Meta-Analysis on the Positive Correlation Between Insomnia and False Memories

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Abstract:

Insomnia is a prevalent sleep disorder that impacts approximately 30% of the whole population in the United States. It is identified by challenges with falling or asleep and has been associated with various cognitive dysfunctions, including issues with memory formation. In this work, we conduct a meta-analysis involving two data sets to analyze the relationship between insomnia and false memory formation (memories of events that did not actually occur), shedding light on the consequences of sleep deprivation. In the first data set, participants engaged in a simulated crime scenario and were assessed on their ability to identify the perpetrator from both lineups after a period of sleep or wakefulness. In the second data set, participants were presented with themed word lists and, after sleep or wakefulness, tested for memory of words on the list. The data underwent processing using R, and meta-analysis techniques were utilized to integrate findings across these two studies. We used various techniques, such as random-effects models and subgroup analyses, to combine the findings from the studies. However, we were unable to assess the variability between studies due to the limitations of working with binary data. The results show a connection between insomnia and an increase in the formation of false memories, with similar effect sizes across studies. Further research is anticipated to deepen the understanding of the link between insomnia and cognitive health, offering valuable insights into sleep disorders and memory.

1. Introduction:

Insomnia is a prevalent sleep disorder that affects approximately 30%, 30-50 million, of individuals in the United States (Morin et al., 2015). It results in chronic sleep deprivation, which has well-documented negative effects on cognitive function, particularly in the area of memory. Sleep plays a crucial role in the consolidation of short and long-term memories, and numerous studies have demonstrated that the feeling of a lack of adequate sleep can impair memory performance (Walker, 2008). One aspect of concern is how sleep disorders, such as insomnia, may contribute to the formation of false memories—instances where individuals recall events inaccurately. For example, someone might vividly remember attending a specific event that they never actually went to. False memories can affect various types of information, including both narrative details (like stories) and factual details (such as numerical data) (Reyna et al., 2002). These false memories can have significant implications for our everyday lives and decision-making processes (Wang et al., 2016).

1.2 Insomnia and Sleep Deprivation

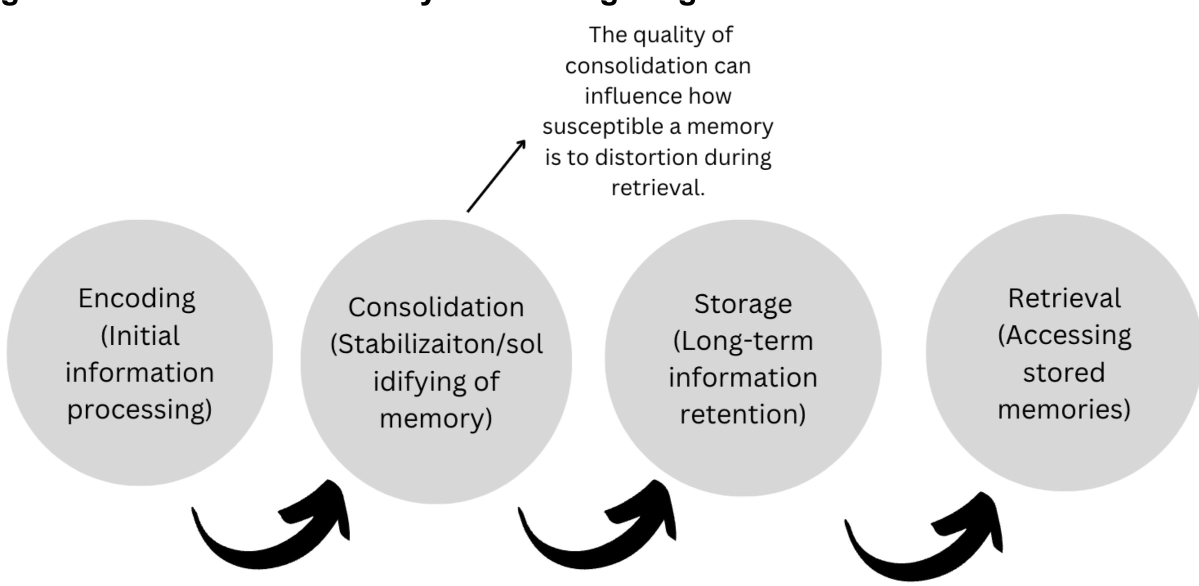
Insomnia is a sleep disorder characterized by persistent difficulties in falling asleep, staying asleep, or achieving restorative sleep, despite having abundant opportunity to do so (Van Someren, 2021). There is no fixed amount of sleep deprivation that defines insomnia, as the severity and impact of sleep disturbances can vary widely among individuals (Ohayon & Roth, 2001). This condition often leads to daytime impairment or distress, such as fatigue, difficulty concentrating, and mood disturbances. Insomnia can manifest in several forms, the most common being initial insomnia, where individuals struggle to fall asleep at the beginning of the night; middle insomnia, involving frequent awakenings during sleep; and terminal insomnia, marked by early morning awakening with an inability to return to sleep (Perlis and Gehrman 2013). Diagnosis typically involves assessing these symptoms over time, such as tracking sleep patterns, self-diagnosis, and sleep studies, ruling out other medical or psychiatric conditions, and evaluating specific criteria related to sleep onset, maintenance, and quality. Patients typically present to a primary care physician or general practitioner with complaints of sleep disturbances. From there, they may be referred to a sleep specialist or sleep clinic for further evaluation. The journey to a diagnosis often includes a detailed medical history, maintaining a sleep diary, physical examinations, and sleep studies like polysomnography (Krystal et al., 2019). Insomnia is also classified based on its duration specifically, transient insomnia refers to brief episodes lasting less than one month, often triggered by situational factors such as stress or changes in routine, like a new job or travel across time zones. Short-term insomnia persists between one and six months and is often due to ongoing stress or lifestyle changes, including starting a new exercise regimen or adjusting to a significant diet modification. Chronic insomnia is severe and persistent, lasting more than six months, and is commonly associated with underlying medical or psychiatric conditions like depression or chronic pain (Yang et al., 2013). The causes of insomnia can vary but commonly include stress, anxiety, or depression, which can disrupt sleep patterns. Additionally, poor sleep habits, such as irregular sleep schedules and excessive screen time before bed, or an uncomfortable sleep environment, such as a noisy room or an uncomfortable mattress, as well as medical conditions such as chronic pain or neurological disorders like depression and epilepsy, can also contribute to insomnia (Stiefel and Stagno 2004). Treatment approaches for insomnia can include cognitive behavioral therapy (CBT, a structured, short-term therapy that helps individuals identify and change negative thought patterns and behaviors) which addresses sleep hygiene and modifies negative thoughts about sleep, or medications like eszopiclone (Lunesta), benzodiazepines or non-benzodiazepine hypnotics for short-term relief (Ramakrishnan, 2007). However, medications can come with potential side effects, such as dizziness or gastrointestinal issues, and risks of dependency, making non-pharmacological interventions preferred for long-term management (De Crescenzo et al., 2022). Despite this, non-pharmacological interventions, such as CBT, are difficult to access due to the small of psychologists offering these treatments (Soong et al., 2021).

Chronic insomnia can have serious consequences on overall health, increasing the risk of cardiovascular disease, obesity, and mental health disorders if left untreated (Riemann et al., 2010). In contrast, sleep deprivation refers to a state where individuals do not obtain sufficient sleep to meet their physiological needs. This condition can stem from lifestyle choices, such as staying up late for work or social activities, or from work-related factors like shift work or irregular schedules (Bandyopadhyay and Sigua, 2019). While sleep deprivation can result from insomnia, insomnia is a treatable condition, whereas sleep deprivation, particularly due to lifestyle or occupational factors, may require changes in habits and environment to address effectively. Environmental factors, such as noise or light pollution, can also disrupt sleep patterns and contribute to sleep deprivation. The effects of sleep deprivation are profound and can include cognitive impairment, such as reduced concentration and memory, mood disturbances like irritability or mood swings, and an increased risk of accidents both in the workplace and during daily activities (Killgore, 2010). Managing sleep deprivation involves prioritizing good sleep hygiene practices, creating a conducive sleep environment, and addressing underlying factors contributing to poor sleep quality (Reddy, 2024). Unlike insomnia, which is a diagnosable sleep disorder with specific criteria for diagnosis and treatment, sleep deprivation is often managed by improving lifestyle choices and environmental conditions conducive to sleep (Nollet et al., 2020).

1.3 Memory

Memory is a complex cognitive function enabling encoding, storage, and retrieval of information. It starts with encoding, where sensory input is processed into a storable form, involving attention, perception, and initial processing. The hippocampus is crucial for consolidating new information and transferring it from short-term to long-term memory (Fokuhl, 2007) (Figure 1). Long-term memory includes explicit (declarative) memory, which consists of episodic (personal experiences) and semantic (facts and knowledge) memory, and implicit (non-declarative) memory, such as procedural memory (skills and tasks). Retrieval involves accessing and bringing stored information into conscious awareness, reactivating neural pathways used during encoding. Factors like context, emotional state, and cues can influence retrieval (Gabrieli, 1998).

Figure 1: Flowchart of Memory Processing Stages



The flowchart above illustrates the stages of memory processing. This flowchart was adapted by Main, 2023.

False memories are inaccuracies in recalling or interpreting events. They arise from the brain's constructive and reconstructive nature of memory. The hippocampus and prefrontal cortex play roles in false memory formation. Normal individuals might generate false memories for approximately 5 to 10 false items for every 100 items they recall (Nash et al., 2016). The hippocampus may confuse the source of information, while the prefrontal cortex can influence the acceptance of incorrect details as true (Loftus, 1996). Real memories are based on actual experiences and the accurate encoding, storage, and retrieval of information. They are typically more vivid and detailed, with a stronger sense of confidence in their accuracy. In contrast, false memories are distortions or visions of events that never occurred or are remembered differently from the actual event. False memories can arise from suggestive questioning, misinformation, or the blending of real experiences with imagined details. Several psychological and neurological disorders can increase the susceptibility to false memories. Individuals with post-traumatic stress disorder (PTSD) may have fragmented memories of traumatic events, which can lead to false memories during recall (Bedard-Gilligan & Zoellner, 2012). Conditions such as dissociative identity disorder (DID) involve disruptions in memory and identity, increasing the likelihood of false memories due to altered states of consciousness and identity fragmentation (Dorahy et al., 2014). People with schizophrenia may experience delusions and hallucinations, which can blur the line between real and imagined events, leading to false memories. Depressive states can affect memory consolidation and retrieval, sometimes resulting in the incorporation of negative or distorted details into memories (Kensinger & Ford, 2020). Age-related cognitive decline and conditions such as Alzheimer's disease can impair memory accuracy and increase the risk of false memories due to neural degeneration and impaired cognitive functions (Malone et al. 2018). Understanding the biological and psychological mechanisms underlying false memories can help in developing strategies to mitigate their occurrence.

1.4 Sleep and Memory

Multiple studies have demonstrated that sleep plays a crucial role in memory consolidation and retrieval (Chambers, 2017). Acute sleep loss impairs memory retrieval, often leading to false memories. Insomnia can cause mild to moderate impairments in cognitive functions such as episodic memory, problem-solving, and working memory. A study by Fortier-Brochu and colleagues found no significant differences in general cognitive function, perceptual processes, or executive functioning (Fortier-Brochu et al. 2012). However, their findings suggest that while these cognitive areas may not be significantly affected, insomnia may still impact memory and executive functions, indicating a need for further investigation into these specific effects. Another study involving college students (18-22 years old) revealed that sleeping soon after learning improves both true and false memories, with slow-wave sleep (a deep stage of non-REM sleep characterized by slow brain waves) reducing false memories (Pardilla-Delgado and Payne, 2017). Furthermore, a study by Lo et al. showed that post-learning sleep (sleeping after learning new material) decreases false memory and enhances memory accuracy in healthy older adults, particularly with increased slow-wave sleep (Lo et al., 2014). In an experiment using the DRM paradigm, individuals with insomnia exhibited higher false memory production and intrusions in free recall (incorrect or irrelevant information recalled during a memory task), along with lower working memory performance, compared to good sleepers. No differences were found in recognition tasks between the two groups. The study indicated a link between poor sleep, executive function deficits, and false memories (Malloggi et al. 2022). Another study using fMRI examined sleep's impact on recollections. Participants who slept after studying word lists showed better accurate and false recollections during a retest fMRI session three days later.

Both types of memories were linked to hippocampal activity post-sleep, suggesting that sleep aids in overall memory consolidation, including false memories based on initial encoding processes (Darsaud et al., 2011).

This meta-analysis aims to explore the relationship between insomnia and the likelihood of developing false memories of adult participants using publicly available data (Mak 2024) and (Stepan 2015). By investigating this connection, the research seeks to elucidate how chronic sleep deprivation might lead to cognitive issues related to memory distortions. This meta-analysis found a positive association between insomnia. These findings are crucial for understanding the intricate interplay between sleep and memory and could lead to strategies to mitigate the impact of insomnia on memory and decision-making in affected individuals.

2. Materials and Methods:

2.1 Study Selection

A literature search was conducted using Mendeley Data to identify relevant studies examining the relationship between sleep and false memories. The search criteria focused on studies that included groups classified as "insomnia" or "sleep deprived" compared to those without sleep issues. The inclusion criteria were studies involving adult participants with insomnia or sleep deprivation alongside a control group with normal sleep patterns, research specifically measuring false memories as an outcome. Based on these criteria, the studies provided the most comprehensive and relevant data for analysis.

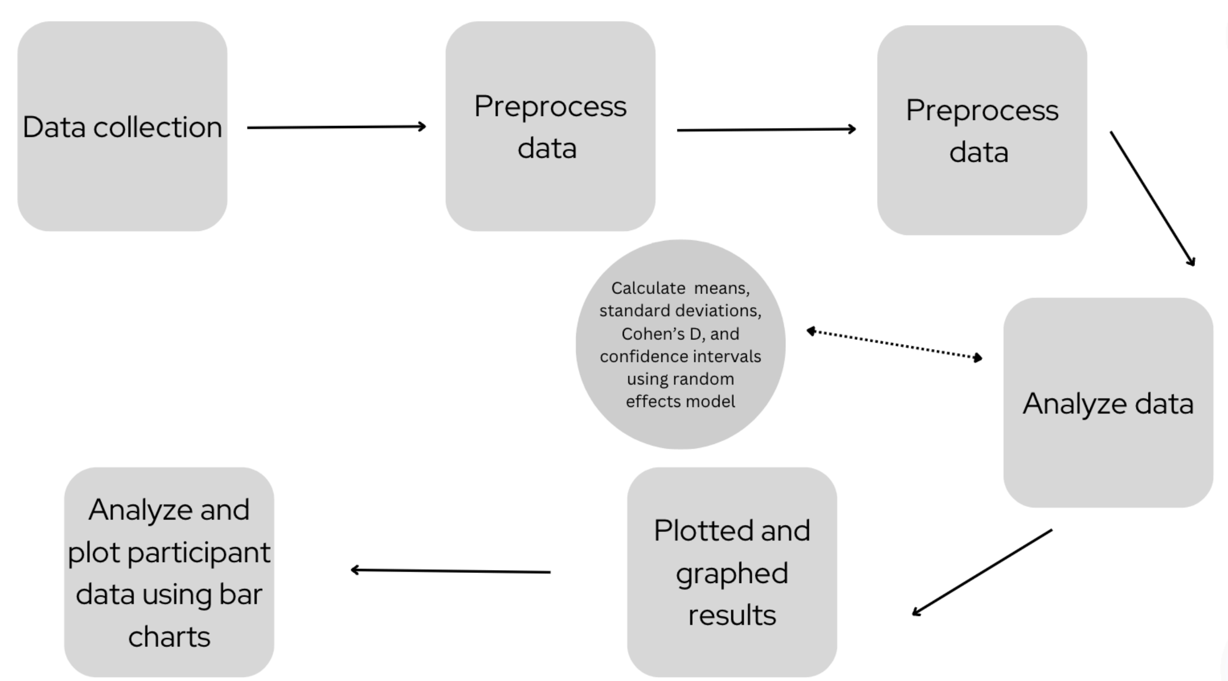
2.2 Data Extraction and Coding

The focus of the analysis was to explore the correlation between "false memories" and "sleep." In two selected studies, sleep deprivation was induced by a period of no sleep for twelve hours to mimic insomnia (Mak, 2024) and (Stepan, 2015). Both studies compared participants who had twelve hours of sleep with those who experienced twelve hours of sleep deprivation. Since one dataset was originally binary and the other was not, it was necessary to transform the data into a binary format for standardization and equal comparison. Participants undergoing sleep deprivation were labeled as 0, while those with regular twelve-hour sleep were labeled as 1. Similarly, participants with false memories were labeled as 1, and those without were labeled as 0. Standardizing the data into a binary format facilitated consistent comparisons across the studies.

2.3 Meta-analysis in R

For conducting the meta-analysis in R, several essential packages were utilized, including dplyr, readr, metafor, ggplot2, and epitools (R Core Team, 2023). The primary objective was to interrogate the relationship between false memories and sleep. The preprocessing phase involved reading and cleaning the datasets, and included tasks such as removing unnecessary columns, and recoding variables into a binary format for standardization across studies. In the analysis phase, relevant statistics such as means, standard deviations, and Cohen's d effect sizes were computed to quantify the relationship between sleep patterns and false memories (Figure 4). For instance, Cohen's d was calculated to measure the effect size between sleep conditions (sleep deprivation vs. regular sleep) and false memory occurrences. The results were then synthesized using the metafor package to perform random-effects meta-analyses, accounting for variability between studies. Confidence intervals were calculated to assess the robustness and generalizability of the findings. Visualizations such as forest plots were generated using ggplot2 to illustrate the effect sizes and their confidence intervals across studies. To explore the composition of the participant pool within the available dataset (demographic data from the second dataset was unavailable), an analysis of participant characteristics (e.g., age, gender, ethnicity) was conducted. The distributions of these variables were then visualized using bar charts.

Figure 2: Flowchart of Methods



The following flowchart presents the methods used for this analysis.

3. Results

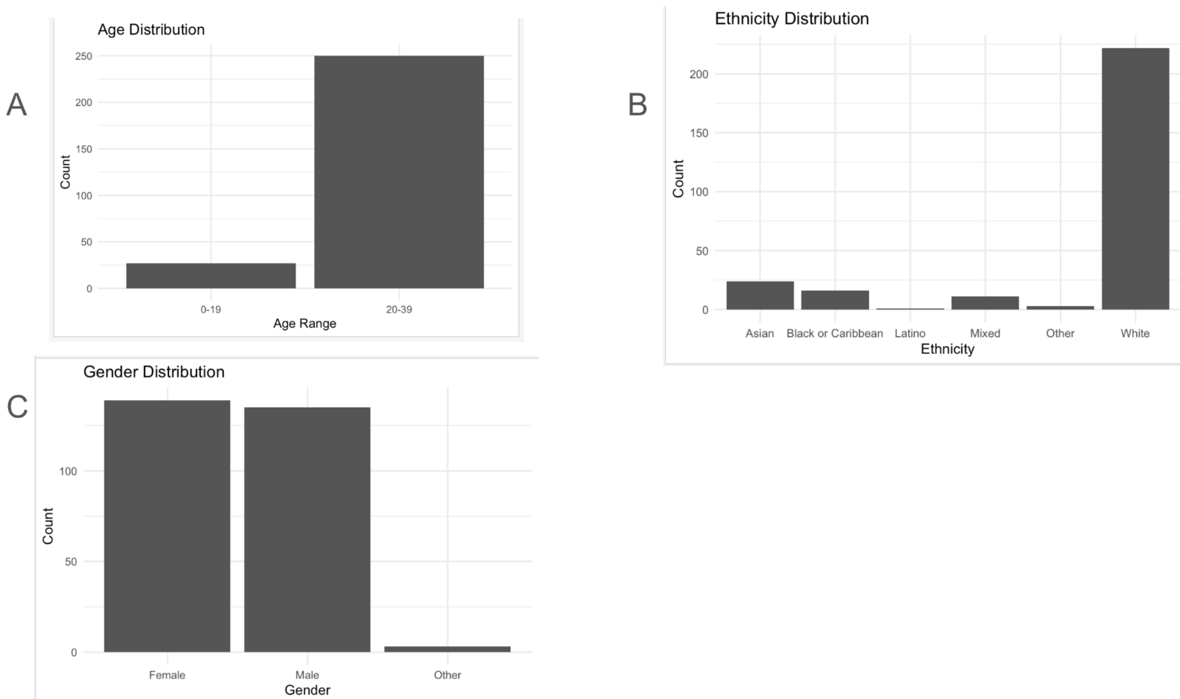
To be considered for this meta-analysis, studies were required to incorporate both a measure and manipulation of sleep. Specifically, this involved comparisons between conditions such as sleep versus no sleep, insomnia versus healthy sleep, or varying protocols of sleep deprivation. Studies needed to employ a valid and reliable measure of false memory formation. This typically entailed participants engaging in tasks designed to assess memory accuracy or recognition, with subsequent evaluations of their performance to determine the presence of false memories. The studies were conducted from 2015-2021 and had 50,044 participants in total (Mak, 2024) and (Stepan, 2015).

Table 1: Study Summary

Study:	**Measure of Sleep**	**Insomnia** Definition	**Type of Memory Test**	**Timeline for Sleep**	**Timeline for Memory Test**
Stepan, M. E. (2015)	Recorded number of hours asleep	12 hours of sleep deprivation	Memory tested on similar words from a list.	12 hours (slept at night)	Within a period of 12 hours after presented lists.
Mak, M. H. (2024)			Identification of perpetrator from mock crime scenario.		After a period of 12 hours from the video

For the second study, there was no available demographic data (which constitutes a limitation of the analysis). In the second study, regarding age distribution, there were 27 participants aged 0-19, 250 participants aged 20-39, and no participants above the age of 39 years (Figure 3A). The ethnicity distribution included 24 Asian participants, 16 Black or Caribbean participants, 11 mixed-race participants, 222 White participants, and 3 participants of other ethnicities (Figure 3B). The gender distribution consisted of 139 female participants, 135 male participants, and 3 participants who identified as 'Other' (Figure 3C).

Figure 3: Demographic Data of Analyzed Data Set



The demographic data is depicted above for one of the sets for ethnicity, age, and gender (Mak, 2024). Demographic data for the other data set was not available and therefore was not analyzed (Stepan, 2015).

Two studies were used in the meta-analysis to investigate the connection between sleep or insomnia and the formation of false memories. Both studies indicated a significant positive correlation. In the first study, the effect size (using Cohen's D) was d = 0.94 (95% CI: 0.8782 0.9972, $p < 0.0001$), with a standard error of 0.03 (Table 2). The second study reported an effect size of d = 0.47 (95% CI: 0.4017 0.5359, $p < 0.0001$), and a standard error of 0.02 (Table 2). Combining these studies resulted in a pooled effect size of d = 0.68 (95% CI: 0.6867 0.7758, $p < 0.0001$) with a standard error of 0.02 (Table 2), suggesting a moderate positive association between insomnia and false memory formation, meaning that an individual experiencing insomnia is more likely to exhibit false memories than someone with sufficient sleep. Heterogeneity was not assessed due to the constraints of binary data. In this case, sleep deprivation primarily disrupts memory consolidation, the stage where memories are stabilized for long-term storage. This disruption leads to errors during retrieval, increasing the likelihood of false memories (Prince & Abel, 2013).

Figure 4: Forest Plot of Analyzed Data

The forest plot, which is a graph that compares the effect sizes (Cohen's D), for the meta-analysis is shown above. The diamond represents the average effect, helping visualize how much more likely people with insomnia are to have false memories compared to those with sufficient sleep.

Table 2: Results Summary

Study	P-value	Confidence interval (95%)	Cohen's D	Standard Error	n
Stepan, M. E. (2015)	p < 0.0001	87.82 to 99.72%	0.94	0.03	49860
Mak, M. H. (2024)	p < 0.0001	40.17 to 53.59%	0.47	0.02	184
Combined	p < 0.0001	68.67 to 77.58%	0.68	0.02	50044

4. Discussion

4.1 Results in the context of insomnia literature

This study aimed to investigate the impact of insomnia on the formation of false memories. By analyzing data sets from two studies, the research found a consistent pattern of increased false memories associated with sleep disturbances (around 48.6%). The findings suggest a significant link between insomnia and memory accuracy, highlighting the importance of sleep in cognitive processes. This research emphasizes the critical role of sleep in preventing the incorporation of false information into memory.

The biology of insomnia and its impact on false memories reveals the crucial role sleep plays in memory consolidation and retrieval. The observed increase in false memories among individuals with insomnia suggests a disruption in cognitive processes, likely affecting the prefrontal cortex. This brain region is responsible for source monitoring (distinguishing between the source of a memory) and executive control (managing conflicting thoughts and memories) (Fuster, 1998). Disruptions in these processes due to insomnia could lead to the formation of inaccurate or distorted memories. During sleep, the brain undergoes synaptic consolidation, strengthening neural connections involved in memory formation. Sleep also supports synaptic pruning, optimizing neural networks for efficient memory storage and retrieval (Clopath, 2011). Additionally, sleep aids in waste product removal from the brain. Byproducts of neuronal activity can accumulate during wakefulness, potentially impairing cognitive function. Sleep allows the glymphatic system, the brain's waste disposal network, to clear these byproducts, promoting optimal brain function and memory accuracy (Luisetto et al., 2019). Insomnia may disrupt these processes, contributing to increased vulnerability to false memories. Specifically, impaired synaptic consolidation and inefficient waste clearance could explain why individuals with insomnia experience higher rates of memory inaccuracies and distortions. Enhanced understanding of these mechanisms underscores the importance of addressing sleep disorders to improve cognitive health and memory reliability (Wafford, 2021).

4.2 Limitations of Study

However, while this research suggests a link between insomnia and increased false memories, other experiments present discordant results. Some studies suggest that sleep can enhance both true (accurate) and false (incorrectly remembered/inaccurate) memories, while others show that insomnia doesn't significantly impact recognition tasks (Fortier-Brochu et al. 2012), (Pardilla-Delgado and Payne, 2017). These contrasting findings may stem from methodological differences between studies, such as the use of different paradigms (e.g., DRM) and technologies (e.g., fMRI) to assess memory. In this meta-analysis, the first study utilized the Deese-Roediger-McDermott (DRM) paradigm to test recognition memory, while the other study assessed recall memory using different protocols. In this meta-analysis, the second study used the Deese-Roediger-McDermott (DRM) paradigm to assess recognition memory, while the first used different protocols for recall memory. This methodological difference is a limitation, as it may affect the comparability of the results. Variations in sample size and participant demographics across studies could have also contributed to the observed differences in outcomes. Moreover, the diverse methodologies in previous research underscore the complexity of understanding the relationship between sleep and memory. Some studies found that sleep enhances both true and false memories due to the consolidation process, whereas others reported that sleep deprivation specifically impairs source memory, a crucial component for distinguishing false from true memories (Newbury and Monaghan 2018). Additionally, the use of different memory tasks and assessment tools can lead to varying results. Some studies employing fMRI technology have demonstrated that sleep deprivation leads to reduced activity in the prefrontal cortex during memory tasks, directly linking biological disruptions to memory distortions. In contrast, behavioral studies without neuroimaging support might not capture the underlying neural mechanisms, resulting in different interpretations of the impact of sleep on memory. The variations in sample sizes and participant demographics, including age, health status, and baseline cognitive function, further contribute to the inconsistencies in findings. Larger, more diverse samples can provide a more comprehensive understanding of how sleep impacts memory across different populations.

4.3 Significance and Future Directions

This research sheds significant light on how sleep deprivation, particularly in relation to false memory formation, impacts cognitive function. By highlighting the crucial role sleep plays in memory consolidation and overall mental health, it underscores the importance of adequate sleep for reliable memory recall and well-being. These findings enhance our understanding of the effects of insomnia, which may inform future therapeutic interventions and contribute to the development of more effective treatments. Demonstrating the cognitive risks associated with insomnia advocates for more comprehensive sleep health education and interventions for adolescents, adults, and the elderly. This can lead to improved mental health outcomes, enhanced memory reliability, and ultimately, greater overall well-being and functionality across various aspects of daily life.

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