Critical Influence of Prefrontal Cortex-hippocampus Interactions on False Memories

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Abstract. This thesis addresses the important role of prefrontal-hippocampal circuits in the generation of false memories. First analyses the influence of prefrontal and hippocampus in the generation of false memories by separately analysing the semantic processing in the prefrontal lobe and the effect of high cognitive load on memory. As well as the impact of the memory extraction process and memory integration on memory in hippocampal function. Finally, the integrated effects of prefrontal-hippocampal circuits on false memories are discussed as a whole. This section includes questions about the interactions between the two, such as prefrontal inhibition of the hippocampus and the mechanisms by which the two are in situations of high cognitive load. The results indicate that the prefrontal-hippocampal circuit has a very critical influence on false memories. Processing on various mechanisms and functional aspects of the interaction between the two affects memory.

Keywords: False memory, prefrontal cortex, hippocampus, neuroscience, psychology.

1. Introduction

The current research on false memories is relatively well understood through different levels of interpretation and different disciplines. False memories: recalling things that never happened or recalling them quite differently from how they actually occurred (Roediger,1995). False memories are presented in several different forms, confabulations and delusions (Kopelman, 1999), Highly superior autobiographical memory individuals (HSAM) (Patihis, 2013), the visual Mandela effect (Prasad,2021), and so on. False memories have numerous implications within society, including their impact on testimonies in the justice system and their influence on learning and education. The study of false memories is crucial to the connection between the individual and society.

The mechanism of false memory formation is influenced by several brain regions of the brain, and as a systematic neural network, the interactions of different regional parts are linked. This paper aims to argue the important influence of the interaction between the prefrontal cortex (PFC) and the hippocampus on false memories. And to further explore the impact of functional connectivity and interaction between the PFC and the hippocampus on memory accuracy, as well as the circumstances under which this interaction can lead to false memories. The research methodology will investigate the activity patterns and interactions between the PFC and the hippocampus in the formation of false memories. This will be achieved by analyzing existing literature, reviewing neuroscientific studies, and examining neuroimaging studies such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET). Next the neural basis of false memories will be explained.

2. The Neural Basis of False Memory

The neural circuits of memory have been summarised in several different forms and will be referred to centrally here in relation to the prefrontal-hippocampal circuits. One important neuronal circuit that controls the specificity and generality of memory is the one that runs from the PFC to the hippocampus (Xu, 2013). The functional role of the PFC in memory work is important, especially the dorsolateral prefrontal cortex (DLPFC).

The DLPFC is responsible for information manipulation and maintenance, as well as supporting the executive function of working memory (Funabashi, 2017). The PFC aids multitasking by dynamically adjusting brain resources for challenging tasks, filtering out irrelevant information, and preserving pertinent information (O'Reilly, 2006). The role of the PFC's executive function and information processing in memory is also important. Including attention management, planning, task switching, and problem-solving (Goldman-Rakic, 1996). The PFC regulates misinformation to prevent false memories. It stores, processes, and evaluates memory accuracy to ensure correctness and relevance (Wagner, 2001). The PFC maintains cognitive accuracy and efficiency by integrating and regulating memory, executive function, and information processing. It plays a crucial role in suppressing misinformation and monitoring memory accuracy.

The hippocampus plays a key role in memory encoding, storage, and retrieval processes. Especially when processing temporal and spatial information (Rolls, 2006). The dorsal CA1 hippocampal subregion processes temporal information for visual objects and the dorsal CA3 subregion aids with spatial location recall (Home,2007). Memory consolidation is also a key function of the hippocampus. Maingret's 2016 experiments using rats led to the reorganization of prefrontal cortical networks by enhancing endogenous coordination between hippocampal sharp ripples, cortical delta waves, and the spindle through timed electrical stimulation. The result shows that during sleep, the hippocampus communicates with the neocortex to consolidate memories, playing a vital role in memory consolidation (Maingret, 2016). The hippocampus not only plays a role in the early stages of memory but is equally important in the retrieval of remote memories (Moscovitch, 2005). After memories are formed, the hippocampus integrates time and space, contributing to memory formation by recording the sequence and spatial location of experiences (Liu, 2021). The role of the hippocampus is indispensable in all three of the core step stages of memory, as well as playing a central role in multidimensional spatial-temporal integration. By modulating prefrontal input to the hippocampus, this circuit is able to control the degree of retention and generalization of specific memory details (Xu, 2013). Prefrontal-hippocampal neural circuits have an important influence on memory.

However, the mechanisms of false memory formation are shaped by a variety of factors, one of which is integration errors. When processing information, the brain can combine details from multiple sources, potentially leading to the formation of inaccurate memories, especially in situations with overlapping elements (Carpenter, 2017). And when it comes to memory extraction, neural activity in the hippocampus and other linked brain areas may lead to the reorganization of memories, generating memory distortions (Carpenter, 2021). The mechanism of false memory formation is largely related to the steps taken by the brain to process information.

3. Role of the Prefrontal Cortex in False Memories

3.1 Semantic Processing in PFC

The PFC plays an important role in the formation of false memories, influencing memory accuracy and error generation mainly through its function in memory encoding and retrieval. In Kim's (2007) study it was explored that the brain correlates of true memory formation (TMF) and false memory formation (FMF) were studied with fMRI. According to research, the left PFC is active during the creation of accurate and false memories. This is connected to the role of semantic processing in the PFC, which accelerates information processing, this heightened processing may also lead to the misattribution of information (Kim, 2007). The creation of false memories was linked in a near-infrared spectroscopy (NIRS) study to higher levels of oxyhemoglobin in the PFC, with specific activity in the left PFC. This suggests that semantic processing remnants in this area may be able to predict the creation of false memories (Kubota, 2006). During prefrontal processing of semantic procedures, machining for semantics is likely to lead to false memories. However, individual variability and different social contacts can lead to limitations in neuroscience research, so the semantic understanding and semantic usage habits of different individuals may be slightly different for the formation of false memories.

3.2 High Cognitive Load and Emotional Distress in PFC

According to Kim, PFC also has a higher probability of producing false memories when they are under high cognitive load. Barch (1997) conducted an fMRI study to determine whether the PFC increased working memory (WM) task activity as a result of WM requirements. The results of this investigation show a twofold dissociation between brain areas sensitive to work difficulty and WM, indicating a specialized role for the DLPFC and associated structures in WM activities (Barch, 1997). It was concluded that cognitive control functions in the prefrontal cortex may be compressed when the difficulty of the task is elevated, thereby increasing the likelihood of false memories.

The effects of emotional distress and high cognitive load on the prefrontal cortex are strongly associated with the formation of false memories. An event-related functional magnetic resonance imaging (fMRI) raised by Dolcos (2004) was used to study the relationship between PFC activity and emotional appraisal and memory. Participants were scanned while assessing the pleasantness of emotionally positive, negative, and neutral visuals, and their memory for the images was assessed following scanning. During high emotional arousal, increased activity in the left DLPFC can lead to the formation of false memories by enhancing semantic and working memory operations, potentially integrating erroneous information (Dolcos, 2004). Significant effects of emotional state on memory extraction and distortion (Mirandola, 2016). In some cases, different fluctuations in mood can prompt the PFC to integrate false memories, leading to the creation of false memories. Conversely, mood swings can help to evoke memories in some situations.

False memory creation has also been linked to altered functional connectivity between the PFC and other brain areas, including the hippocampus. According to fMRI studies, The coordinated activity between the PFC and other memory-related areas may be disrupted under situations of emotional arousal or high cognitive load, which can result in the integration of incorrect information during memory consolidation and retrieval and increase the likelihood of erroneous recollections (Longe, 2009). Prefrontal brain impairment may result in reduced cognitive control under conditions of high cognitive load, which raises the possibility of false recollections.

In the mechanism of false memory formation, the working of the PFC may be influenced by mood swings, high cognitive loads, and different phases of phonological processing. These factors may increase the risk of generating false memories, as they are closely tied to the encoding and retrieval stages of the memory process. Paradoxically, PFC has also made an outstanding contribution at the level of correcting false memories. It is this paradoxical double-edged sword that exemplifies the amazing and interesting functions of the human brain.

4. Role of the Hippocampus in False Memories

4.1 Memory Extraction and Synaptic Plasticity in the Hippocampus

The hippocampus is an important structure for memory in the brain, involved in memory storage and responsible for managing long-term and short-term memory. In addition, it plays a key role in consolidating false memories. Activity-dependent synaptic plasticity plays a key role in the hippocampus's role in memory encoding and intermediate storage, These traces eventually disappear, although occasionally they are kept by the cellular integration process (Morris, 2003). Interactions between the hippocampus and the neocortex are involved in the process of systemic consolidation. The hippocampus facilitates the integration of new information with preexisting memory networks by repeatedly activating memory traces. This consolidation process can either strengthen or weaken memory accuracy (Morris, 2006). Synaptic plasticity in the hippocampus during the integration of old and new information may impair memory accuracy to some extent.

In addition to this, the hippocampus has the potential to cause memory errors during memory extraction. Cutsuridis' (2009) article exploring associative memory by analyzing biophysical models mentions that synaptic plasticity in the hippocampus also plays a role in the process of memory retrieval and updating. While this supports the accurate recall of memories, it may trigger memory updating or revision (Cutsuridis, 2009). The hippocampus helps with correct recall during memory retrieval by reactivating memory traces linked to certain experiences. Research has demonstrated that during retrieval, the hippocampus triggers a number of neural networks associated with memory material; precise recall depends on the synchronized activity of these networks (Carr, 2011). On the other hand, malfunctioning synchronization might result in mistakes or distortions in memory. During the retrieval step procedure, synaptic plasticity in the hippocampus may trigger memory revision, leading to the formation of false memories. In addition to this errors in synchronization of neuronal networks when reactivating memories may also lead to false memories.

4.2 Memory Integration in the Hippocampus

Apart from the processes involved in consolidation and extraction, it is also possible to generate false memories during the period when the hippocampus acts to integrate memories (Liu, 2021).

Morris' 2006 study of the hippocampus showed that the hippocampus integrates memories through synaptic tagging, marking individual synapses during events. Subsequent occurrences strengthen or weaken the labels on existing memory traces, influencing memory accuracy and consolidation (Morris, 2006). The hippocampus supports the integration and accurate recall of event memories through synaptic plasticity and complex interactions with other brain regions during the processing of memories, often enhancing accuracy but occasionally leading to distorted or incorrect memories.

Integration of the hippocampus is manifested in spatial and temporal integration, and this process may involve distorting the details of events in memory. The hippocampus uses comparable computational techniques to encode temporal and spatial information, which deal with factors that cannot be readily deduced from direct sensory input (Howard, 2014). Howard (2014) proposed a mathematical framework to explain how the hippocampus encodes temporal and spatial information through the 'leaky integrator’. The framework calculates spatial location and time functions as specific examples of more generalised computations. Memory distortions can occur when there is a mismatch between temporal and spatial information (Hailer, 2018). Another article by Howard in 2013, analyzing animal experiments, also mentioned that spatiotemporal disintegration in the hippocampus may be affected by changes in synaptic plasticity in neural networks, which can lead to changes in the accuracy of memory traces (Howard, 2013).

Overall the hippocampus has a profound influence on memory procedures (encoding, storage, retrieval) to produce false memories. Not only that, but the memory integration function of the hippocampus also leads to temporal and spatial distortions of remembered events. However, with synaptic plasticity in the hippocampus, the ability to improve memory accuracy. With the interaction of prefrontal-hippocampal circuits, the formation of false memories will be more systematically manifested

5. Interaction of the Prefrontal Cortex with the Hippocampus

The PFC and the hippocampus are closely linked functionally and work synergistically on memory retrieval and integration. These brain areas communicate via unique neural networks, with the hippocampus in charge of memory development and playback and the PFC processing contextual information about memory (Preston, 2013). Place demonstrated in 2016 conducted a comparative analysis of the dynamics of hippocampal and prefrontal interactions in rats. Using functional connectivity analysis shows a bidirectional flow of information between the hippocampus and PFC during memory recall. This relationship permits the hippocampus to supply context-specific memories, while the PFC controls their selection and extraction (Place, 2016). The interaction of these regions is particularly important during memory retrieval, supporting the process of memory integration and consolidation (Preston, 2013). Functional transmission in prefrontal-hippocampal neural circuits also relies on synaptic plasticity (Laroche, 2000), and theta wave oscillations (Backus, 2016), which allow for more efficient transmission and memory integration. In terms of the neural mechanisms of memory in the brain, the interaction between the PFC and the hippocampus is inextricably linked to memory procedures.

5.1 Inhibitory Effects of PFC on the Hippocampus

However, the inhibitory effect of PFC on the emergence of hippocampal encoding functions during false memory generation contributes to the balance of generation. Jeye's (2017) fMRI experiment, participants would view abstract shapes in either the left or right field of view and categorise them. Revealed a negative connection between PFC (particularly anterior/dorsolateral prefrontal cortex) and hippocampus activity during false memory formation. This suggests that the PFC may alter memory accuracy by inhibiting hippocampus activity during false memory formation (Jeye, 2017). Although the design of this experiment was not entirely rigorous, and the lack of a reference group to consider prevented the data from being an authoritative reference, it went a long way towards providing observable experimental data as material for analysis. This combination of inhibition and encoding enables people to properly recall relevant information while suppressing irrelevant or inaccurate data (Legon, 2016). But may also lead to false memories through poor judgement (Preston, 2013). Therefore the inhibitory effect of PFC on the hippocampus can enhance memory accuracy at some levels, but it can also lead to false memories in cases of misjudgement.

5.2 Effects of High Cognitive Load on the PFC and Hippocampus

The balance between top-down and low-up information flow under high cognitive load may also influence the generation of false memories. During memory encoding and retrieval, information flows in one way from the PFC to the hippocampus. The dynamic equilibrium of this information flow contributes to memory accuracy, particularly under high cognitive stress (Das, 2021). But in the same situation, the PFC, while filtering irrelevant or erroneous information, may hinder the hippocampus from accurately recording true information, leading to the production of false memories (Jeye, 2017). The high degree of collaboration between the PFC and the hippocampus is also reflected in high cognitive load environments, where the bidirectional flow of information between the two ensures memory accuracy. At the same time, false memories may be generated due to disturbances in the balance that impede the recording of correct information. To explain the relationship between the PFC and the hippocampus in terms of executive control at the level of synaptic plasticity, executive control in the prefrontal cortex regulates memory integration and retrieval by modifying synaptic plasticity in the hippocampus (Bero, 2014). This plasticity enables the neural connections between the two to adapt to the demands of the task, which may lead to the generation of misleading memories if synaptic strength is not correctly adjusted during memory integration (Laroches, 2000). The interaction between the PFC and the hippocampus has many implications for the generation of false memories, not only in terms of high cognitive load but also synaptic plasticity.

6. Conclusion and Future Research Directions

To summarise, the PFC and the hippocampus are very inextricably linked to memory. Both in terms of their separate neural mechanisms and their interactions with each other, the PFC manages information accuracy through selective attention and inhibition of interference and monitors memory for error correction. The memory integration and activation aspects of the hippocampus are also balanced to ensure memory accuracy. However, both show possible accuracy effects on memory in terms of high cognitive load and synaptic plasticity. The interaction between the two also reflects the same problem; while the PFC and the hippocampus work in tandem to maintain the dynamic balance of the memory formation process, the inhibitory effect of the PFC on the hippocampus and the cooperative relationship in the high cognitive load state reflect the potential for misjudgments or errors in the procedure. The risk of false memories likewise emerges in the process of bidirectional information flow, synaptic plasticity and memory integration between the two.

Even though the existing data studies can corroborate some aspects of the influence of neural mechanisms on false memories, there are still many limitations in the studies. For example, there are limitations in neuroimaging technology that make it difficult to obtain more accurate and comprehensive dynamic information. The complexity of the data also affects the precision of the statistical results, including the latency of fMRI. The most significant problem in neuroscience is also the impact of individual variability on research results, which can lead to a decrease in average social acceptance. This needs to be supported by larger statistical data to obtain more authoritative conclusions.

Future developments should incorporate more interdisciplinary research to make up for the current shortcomings in psychology and neuroscience. The aim is to improve the direction of the data, and at the same time to be more flexible for the future development of the relevant fields in terms of potential applications at the individual and societal levels.

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