Remittances Review
July 2024,
Volume: 9, No: S 3, pp.351-371
ISSN: 2059-6588(Print) | ISSN 2059-6596(Online)

Received: 07 June 2024, Accepted: 20 July 2024
DOI: https://doi.org/10.33282/rr.vx9i4.19

Cognitive Neuroscience Perspectives on Memory Consolidation Mechanisms; Bridging the Gaps, A review

Ayesha Tasawar[1*], Gul-E-Zahra[2], Iqra Bukhari[3], Aqsa Waqar[4], Muhammad Shahzad[5], Muhammad Atif Rasool[6], Awais Ur Rahman[7], Waqas Ali[8], Sniya Siddique[9]

[*1]Department of Psychology, University of Sargodha, Punjab Pakistan

[2]Department of Psychology, University Institute of Southern Punjab, Multan, Pakistan

[3]Department of Applied Psychology, Bahauddin Zakariya University Multan, Pakistan

[4]Department of Clinical and Professional Psychology, Riphah International University, Pakistan

[5]Department of Sociology, University of Sargodha sub-campus Bhakkar

[6]Department of Clinical Psychology, Superior University Lahore, Punjab Pakistan

[7]Department of Sociology, Abdul Wali Khan University Mardan

[8]Department of Applied Psychology, Government Graduate College of Science Faisalabad

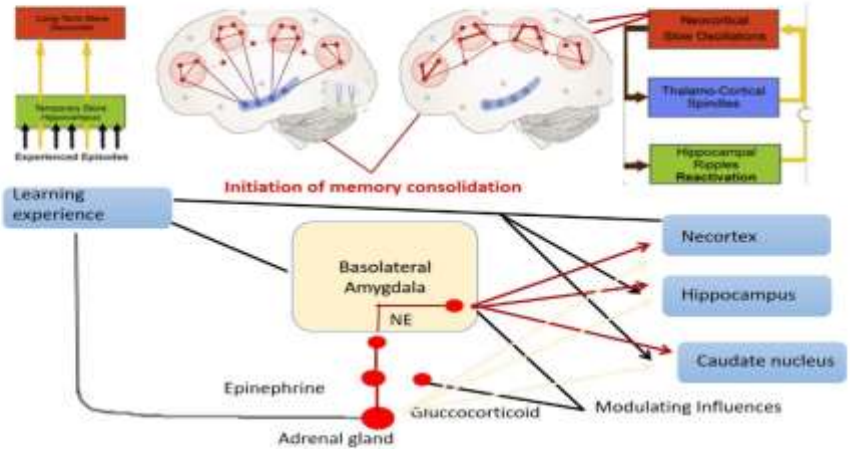
[9]Department of Psychology, University of Haripur, Pakistan

***Corresponding Author:** Ayesha Tasawar (ranaayesha116@gmail.com)

Abstract

Memory consolidation, a fundamental cognitive neuroscience process, stabilizes and integrates recently acquired knowledge into long-term memory. The present study focuses on contemporary advances and highlights substantial flaws in the research while offering a thorough overview of the current viewpoints on memory consolidation processes. This study investigates the functions of particular brain areas, such as the neocortex and hippocampal regions, in converting short-term memory to long-term memory storage. This consideration emphasizes the significance of synaptic plasticity by investigating the role variations in synapse activation and accessibility play in establishing memories. Furthermore, the impact of sleep on memory consolidation is examined, highlighting how sleep-related mechanisms promote memory stability and integration. It is also thought that molecular and cellular processes like gene expression and protein synthesis affect memory consolidation. Despite tremendous advancements, many obstacles remain, such as

combining disparate data into coherent models and turning these discoveries into practical applications. By combining the best available research to date with suggested future lines of inquiry, the evaluation seeks to close these gaps in our knowledge of memory consolidation processes.



Keywords: Neuroscience, Memory Consolidation, long-term memory, Memory Stabilization, Molecular Mechanisms, Hippocampus, Neocortex, short-term memory

Introduction

Memory consolidation is a mechanism that moves from its vulnerable temporary state to a more permanent, long-term one (Alberini et al., 2011). Encoding events into short-term memory is the first step in this process, followed by consolidation processes using brain plasticity to consolidate the memory (Dudai et al., 2015). Brain regions, including the cortex and the hippocampus, are essential to this process (Opitz et al., 2014). The hippocampal region first assimilates new information and connects it to previously acquired knowledge (Bein et al.,2020). This data is progressively moved to the cortex over time for permanent retention (Takehara et al.,2003). The consolidation process is crucial for the construction of long-lasting memories and the capacity to recover them efficiently. It is impacted by psychological importance, practice, and insomnia (Zeng et al., 2021). It is crucial to appreciate memory systems because they lay the groundwork for understanding how to acquire, retain, and use information in daily life (Squire et al., 2004). These processes affect everything from our capacity for basic activities to sophisticated problem-solving and decision-making. Memory is closely intertwined, as memory shapes experiences, knowledge, and feelings (Egan et al., 1989). Researchers can decipher the mechanisms governing memory's encoding, storing, and retrieval by investigating memory's biological, cognitive, and neurological foundations (Marshall et al., 2016). This can provide insights into how these mechanisms might be improved or hampered. This information is essential for treating memory-related conditions, including Alzheimer's disease, amnesia, and other cognitive impairments, and improving teaching methods and learning techniques (Molina et al., 2020). Moreover, by developing tailored therapy interventions, knowledge of memory systems might assist people with neurological problems regain or enhancing their memory function (Harvey et al., 2014). More broadly, understanding memory systems helps the domains of artificial intelligence and machine learning, where mimicking human memory functions is essential to technological progress (Mehonic et al., 2020). In the end, a thorough grasp of memory mechanisms enables us to recognize the intricacies of human cognition and the fact that brains receive and use information dissemination. The aforementioned understanding awareness ultimately opens the door to technological advancements, education, and medicine that can improve human potential and well-being (Fernandez et al., 2020).

The intricate process that is consolidated and incorporated into long-term memory, moving from a labile to a more permanent state, is called memory consolidation in contemporary neuroscience (Alberini et al., 2011). This process involves a dynamic interaction of cellular, molecular, and systems-level alterations rather than being limited to a single brain mechanism or period (Castrillo et al., 2016). Memory consolidation was formerly thought to be a one-way transfer from the hippocampal region to the neocortex. Modern studies, however, have broadened this perspective by acknowledging the contributions of sleep, non-neuronal cells, and synaptic plasticity in this complex process (Wigren et al., 2018). In addition, contemporary neuroscience highlights the temporal dynamics of consolidation, emphasizing that it takes place across a range of time scales, from minutes to even years. Research is still being conducted to fully understand the intricate processes involved in forming, storing, and modifying memories (Nadel et al., 2012s).

Unanswered inquiries about memory consolidation create difficulties and great possibilities for learning more about the brain's complex workings (Wang et al., 2010). Uncovering the intricate interplay between molecular, biological, and cognitive systems underlying memory formation and retention requires filling in these gaps that must be addressed or thought too challenging to work on (Manicka et al., 2019). Closing these gaps may lead to ground-breaking findings about how external influences like stress and sleep affect consolidation, or it may disclose new brain pathways or the effects of individual variability (De Kock et al., 2022). By concentrating on these unexplored areas, scientists can close the gap between current theories and new data, leading to the development of a more thorough and integrated model of memory consolidation that has the potential to transform therapy modalities and improve cognitive performance. The main objective of this assessment is to critically analyze and summarize recent findings on memory consolidation processes from the standpoint of cognitive neuroscience. This study attempts to fill knowledge gaps by summarizing the developing theories, molecular and cellular mechanisms, sleep, and technology advancements in memory consolidation. It also aims to draw attention to open-ended issues and suggest future lines of inquiry incorporating interdisciplinary perspectives, thereby expanding our understanding of how memories are created, maintained, and recovered in the human brain.

Neurobiological Mechanisms

The neurobiological mechanisms enabling memory consolidation include a variety of complex processes that help to integrate and stabilize memories inside the cerebellum (Takehara-Nishiuchi et al., 2021). Synaptic plasticity, particularly LTP, which fortifies synaptic connections between neurons after repeated activation, is essential to these processes. Stable memory traces are formed in tandem with this synaptic strengthening by molecular modifications such as controlling gene expression and activating signaling pathways (Alberini et al., 2009). Furthermore, new memories are encoded and temporarily stored in the hippocampus and then gradually transferred to cortical areas for long-term storage through complex connections between various brain regions. Neurochemical elements, such as hormones and neurotransmitters, which affect the cellular and synaptic plasticity required for memory stability, also affect consolidation (Feld et al., 2020). Advances in neuroimaging and electrophysiological methods reveal the complex interactions between these biological systems, deepening our understanding of how memories are encoded and preserved (Chen et al., 2023).

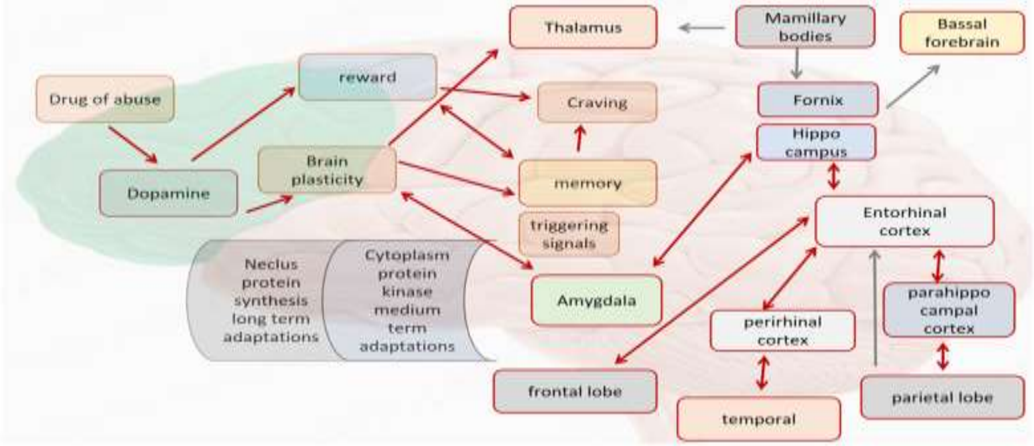


Fig 1: Neurobiological Mechanisms

Synaptic Plasticity and Memory Formation

An essential process behind memory development and storage is synaptic plasticity, or the capacity of synapses to become stronger or weaker over time (Martin et al., 2000). On the other hand, long-term depression (LTD) can weaken synapses, which can improve neuronal circuitry and aid in memory retrieval and updating. Combining LTP and LTD offers a dynamic paradigm that clarifies synaptic changes' critical role in cognitive processes, including memory formation, maintenance, and adaptation (Lisman et al., 2017).

Role of the Hippocampus in Memory Consolidation

The hippocampus is essential to memory consolidation as a fundamental center for the initial encoding and short-term storage of newly acquired information before its transfer to the neocortex for long-term storage (Dudai et al., 2015). The creation of declarative memories, or memories about facts and events, depends on this area of the brain, which is housed inside the medial temporal lobe (Eichenbaum et al., 2000). The hippocampus quickly absorbs and arranges sensory information and experiences during the early phases of consolidation, which helps to create coherent memory traces. LTP is involved, a synaptic plasticity mechanism that fortifies connections between hippocampus neurons. Memories undergo systems consolidation as they grow more stable, in which the neocortex takes over the job of the hippocampal region and integrates the information into a more dispersed cortical network (Schwindel et al., 2011). The hippocampus is anticipated to reactivate and practice the recently learned memories during sleep, especially during slow-wave and REM sleep. Although the hippocampus plays a crucial role in memory consolidation, new research indicates that it also interacts with other brain areas, such as the prefrontal cortex and the amygdala, to modify and improve memory storage. Furthermore, research suggests that the hippocampal functions extend beyond memory storage to include contextual processing and memory retrieval, raising questions about the hippocampal's role in memory consolidation (McClelland et al., 1995).

Molecular and Cellular Mechanisms

Memory consolidation is mediated by complex molecular and cellular mechanisms that include various activities that cooperate to solidify and integrate newly formed memories (Anastasio et al., 2012). Synaptic plasticity, particularly LTP and LTD, is central to these systems. These processes modify the strength of synaptic connections between neurons and are essential for memory encoding and consolidation. Several intracellular signaling pathways, including activating protein kinases like PKC and CaMKII, drive these alterations (Wayman et al., 2011). CREB is a transcription factor modulated by these changes. The expression of genes involved in synaptic development and the synthesis of proteins required to maintain synaptic alterations are brought about by CREB activation. Furthermore, during memory consolidation, epigenetic changes like DNA methylation and histone acetylation are essential for controlling gene expression, influencing how neurons react to stimuli, and fortifying synaptic connections (Liu et al., 2009). These processes are further aided by non-neuronal cells like microglia and astrocytes, which control synaptic plasticity and function by releasing gliotransmitters and clearing synaptic debris (Iannella et al., 2020). The importance of neurogenesis has been brought to light recently, especially in the hippocampus, where the development of new neurons might affect the integration and creation of memories. These molecular and cellular mechanisms are coordinated across a network spanning several brain areas, reflecting the intricacy of memory consolidation and the ongoing development of our comprehension of the stabilization and integration of memories (Squire et al., 2015).

Mechanism	**Description**	**Key Players**	**Current Research Focus**	
Long-Term Potentiation (LTP)	Persistent increase in synaptic strength following high-frequency stimulation.	Hippocampus, Dentate Gyrus	Molecular pathways, role in spatial memory	Miyamoto et al., 2006
Synaptic Plasticity	The ability of synapses to strengthen or weaken over time impacts memory encoding and storage.	AMPA and NMDA receptors, Ca2+ ions	Mechanisms of Long-Term Potentiation (LTP) and Long-Term Depression (LTD)	Mayadevi et al., 2012
Neurotransmitter Systems	Chemical systems that mediate communication between neurons are crucial for modulating memory processes.	Glutamate, GABA, Dopamine, Acetylcholine	Impact on memory modulation and synaptic plasticity	Reis et al., 2009
Sleep-Dependent Consolidation	The process by which sleep enhances memory retention and integration	REM and Non-REM Sleep Stages	Sleep architecture, neural replay during sleep	MacDonald et al., 2021
Epigenetic Modifications	Changes in gene expression without altering DNA sequence influence memory consolidation.	Histone acetylation, DNA methylation	Mechanisms of gene regulation in memory processes	Jarome et al., 2014
Non-Neuronal Cells	Supportive cells such as glia contribute to the	Astrocytes, Microglia	Role in synaptic pruning and memory support	Abdolmaleky et al., 2023

	maintenance and modulation of neural circuits.			
Long-Term Depression (LTD)	Long-lasting decrease in synaptic strength following low-frequency stimulation.	Cerebellum, Hippocampus	Mechanisms and functional implications in learning	Massey et al., 2007

Table 1: Neurobiological mechanisms

Techniques and Methodologies

Fundamental mechanisms regulating the stabilization and storage of memories in the brain have been made possible by the substantial evolution of approaches and methodology in the study of memory consolidation (Wang et al., 2006). Neuroscience methods, including PET and fMRI, have been crucial in delineating the brain regions associated with memory consolidation, specifically the hippocampus and related cortical areas. With these imaging techniques, researchers may watch the dynamics of memory processing through, providing valuable information on the consolidation phases throughout time. Furthermore, electrophysiological techniques such as MEG and EEG provide high temporal resolution data, which record the electrical activity linked to memory reactivation and construction, particularly during sleep, a crucial time for consolidation (Lendner et al., 2023). Despite standard diagnostic techniques and electrophysiology, advances in molecular biology have made it possible to precisely manipulate specific neuronal circuits involved in memory consolidation using methods like optogenetics and chemogenetics. These techniques enable the exploration of the causal relationships between particular neurons and neurotransmitter systems and the consolidation and fortification of memories. Besides, the amalgamation of computational models with experimental data has gained significant importance, providing a structure for comprehending intricate interplay across neural networks during memory consolidation (Benna et al., 2016). The interdisciplinary collaboration of cognitive neuroscience, molecular biology, and computational techniques creates new opportunities for research and therapeutic approaches while mitigating long-standing gaps in memory consolidation mechanisms. This approach leads to a more comprehensive and nuanced understanding of these strategies (Keast et al., 2007).

Neuroimaging Techniques (fMRI, PET)

Although neuroimaging methods, such as fMRI and PET, enable researchers to map and watch brain activity in vivo with unprecedented detail, they have completely changed our knowledge of memory consolidation (Amunts et al., 2024). The importance of the hippocampus and cortical areas during consolidation has been notably highlighted by fMRI, which uses variations in blood oxygenation levels as a surrogate for neural activity. fMRI has been essential in identifying the brain regions engaged in distinct phases of memory processing (Donaldson et al., 2001). fMRI has shed light on the temporal features of memory consolidation by monitoring the dynamic changes in these areas over time. This study revealed that memories are progressively restructured and transported from the hippocampus to the neocortex, a process known as systems consolidation. However, PET has advanced our knowledge of the molecular and neurochemical mechanisms underpinning memory consolidation by measuring metabolic activity using radioactive tracers (Boecker et al., 2016). PET investigations give a molecular viewpoint to supplement the structural and functional data from fMRI, helping to clarify the role of neurotransmitters like acetylcholine and dopamine in influencing memory formation and retention. Furthermore, the limitations of laboratory settings have been lifted since researchers can now examine memory consolidation in real-time and in more naturalistic circumstances thanks to advancements in neuroimaging techniques, which include the creation of more sophisticated and rapid imaging modalities (Lenormand et al., 2022).

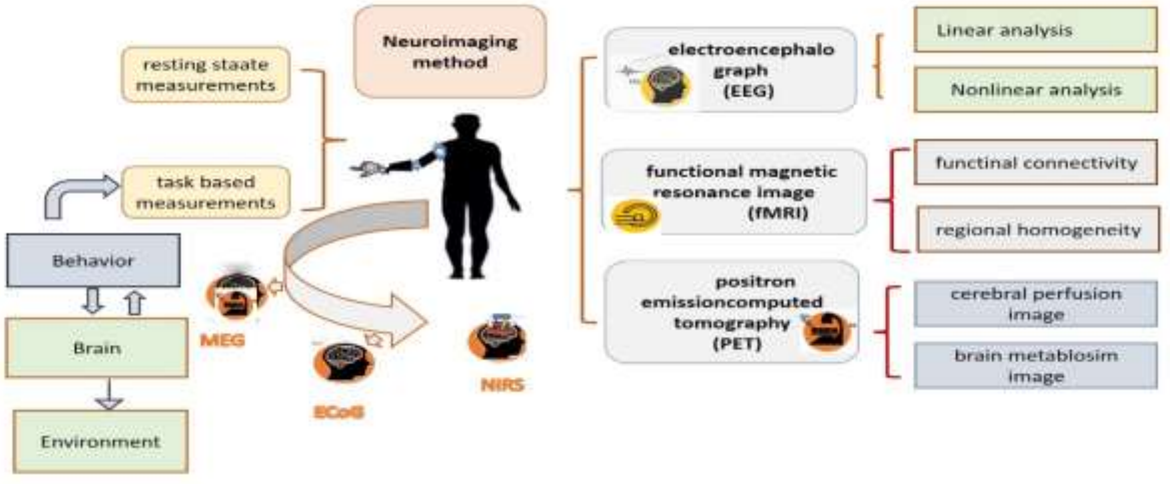


Fig 2: Neuroimaging Techniques (fMRI, PET)

Computational Models and Simulations

The application of computational models and simulations has become essential for comprehending the intricate mechanisms that underlie memory consolidation (Benna et al., 2016). These models provide a framework to investigate how multiple neurological systems interact to enable the stability and improvement of memories. They are a potent way to combine data from many levels of study, ranging from molecular dynamics to whole-brain activity (Lin et al., 2022). Researchers may test theories on the functions of synaptic plasticity, network rearrangement, and the impact of outside variables like stress or sleep on memory consolidation by simulating neural networks. Computational models facilitate the investigation of scenarios that may not be readily visible in vivo by allowing for the modification of variables in ways that are frequently not attainable in biological research (Bartocci et al., 2016). These frameworks can also include information from behavioral, electrophysiological, and neuroimaging research, providing a more comprehensive understanding of temporal and spatial dynamics of memory processes. Furthermore, these discoveries provide prospective treatment options by shedding light on how disturbances in these processes may cause memory impairments. These models have the potential to bridge the gap between theoretical frameworks and empirical findings, shed light on the complexities of memory consolidation in unprecedented detail, and inspire the next wave of cognitive neuroscience research as they develop and incorporate machine learning algorithms and sophisticated computational techniques (Torre-Bastida et al., 2021).

Factors Affecting Memory Consolidation

Various factors impact memory consolidation, a complex process that shapes how memories consolidate and are kept over time (Hu et al., 2020). Sleep is one of the most critical factors, and sleep is widely acknowledged as a crucial time for memory consolidation. Neural activity patterns initially involved in encoding experiences are reactivated during sleep, particularly in SWS and REM sleep. This process is thought to strengthen synaptic connections and facilitate the transfer of information from the hippocampus to the neocortex. This reactivation is believed to strengthen memories, increasing their resistance to disruption and deterioration. Meanwhile, improving memory consolidation, especially for declarative memories, has been connected to sleep spindles, which are rhythmic brain activity bursts that occur during non-REM sleep.

However, the effects of stress on memory consolidation are complicated and highly reliant on the kind and timing of the stressor; after learning that experiencing acute stress can improve memory consolidation by triggering the HPA axis, which releases glucocorticoids that affect synaptic plasticity (Doewes et al., 2021). Long-term stress or exposure to stressors might have the opposite impact, decreasing neurogenesis and hippocampus function, which can hinder memory consolidation. Memory consolidation is also highly impacted by age and developmental changes. Young people's memory systems are malleable, and their hippocampus function helps to speed up the consolidation process. Nevertheless, the efficacy of memory consolidation gradually decreases with age, a phenomenon frequently linked to alterations in the hippocampus's volume, density, and neurochemical surroundings. This decrease may make creating new memories and recovering consolidated ones more difficult (McKenzie et al., 2011). Memory consolidation is significantly influenced by neurotransmitter systems, especially those involving acetylcholine, dopamine, and norepinephrine. For example, dopamine plays a role in reward-related systems that reinforce memories, whereas acetylcholine is necessary for hippocampus function and encoding new information. When traumatic occurrences occur, norepinephrine is produced, which improves memory consolidation by promoting neuronal plasticity and raising vigilance (Meir Drexler et al., 2017).

Category	**Specific Factor**	**Mechanism of Action**	**Effect on Memory Consolidation**	**Relevant Studies/References**
Biological Factors	**Hormones**	Hormones such as cortisol and adrenaline influence memory encoding and retrieval processes	Can enhance or disrupt memory consolidation depending on timing and levels	Zhang et al., 2021

	Sleep	Sleep stages, particularly REM and slow-wave sleep, facilitate the replay of memories.	Critical for systems consolidation and long-term memory retention	Schreiner et al., 2017
	Neurotransmitters	Enhances or impairs synaptic changes essential for memory consolidation	Modulation of synaptic plasticity through neurotransmitters like glutamate, dopamine, and acetylcholine	Perez et al., 2020
	Genetic Factors	Variations in genes related to synaptic proteins, receptors, and neurotransmitter synthesis	Genetic predispositions can influence the efficiency of memory consolidation.	Lin et al., 2019
Environmental Factors	**Stress**	Acute and chronic stress influence HPA axis and cortisol release	Can enhance or impair memory consolidation depending on the context	James et al., 2023
Physical activity	**Exercise increases brain-derived**	neurotrophic factor (BDNF) and enhances neurogenesis	Promotes hippocampal-dependent memory consolidation	Miranda et al., 2019

Cognitive factors	**Attention and Focus**	Attention enhances the encoding of information by increasing neural resource allocation.	Improved attention leads to better memory consolidation.	Fougnie et al., 2008

Table 2: Factors Affecting Memory Consolidation

Bridging the Gaps: Current Challenges and Future Directions

Closing the gaps in our knowledge of memory consolidation processes offers fascinating new directions for future study and formidable difficulties (Lamnabhi-Lagarrigue et al., 2017). The unanswered concerns and disagreements that still split the research are among the most urgent. These mainly concern the specific function of the hippocampus and how it interacts with other brain areas during systems consolidation. Though more recent research points to a more dispersed network comprising several brain areas, conventional theories have focused on the hippocampus as the primary hub for memory creation. It raises concerns over the unpredictability of these processes between various types of memories and individuals. Resolving these conflicts requires integrating results from several approaches, including electrophysiology, neuroimaging, and computational modeling. Conciliating the contradictory data that these methods yield, each providing a unique perspective on memory consolidation's temporal and spatial dynamics, is difficult (Abbas et al., 2015). Notwithstanding these difficulties, this integration has the potential to significantly improve our knowledge of memory-related problems and provide new avenues for treatment. Thus, integrating knowledge from molecular biology and cognitive neuroscience may result in the creation of focused therapies, such as medication or neurostimulation, that improve memory consolidation or lessen the impact of memory deficits. Future studies should concentrate on using multimodal techniques that combine the advantages of many methodologies and put more emphasis on longitudinal studies to monitor memory consolidation over time. Furthermore, investigating individual variations in memory consolidation that are impacted by lifestyle, environment, and genetics may yield tailored treatment approaches. Integrating various research findings will be crucial in bridging these gaps and expanding our understanding of memory consolidation and its broader implications for cognitive neuroscience and therapeutic applications (Sridhar et al., 2023).

Implications and Applications

Advances in cognitive neuroscience views on memory consolidation mechanisms have deep and complex consequences and applications that have the potential to revolutionize several disciplines (Maguire et al., 2014). From a clinical perspective, a more profound comprehension of memory consolidation can result in more successful treatments for memory disorders like Alzheimer's, amnesia, and other cognitive impairments. These customized therapies could address the unique neurobiological deficiencies linked to these conditions. Understanding how memories are consolidated might help build learning and retention strategies in education and cognitive improvement (Larsen et al., 2018). This would allow the creation of specialized teaching resources and techniques that maximize cognitive performance in various age groups. Furthermore, tailored therapies promise to improve memory and address cognitive deficiencies. Based on each individual's neurobiological profile, these personalized methods can potentially transform the field. Utilizing cutting-edge technology and customized data, treatments may be tailored to meet each person's unique requirements, optimizing therapeutic efficacy and cognitive advantages. In general, filling up the gaps in memory consolidation research has promise for improving educational practices, tailoring cognitive therapies to individual needs, and using them in therapeutic settings. This will open the door to more focused and efficient methods of strengthening memory and cognitive performance (Morrison et al., 2011).

Summary

Cognitive neuroscience has made great strides recently in understanding the mechanisms behind memory consolidation. These discoveries have shown a complex interplay between molecular, cellular, and system-level processes. Important discoveries emphasize the complex function of synaptic plasticity, the impact of sleep phases, and the growing significance of non-neuronal cells in establishing and maintaining memory. Advanced neuroimaging and real-time monitoring are technological advancements that have given researchers better insights into these processes, while cross-disciplinary methods have promoted a more thorough understanding. Even with these advances, there are still many unanswered questions, especially about the precise function of the hippocampus and the impact of individual variability. Cognitive neuroscience has significantly influenced memory research, providing fresh viewpoints and approaches to fill previously identified knowledge gaps. Additional investigations are expected to expand on these discoveries and may produce new treatment approaches and a more comprehensive understanding of the mechanisms behind memory consolidation.

Reference

Abbas, A. K., Villers, A., & Ris, L. (2015). Temporal phases of long-term potentiation (LTP): myth or fact? *Reviews in the Neurosciences*, *26*(5), 507-546.

Abdolmaleky, H. M., Martin, M., Zhou, J. R., & Thiagalingam, S. (2023). Epigenetic alterations of brain non-neuronal cells in major mental diseases. *Genes*, *14*(4), 896.

Alberini, C. M. (2009). Transcription factors in long-term memory and synaptic plasticity. *Physiological reviews*, *89*(1), 121-145.

Alberini, C. M. (2011). The role of reconsolidation and the dynamic process of long-term memory formation and storage. *Frontiers in behavioral neuroscience*, *5*, 12.

Amunts, K., Axer, M., Banerjee, S., Bitsch, L., Bjaalie, J. G., Brauner, P., ... & Zaborszky, L. (2024). The coming decade of digital brain research: A vision for neuroscience at the intersection of technology and computing. *Imaging Neuroscience*, *2*, 1-35.

Anastasio, T. J., Ehrenberger, K. A., Watson, P., & Zhang, W. (2012). *Individual and collective memory consolidation: Analogous processes on different levels*. MIT Press.

Bartocci, E., & Lió, P. (2016). Computational modeling, formal analysis, and tools for systems biology. *PLoS computational biology*, *12*(1), e1004591.

Bein, O., Reggev, N., & Maril, A. (2020). Prior knowledge promotes hippocampal separation but cortical assimilation in the left inferior frontal gyrus. *Nature Communications*, *11*(1), 4590.

Benna, M. K., & Fusi, S. (2016). Computational principles of synaptic memory consolidation. *Nature neuroscience*, *19*(12), 1697-1706.

Boecker, H., & Drzezga, A. (2016). A perspective on the future role of brain pet imaging in exercise science. *Neuroimage*, *131*, 73-80.

Castrillo, J. I., & Oliver, S. G. (2016). Alzheimer's as a systems-level disease involving the interplay of multiple cellular networks. *Systems Biology of Alzheimer's Disease*, 3-48.

Chen, Z. S., & Wilson, M. A. (2023). How our understanding of memory replay evolves. *Journal of Neurophysiology*, *129*(3), 552–580.

De Kock, J. (2022). *The Psychological and Physiological Effects of Stress on the Human Epigenetic Profile and Brain* (Doctoral dissertation, Honors Program, The University of Tampa).

Doewes, R. I., Gangadhar, L., & Subburaj, S. (2021). An overview on stress neurobiology: Fundamental concepts and its consequences. *Neuroscience Informatics*, *1*(3), 100011.

Donaldson, D. I., Petersen, S. E., Ollinger, J. M., & Buckner, R. L. (2001). Dissociating state and item components of recognition memory using fMRI. *Neuroimage*, *13*(1), 129-142.

Dudai, Y., Karni, A., & Born, J. (2015). The consolidation and transformation of memory. *Neuron*, *88*(1), 20-32.

Egan, K. (1989). Memory, imagination, and learning: Connected by the story. *Phi Delta Kappan*, *70*(6), 455-459.

Eichenbaum, H. (2000). A cortical–hippocampal system for declarative memory. *Nature reviews neuroscience*, *1*(1), 41–50.

Feld, G. B., & Born, J. (2020). Neurochemical mechanisms for memory processing during sleep: basic findings in humans and neuropsychiatric implications. *Neuropsychopharmacology*, *45*(1), 31-44.

Fernandez, R. M. (2020). SDG3 good health and well-being: integration and connection with other SDGs. *Good Health and Well-Being*, 629-636.

Fournier, D. (2008). The relationship between attention and working memory. *New research on short-term memory*, pp. *1*, 45.

Harvey, A. G., Lee, J., Williams, J., Hollon, S. D., Walker, M. P., Thompson, M. A., & Smith, R. (2014). Improving outcome of psychosocial treatments by enhancing memory and learning. *Perspectives on Psychological Science*, *9*(2), 161–179.

Hu, X., Cheng, L. Y., Chiu, M. H., & Paller, K. A. (2020). Promoting memory consolidation during sleep: A meta-analysis of targeted memory reactivation. *Psychological bulletin*, *146*(3), 218.

Iannella, N., & Condemine, M. (2020). Neurons and Plasticity: What Do Glial Cells Have to Do with This?. *Functional Brain Mapping: Methods and Aims*, 13-46.

James, K. A., Stromin, J. I., Steenkamp, N., & Combrinck, M. I. (2023). Understanding the relationships between physiological and psychosocial stress, cortisol, and cognition. *Frontiers in Endocrinology*, *14*, 1085950.

Jarome, T. J., & Lubin, F. D. (2014). Epigenetic mechanisms of memory formation and reconsolidation. *Neurobiology of learning and memory*, *115*, 116-127.

Keast, R., Brown, K., & Mandell, M. (2007). Getting the right mix: Unpacking integration meanings and strategies. *International public management journal*, *10*(1), 9–33.

Lamnabhi-Lagarrigue, F., Annaswamy, A., Engell, S., Isaksson, A., Khargonekar, P., Murray, R. M., ... & Van den Hof, P. (2017). Systems & control for the future of humanity, research agenda: Current and future roles, impact and grand challenges. *Annual Reviews in Control*, *43*, 1-64.

Larsen, D. P. (2018, August). Planning education for long-term retention: the cognitive science and implementation of retrieval practice. In *Seminars in neurology* (Vol. 38, No. 04, pp. 449-456). Thieme Medical Publishers.

Lendner, J. D., Niethard, N., Mander, B. A., van Schalkwijk, F. J., Schuh-Hofer, S., Schmidt, H., ... & Helfrich, R. F. (2023). Human REM sleep recalibrates neural activity in support of memory formation. *Science Advances*, *9*(34), eadj1895.

Lenormand, D., & Piolino, P. (2022). In search of a naturalistic neuroimaging approach: Exploration of general feasibility through the case of VR-fMRI and application in the domain of episodic memory. *Neuroscience & Biobehavioral Reviews*, *133*, 104499.

Lin, A., Witvliet, D., Hernandez-Nunez, L., Linderman, S. W., Samuel, A. D., & Venkatachalam, V. (2022). Imaging whole-brain activity to understand behaviour. *Nature Reviews Physics*, *4*(5), 292-305.

Lin, C. H., & Lane, H. Y. (2019). The role of N-methyl-D-aspartate receptor neurotransmission and precision medicine in behavioral and psychological symptoms of dementia. *Frontiers in Pharmacology*, pp. *10*, 540.

Lisman, J. (2017). Glutamatergic synapses are structurally and biochemically complex because of multiple plasticity processes: long-term potentiation, long-term depression, short-term potentiation and scaling. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1715), 20160260.

Liu, L., van Groen, T., Kadish, I., & Tollefsbol, T. O. (2009). DNA methylation impacts on learning and memory in aging. *Neurobiology of aging*, *30*(4), 549-560.

MacDonald, K. J., & Cote, K. A. (2021). Contributions of post-learning REM and NREM sleep to memory retrieval. *Sleep medicine reviews*, p. *59*, 101453.

Maguire, E. A. (2014). Memory consolidation in humans: new evidence and opportunities. *Experimental physiology*, *99*(3), 471–486.

Manicka, S., & Levin, M. (2019). The Cognitive Lens: a primer on conceptual tools for analysing information processing in developmental and regenerative morphogenesis. *Philosophical Transactions of the Royal Society B, 374*(1774), 20180369.

Marshall, P., & Bredy, T. W. (2016). Cognitive neuroepigenetics: the next evolution in our understanding of the molecular mechanisms underlying learning and memory?. *NPJ science of learning*, *1*(1), 1–8.

Martin, S. J., Grimwood, P. D., & Morris, R. G. (2000). Synaptic plasticity and memory: an evaluation of the hypothesis. *Annual review of neuroscience*, *23*(1), 649–711.

Massey, P. V., & Bashir, Z. I. (2007). Long-term depression: multiple forms and implications for brain function. *Trends in neurosciences*, *30*(4), 176–184.

Mayadevi, M., Archana, G. M., Prabhu, R. R., & Omkumar, R. V. (2012). Molecular mechanisms in synaptic plasticity. *Neuroscience-Dealing With Frontiers*, pp. 295–330.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychological review*, *102*(3), 419.

McKenzie, S., & Eichenbaum, H. (2011). Consolidation and reconsolidation: two lives of memories?. *Neuron*, *71*(2), 224-233.

Mehonic, A., Sebastian, A., Rajendran, B., Simeone, O., Vasilaki, E., & Kenyon, A. J. (2020). Memristors—From in‐memory computing, deep learning acceleration, and spiking neural networks to the future of neuromorphic and bio‐inspired computing. *Advanced Intelligent Systems*, *2*(11), 2000085.

Meir Drexler, S., & Wolf, O. T. (2017). Stress and memory consolidation. *Cognitive neuroscience of memory consolidation*, 285-300.

Miranda, M., Morici, J. F., Zanoni, M. B., & Bekinschtein, P. (2019). Brain-derived neurotrophic factor: a key molecule for memory in the healthy and the pathological brain. *Frontiers in cellular neuroscience*, *13*, 472800.

Miyamoto, E. (2006). Molecular mechanism of neuronal plasticity: induction and maintenance of long-term potentiation in the hippocampus. *Journal of pharmacological sciences*, *100*(5), 433–442.

Molina, M., Carmona, I., Fuentes, L. J., Plaza, V., & Estévez, A. F. (2020). It has enhanced learning and retention of medical information in Alzheimer’s disease after differential outcomes training. *Plos one*, *15*(4), e0231578.

Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic bulletin & review*, *18*, 46-60.

Nadel, L., Hupbach, A., Gomez, R., & Newman-Smith, K. (2012). Memory formation, consolidation, and transformation. *Neuroscience & Biobehavioral Reviews*, *36*(7), 1640–1645.

Opitz, B. (2014). Memory function and the hippocampus. *The hippocampus in clinical neuroscience*, pp. *34*, 51–59.

Perez, D. M. (2020). α1-Adrenergic receptors in neurotransmission, synaptic plasticity, and cognition. *Frontiers in pharmacology*, p. *11*, 581098.

Reis, H. J., Guatimosim, C., Paquet, M., Santos, M., Ribeiro, F. M., Kummer, A., ... & Palotas, A. (2009). Neuro-transmitters in the central nervous system & their implication in learning and memory processes. *Current medicinal chemistry*, *16*(7), 796-840.

Schreiner, T., & Rasch, B. (2017). The beneficial role of memory reactivation for language learning during sleep: A review. *Brain and language*, *167*, 94-105.

Schwindel, C. D., & McNaughton, B. L. (2011). Hippocampal–cortical interactions and the dynamics of memory trace reactivation. *Progress in brain research*, pp. *193*, 163–177.

Squire, L. R. (2004). Memory systems of the brain: a brief history and current perspective. *Neurobiology of learning and memory*, *82*(3), 171–177.

Squire, L. R., Genzel, L., Wixted, J. T., & Morris, R. G. (2015). Memory consolidation. *Cold Spring Harbor perspectives in biology*, *7*(8), a021766.

Sridhar, S., Khamaj, A., & Asthana, M. K. (2023). Cognitive neuroscience perspective on memory: overview and summary. *Frontiers in Human Neuroscience*, *17*, 1217093.

Takehara, K., Kawahara, S., & Kirino, Y. (2003). Time-dependent reorganization of the brain components underlying memory retention in trace eyeblink conditioning. *Journal of Neuroscience*, *23*(30), 9897-9905.

Takehara-Nishiuchi, K. (2021). Neurobiology of systems memory consolidation. *European Journal of Neuroscience*, *54*(8), 6850-6863.

Torre-Bastida, A. I., Díaz-de-Arcaya, J., Osaba, E., Muhammad, K., Camacho, D., & Del Ser, J. (2021). Bio-inspired computation for big data fusion, storage, processing, learning, and visualization: state of the art and future directions. *Neural Computing and Applications*, 1-31.

Wang, H., Hu, Y., & Tsien, J. Z. (2006). Molecular and systems mechanisms of memory consolidation and storage. *Progress in neurobiology*, *79*(3), 123-135.

Wang, S. H., & Morris, R. G. (2010). Hippocampal-neocortical interactions in memory formation, consolidation, and reconsolidation. *Annual review of psychology*, *61*(1), 49–79.

Wayman, G. A., Tokumitsu, H., Davare, M. A., & Soderling, T. R. (2011). Analysis of CaM-kinase signaling in cells. *Cell calcium*, *50*(1), 1-8.

Wigren, H. K., & Porkka-Heiskanen, T. (2018). Novel concepts in sleep regulation. *Acta Physiologica*, *222*(4), e13017.

Zeng, S., Lin, X., Wang, J., & Hu, X. (2021). Sleep's short-term memory preservation and long-term affect depotentiation effect in emotional memory consolidation: behavioral and EEG evidence. *Sleep*, *44*(11), zsab155.

Zhang, R. C., & Madan, C. R. (2021). How does caffeine influence memory? Drug, experimental, and demographic factors. *Neuroscience & Biobehavioral Reviews*, pp. *131*, 525–538.