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Research Progress of Memory Mechanism in Cognitive Psychology

Luoyu Wang

College of Medical, Veterinary & Life Sciences, University of Glasgow, Glasgow, UK

ABSTRACT

Memory is a core problem in cognitive psychology and is crucial to understanding the acquisition, preservation and extraction of information. This study summarizes the dynamics of memory mechanisms, including theoretical evolution, systematic partitioning, process analysis, performance factors, barrier exploration, and clinical practice. Starting with the basic concept of memory and its importance in psychology, this paper reviews the background and value of memory research, and makes an in-depth study of classical and modern memory models to deepen the understanding of memory operation. Types of memories, such as instantaneous, persistent, unconscious, and conscious, are distinguished, with emphasis on encoding, retention, extraction, and fading. This paper discusses the biological, psychological, sociocultural, and environmental factors that influence memory, and highlights advances in the study of memory disorders, interdisciplinary collaboration, and neuroimaging. It concludes with a summary of the findings and future directions, including personalized memory enhancement and contributions to education, healthcare, and social development. This study deepens the understanding of memory mechanism and has practical guiding significance.

KEYWORDS

Memory mechanism; Cognitive psychology; Theoretical model; Memory process; Memory impairment; Interdisciplinary research

1. INTRODUCTION

Memory, a key cognitive function, influences daily actions, decisions, cognitive frameworks, and self-identity. It involves acquiring, preserving, and extracting information, underpinning higher-level activities like language, problem-solving, and social interactions. Memory also preserves personal and collective history [1]. Technological advances, especially in brain imaging, offer unprecedented insights into memory's neural basis, aiding treatment of disorders. However, many questions remain, impacting teaching, elderly quality of life, and mental health. Memory research is active, evolving from multi-memory models to complex structures like working memory and connectionist models. Empirical studies cover various memory aspects, but limitations exist. This research integrates frameworks and methods to focus on memory encoding, storage, retrieval, and efficiency factors. It also explores diagnosis, treatment, especially for Alzheimer's, and the impact of emerging technologies like AI and VR on memory research.

2. A THEORETICAL MODEL OF MEMORY

Theoretical models of memory are fundamental to understanding memory mechanisms, and they provide us with a conceptual framework for how information is encoded, stored, and retrieved.

2.1. Multistage Model

The multiple memory model by Atkinson and Shiffrin (1968) is an early, fundamental theory. It divides memory into three levels: sensory storage, short-term memory (STM), and long-term memory (LTM) [2]. Sensory storage captures external stimuli briefly. STM processes immediate information with limited capacity and short retention. LTM stores information indefinitely for a long time.

Sensory registration, done instantaneously in milliseconds, captures visual, auditory, and other sensory info. It then moves to short-term memory (STM), lasting 20-30 seconds with a capacity of 7±2 chunks. Some STM info can be transferred to long-term memory (LTM) through paraphrasing or attention. LTM stores info long-term and can be retrieved through recall or recognition.

Despite its simplicity, the multimemory model fails to account for complex cognitive phenomena such as the ability to multitask simultaneously in working memory. Therefore, subsequent studies have gradually introduced more complex and refined models.

2.2. Working Memory Model

In 1974, Baddeley and Hitch proposed the Working memory model, which presents a more dynamic and interactive memory architecture. Working memory is not limited to short-term information storage, but is composed of central executive system, speech loop, visual spatial template, and the component of episodic buffer is introduced in subsequent research. [3] Each component is responsible for a specific type of information processing. Central executive system: Similar to a command center that coordinates the work of other components and is responsible for functions such as attention allocation, planning, and decision making. Speech loop: Specialized for processing linguistic material, especially auditory information, it maintains information through internal "sound" repetition. Visual spatial sketch board: Responsible for processing visual and spatial information, such as the position and shape of objects. Scenario buffer: Integrate information from different sources to form a coherent representation of the situation. The working memory model emphasizes the flexibility and interactivity of the memory system, which makes it better able to explain complex behaviors in human cognitive activities.

2.3. The Difference Between Episodic and Semantic Memory

Tulving (1972) differentiates between Episodic and Semantic Memory, highlighting functional differences [4]. Episodic memory covers personal experiences with time and place details, e.g., what you ate last night and where. Semantic memory stores facts, concepts, and general knowledge, unrelated to specific contexts, like knowing Paris is France's capital. Both are interconnected but distinct, forming our comprehensive memory bank.

2.4. Connectionist Models and Other Emerging Models

With the development of neuroscience, connectionist models began to rise. Such models are based on the principle of neural networks, which view memory as a distributed representation formed by complex patterns of connections between a large number of neurons. Information is not stored in a fixed location, but is represented by changes in the state of the entire network. This model is particularly suitable for the establishment of associations between old and new knowledge in the process of simulation learning. In addition, many new memory models have emerged in recent years, such as the ACT-R model, a comprehensive cognitive architecture that attempts to unify various cognitive processes, including perception, attention, memory, and action; Generative adversarial networks (GANs) are applied to memory research to explore generative and creative aspects of memory using machine learning technology [5].

3. CLASSIFICATION OF MEMORY SYSTEMS

3.1. Short-term Memory (STM) and Long-term Memory (LTM)

As a memory model, short-term memory is characterized by the fact that information can be temporarily stored and can be extracted and used in a very short time. This type of memory has a relatively limited storage capacity and a short duration, generally estimated to be about 7±2 units of information, which can be single characters, words, or more complex combinations of information. The main feature of STM is rapid decay, and if the information is not repeated or further processed in a timely manner, it will be quickly forgotten. The STM functions like a workbench, allowing us to manipulate and process information in the current task. It is characterized by. Capacity limited is approximately 7±2 units. The duration is about 20 to 30 seconds. Susceptible to external factors, new information is easy to replace the original information. Repetition is essential to maintaining the memory of information through repetition.

Long-term memory can encode information and store it for a long time or even a lifetime, and its capacity is nearly infinite, holding a large amount of factual knowledge, skills, and personal experiences. Information extraction from long-term memory relies on specific cues, such as environmental factors or other information associated with it. According to the different content, LTM can be subdivided into episodic memory and semantic memory. Its characteristics are: the capacity is almost unlimited; Long duration, which can range from a few days to decades; Rely on cues and need appropriate cues to activate memory; Highly malleable and constantly updated through practice and experience.

3.2. Implicit and Explicit Memory

Implicit memory manifests without conscious recall and is linked to automated behaviors or skills like biking, typing, or playing an instrument. The manifestations of implicit memory include classical conditioning, operational conditioning and priming effect. Since the operation of implicit memory is unconscious, relatively intact implicit memory function can be observed even in amnesic patients. Its characteristics are: one is the classical conditioned reflex, such as the dog in Pavlov's experiment salivates when he hears the bell. The second is operational conditioning, learning to reward behavior through trial and error. The third is the priming effect, where previously exposed stimuli are more easily recognized or responded to

Explicit memory, by contrast, involves the conscious recall of past experiences or knowledge. When we try to remember something or answer a question, we are actually using explicit memory. This form of memory is often associated with episodic and semantic memory because it involves information about the time and place of specific events (episodic memory) as well as general knowledge (semantic memory). Its characteristics are: first, recall what happened yesterday. Answer questions about historical events. 3. Stories that describe personal experiences.

3.3. Prospective Memory and Retrospective Memory

Prospective memory covers to keep future actions or intentions and back, especially for reservation at a certain moment in the future to implement the task of memory function. Examples include setting a specific time to remind yourself to call a friend or taking a medication at the same time of day. Such memories form in daily life activities in the process of planning and organization play a very important role. However, until modern times, the research in related fields has gradually received extensive attention from the academic community. There are two problems that need to be further demonstrated: First, time management, correctly predicting when a predetermined task should be performed. The second is attention allocation, making sure you don't forget important things because you're distracted.

Retrospective memory refers to the memory of past events, such as particular moments in childhood, or acquired knowledge, such as what was discussed in the previous week's meeting. Such memories form a core part of our everyday cognition, covering experiences that occurred from minutes to years ago. The field of memory has been studied for a long time, covering many aspects of memory encoding, storage and retrieval mechanism.

3.4. Procedural Memory and Declarative Memory

Procedural memory involves how to do something, known as "knowing and doing" memory. It mainly involves the learning of motor skills, such as walking, swimming or driving, but also some complex cognitive skills, such as reading comprehension and numeracy. Procedural memory is usually acquired through repeated practice, and once mastered, these skills tend to become very solid and not easily forgotten. Features are: automation, after a lot of practice can be automatically completed; Anti-forgetting, even if it is not used for a long time, it is difficult to completely lose; It is difficult to express, it is difficult to describe the steps accurately in words

Declarative memory involves the cognitive storage of specific facts and events, known as "knowledge" memory. This type of memory can be further subdivided into two subcategories. One is episodic memory which involves the recall of specific events that the individual personally experienced. Second, semantic memory involves the recording of widely accepted facts and concepts. Declarative memory can be clearly expressed in language and is easy to share and communicate. More susceptible and may be altered by factors such as emotional stress; It can be significantly improved through education and training, and regular review helps to consolidate memories.

4. THE STUDY OF MEMORY PROCESSES

Memory is not a single process, but consists of several interrelated stages of encoding, storing, retrieving and forgetting information.

4.1. Coding: How Does Information Enter The Memory System

Encoding transforms external information into a brain-processable form. It's affected by information content and individual cognitive status, with attention playing a key role. Focused attention boosts short-term memory conversion, while distraction impairs encoding efficiency and subsequent memory.

According to the deep processing theory proposed by Craik and Lockhart (1972), deep processing of information at the semantic level can promote the formation of long-term memory more than shallow processing of surface features. For example, thinking about the meaning of a word (such as whether a "bird" can fly) helps you remember the word better than simply judging its glyphs (such as the number of letters).

Contemporary studies have revealed that multi-sensory experiences can greatly improve the encoding efficiency of memory. In the process of information processing, if a variety of perceptual channels, such as vision, hearing and touch, can be synchronously mobilized, a more solid connection will be formed between the related information elements, and the memory performance will be further optimized. Taking foreign language learning as an example, the integration of visual images and phonetic training can effectively promote the memory and mastery of vocabulary.

4.2. Storage: How is Information Maintained in Memory

After encoding, the next step is understanding long-term memory storage. It involves synaptic plasticity, where neuron connections change strength based on experience. Long-term enhancement (LTP) boosts synaptic transmission efficiency in specific situations. LTP is considered an important

building block for learning and memory function because it facilitates the reactivation of relevant information.

Consolidation theory posits that newly acquired memories aren't immediately stable and can be fragile until fully fixed. Continuous practice enhances stability and reduces forgetting. Sleep, particularly REM sleep, is crucial for memory stabilization. The re-stabilization mechanism shows that recalled memories briefly become unstable and require re-stabilization. This suggests that even formed memories can be malleable under certain conditions.

4.3. Extraction: The Process of Recalling or Identifying Past Experiences

Extraction is the retrieval of desired info from memory. Success depends on cues and conditions activating memory traces. Recall, harder, involves reproducing past experiences. Recognition, easier, involves choosing the right answer from options. Free recall tests and multiple-choice questions exemplify these. Despite having many memories, we may experience tip-of-the-tongue failures due to lack of clues. Interference theory states similar info can compete, causing extraction difficulty, especially with high overlap.

Context dependency and state dependency refer to the fact that memory retrieval is often more efficient when the environment or mental state is similar to the original encoding. For example, memories are more likely to be recalled in the same place or in a similar emotional state. This suggests that external and internal factors have important effects on memory retrieval.

4.4. Forgetting: Causes and Mechanisms of Memory Decline

Forgetting is the gradual weakening or disappearance of the contents of a memory over time. Although forgetting may seem negative, it is actually a normal function of the cognitive system, helping to filter out the really important information and avoid brain overload. Interference theory holds that forgetting is mainly caused by mutual interference between old and new information. proactive interference occurs when previous learning interferes with subsequent learning; In contrast, retroactive interference is when recently learned content affects early memory performance. The hypothesis of decay theory is that memory traces fade naturally over time unless they are reviewed or reinforced in time. However, in recent years, more and more research evidence supports the idea of synaptic plasticity and neural network reorganization rather than simple physical decay.

In addition to the above objective reasons, individuals may consciously or unconsciously choose to forget certain unpleasant experiences for the purpose of protecting their self-image or alleviating pain. This kind of motivated forgetting can be achieved through a mechanism of repression or denial, although the exact mechanism of action remains to be further studied.

5. FACTORS THAT AFFECT MEMORY

5.1. Physiological Factor

Age is an important factor affecting memory performance. As an individual ages, the structure and function of the brain undergo a series of changes, which may lead to a decline in memory. For example, working and episodic memory in older age groups often show a significant decline, while semantic memory usually remains relatively stable. Research suggests that memory changes in old age may be linked to atrophy in the hippocampus and other related brain regions. Sleep is essential for memory consolidation. SWS and REM sleep stages reinforce new memories. Inadequate or poor sleep impairs memory, especially shortly after learning. Midday napping boosts memory recovery, especially for long-term memory. Hormone fluctuations like cortisol and estrogen directly affect memory. High cortisol may damage hippocampal nerve cells, hindering memory. Adequate estrogen

boosts spatial and verbal memory. Neurotransmitters regulate attention, motivation, and emotions, indirectly impacting memory.

5.2. Psychological Factor

Emotional states have a profound effect on memory. Positive emotional experiences generally enhance memory encoding and retrieval efficiency, while negative emotions may lead to selective attention biased toward negative information and increase memory for unpleasant events. In extreme cases, people with post-traumatic stress disorder (PTSD) may experience excessive recall and flashback phenomena, showing strong emotional memory effects. An individual's level of motivation also affects memory performance. In the state of high motivation, people are more inclined to devote more attention and cognitive resources to the current task, thus improving the quality of information encoding. Conversely, low motivation may lead to distraction and shallow processing, reducing memory effects. Reward mechanisms enhance memory retention by reinforcing behaviors. Attention is key for encoding memory. Distractions or multitasking can cause information loss or errors, affecting memory. Creating a focused environment is essential for learning or remembering important information.

5.3. Sociocultural Factors

Education level positively correlates with memory performance. Higher education fosters strategic thinking and critical reading, aiding effective content management. School training cultivates good learning habits, enhancing memory efficiency. Cultural background influences memory strategies; Eastern cultures may rely on group interaction, while Western cultures value independent remembering. Language and customs also shape cultural memory patterns. Environmental factors play a role.

5.4. Environmental Factor

The design and arrangement of learning environment directly affect the memory effect. Quiet and distrance-free Spaces help reduce outside distractions and allow individuals to focus on the task at hand. Conversely, noisy or changing environments can be distracting and prevent effective memory. In addition, moderate adjustment of elements such as light intensity and temperature can also improve the learning environment and further enhance the memory efficiency. Modern information technology has changed how we acquire and process information. While facilitating access, the Internet, social platforms, and portable devices have led to information overload. Too much choice and frequent switching of focus of attention can lead to shallow cognitive processing, which is not conducive to deep memory construction. On the other hand, the application of multimedia teaching resources creates conditions for visual and contextual learning, which helps to deepen understanding and memory.

6. NEW TRENDS IN MEMORY RESEARCH

6.1. The influence of Technological Progress on Memory Research

Brain imaging advances have deepened memory research. Non-invasive methods like fMRI, PET, and NIRS monitor brain activity in real-time, exploring memory mechanisms. EEG and LFP track neuronal activity changes with high temporal accuracy. TMS and tDCS adjust brain region function in controlled experiments, exploring memory effects. Big data and machine learning extract key information from complex data, enabling accurate memory models and predictions. For example, a memory evaluation system designed with deep learning algorithms can effectively identify early

warning signals of cognitive decline and provide scientific basis for prevention and treatment strategies of related diseases.

6.2. Interdisciplinary Research

Cognitive neuroscience combines neuroscience and psychology to explore brain mechanisms behind psychological phenomena. In emotional memory studies, researchers focus on brain regions like the amygdala and individual emotional responses' impact on memory. AI mimics human memory systems, validating theories and inspiring new hypotheses. GANs create virtual environments for episodic memory studies, while multi-agent systems explore social interaction's effect on collective memory. Cross-disciplinary integration and computational biology provide new perspectives and models for memory research.

6.3. Development of Personalized Memory Enhancement Schemes

Gene-editing techniques like CRISPR-Cas9 have offered new insights into genetic factors affecting memory. By modifying genes, scientists can detail their roles in memory formation and maintenance. Personalized gene therapy holds promise for treating gene-defect-related memory disorders, considering factors like age, gender, and lifestyle. Digital health technology advances facilitate real-time personal memory monitoring and management. Smartphone apps, wearables, and other tools record activities, offer customized memory training, and improve treatment compliance, self-management, and preventive care awareness.

6.4. Ethical Considerations and Privacy Protection

Although the emerging technology shows great promise, its application also raises ethical controversy about the use of genetic information. To avoid potential discrimination and abuse, there is an urgent need for a solid legal framework to precisely delineate the circumstances under which such sensitive data can be accessed and shared, and to establish appropriate information safeguards.

7. CONCLUSION

This paper not only presents a rich and colorful memory world for us, but also points out the direction for future academic research and practical application. We look forward to more innovative work emerging in this field of challenges and opportunities.

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