinformation	40	3.12 (1.16)	40	3.35 (1.44)
	Post-interval Misinformation	40	2.97 (1.00)	40	3.15 (1.44)
Control	AM	20	3.05 (.61)	--	--
	PM	20	3.05 (.89)	--	--

Misinformation Question Responses

A total of 43 participants, roughly evenly distributed amidst the control and experimental groups (7 Wake Pre, 7 Wake Post, 8 Sleep Pre, 10 Sleep Post, 10 Controls), refuted at least one piece of misinformation from the misinformation questionnaire. Of those 43, 27 participants refuted only one item of misinformation, 9 participants refuted 2 or 3 pieces of misinformation, and 7 refuted four or five. None of the participants refuted all six pieces of misinformation. Most of the participants who refuted misinformation in the questionnaire also indicated that they did not see the corresponding item on the recognition test in the film. Therefore, a majority of these refutes were already reflected in the recognition test scores. Only three participants refuted the misinformation in the questionnaire and then indicated that the corresponding item from the recognition test was “from the film”.

Discussion

The goal of the present study was to assess sleep-dependent consolidation of false memory, based on when false memory was encountered, with respect to the sleep period. We manipulated whether participants encountered misinformation before or after a period of sleep and we warned participants that they had encountered misleading information prior to the test so that they would more critically monitor their memory. Interestingly, sleep had opposite effects on false memory depending on when the misinformation was presented. That is, the effect of sleep on false memory was entirely dependent on when the misinformation was encountered. When misinformation was encountered before sleep, sleep seemed to increase false memory whereas when it was encountered after sleep, sleep seemed to protect against memory distortion. However, timing of misinformation did not significantly affect false memory when participants remained awake during the retention interval. Importantly, these results were not due to diurnal or circadian variation, sleepiness, or group differences in working memory capacity.

The results of this study lend support to both theories of false memory formation — interference and memory reupdating processes. Consistent with adaptive memory updating theories, when misinformation was encountered prior to sleep, sleep seemed to integrate the false information with the original memory, increasing false memory (Schacter, Guerin, & St. Jacques, 2011; Inostroza & Born, 2013). This is also consistent with prior work showing memory integration during sleep (Tamminen et al., 2010; Tamminen, Ralph, & Lewis, 2013). In contrast, when misinformation was presented after sleep, there was lower false memory. This result could be explained by either theory. We speculate that sleep may have protected against memory distortion by reducing the harmful effects of interference, as has been shown in prior work using traditional interference paradigms (Sheth, Varghese, & Truong, 2012; Ellenbogen,

Hulbert, Stickgold, Dinges, & Thompson-Schill, 2006, for recent opposing results see Bailes, Caldwell, Wamsley, & Tucker, 2020). This result suggests a protective effect of sleep against memory distortion. Thus, sleep can both increase memory distortion and protect memory from distortion and these two opposing results are most parsimoniously explained by two separate theories of false memory.

These results are not only important for theories of memory but also have applied implications for eyewitness interrogation practices. Importantly, sleep does not always lead to optimal memory performance. Sleep can actually increase memory distortion if individuals encounter conflicting information before they sleep. Thus, it is critical that eyewitnesses do not encounter misinformation about the witnessed event before they sleep to help preserve memory accuracy. It is unlikely that witnesses will be able to avoid all sources of misinformation (e.g. internal rumination about the event that may be influenced by schemas), but investigators could take measures to reduce the misleading information introduced in their questions. Interrogation practices regularly involve coercive methods and suggestion, and these methods can lead to false testimony (Loney & Cutler, 2016) or even false confessions (see Henkel & Coffman, 2004 and Leo, 2009 for reviews of how interrogation practices lead to false confessions). If an interrogation riddled with coercion and suggestion occurs before the witness has slept, their memory for the event could be distorted. Overall, investigators should be aware of the positive and negative effects of sleep.

This work takes an important first step into understanding how false memory is impacted by sleep, but future studies should continue investigating this phenomenon to determine the full effect of sleep on false memory and to better understand the underlying mechanisms. One important avenue for future work is to manipulate whether and when a warning is given.

Warnings reduce the misinformation effect (Blank & Launay, 2014), so it is likely that including a warning in our study reduced memory distortion. If we were to remove the warning from our procedure, memory distortion may be differentially affected depending on when the misinformation is given. Along with removing the warning, it may be informative to manipulate when a warning is given relative to the retention interval. If a warning is given before a period of sleep, it may cue the misinformation in memory to be forgotten during sleep, leading to reduced memory distortion (for an investigation of directed forgetting during sleep see Saletin, Goldstein, & Walker, 2011). That is, a warning given prior to sleep may help reduce integration processes during sleep.

In conclusion, prior studies have found equivocal results regarding the effect of sleep on false memory. We used an ecologically valid task, the misinformation paradigm, and found that sleep can both increase memory distortion and protect against it, thus providing new insight into the benefits and potentially harmful effects of sleep on false memory.

APPENDIX

Additional Results

Reanalysis of the data, excluding the 47-year-old participant.

After we completed data collection, we realized that one of our participants was 47 years old. Although it is unlikely that one participant could have drastically changed the results of the study, we removed the data from the 47-year-old participant and re-analyzed all data. For each of our factors of interest (correct recognition, false recognition of suggested items, and false recognition of unrelated lures), we analyzed the data using a two-way ANOVA with Condition (Wake, Sleep) and Timing of Misinformation (Pre-Interval, Post-Interval) as between subject factors. Means and standard deviations are reported in Table S1 and results of the ANOVAs are reported in Table S2. There was only one different result between these analyses and the analyses reported in the primary document. When we exclude the participant who was 47 years old, the main effect of condition for the unrelated lures is only marginally significant. All of the other results are consistent with the results from our main analyses. This was not a primary finding in the study.

Table S1. Means and SDs for each experimental group of proportion of items identified as from the film without the data from the 47-year-old participant. Only the means for the Wake-Post-interval group (shaded) changed because the 47-year-old was from that group.

		N	Correct Items	Suggested Items	Unrelated Lures
Wake	Pre-interval Misinformation	40	.74 (.11)	.47 (.28)	.13 (.10)
	Post-interval Misinformation	39	.74 (.13)	.48 (.31)	.17 (.14)
Sleep	Pre-interval Misinformation	40	.80 (.11)	.56 (.28)	.11 (.11)
	Post-interval Misinformation	40	.76 (.11)	.37 (.29)	.12 (.09)

Table S2. F-tests and effect sizes from the two-way ANOVAs analyzing each item type with Condition and Timing of Misinformation as between subject factors.

	$F(1, 155)$	p	η_p^2
Correct Items			
Condition	4.826	0.030	0.030
Timing of Misinformation	1.987	0.161	0.013
Condition*Timing of Misinformation	1.081	0.300	0.007
Suggested Items			
Condition	0.049	0.826	0.000
Timing of Misinformation	3.775	0.054	0.024
Condition*Timing of Misinformation	4.858	0.029	0.030
Unrelated Lures			
Condition	3.767	0.054	0.024
Timing of Misinformation	3.061	0.082	0.019
Condition*Timing of Misinformation	0.969	0.326	0.006

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