

Review

The anatomical perspective of memory: a review article

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Accepted 10 January, 2015

Memory has been defined as the process of encoding, storing, consolidating, and retrieving information. Studies in cognitive neuroscience have demonstrated that memory is a dynamic property of the brain as a whole, rather than being localized to any single region. Memory is critical to humans and all other living organisms. The science of memory began in 1885 with Hermann Ebbinghaus. Memory has been classified into many subtypes depending on its persistence, the contents of its stored material, and the presence or not of consciousness during learning and memory. Memory networks are integrated by specific anatomical structures such as the hippocampus, cerebellum, amygdala, frontal lobes, temporal lobes, entorhinal cortex, and basal ganglia. Memory improvement techniques known as mnemonic devices include: method of loci, Pegword method and PQ4R method. The puzzling phenomena of memory retrieval include: *Déjà vu*, *Jamais vu*, Flashbulb memories and Tip-of-the-tongue State. Disorders of memory known as amnesia could be functional or organic and include other conditions such as Alzheimer disease, Parkinson disease, Korsakoff syndrome, infantile amnesia, etc. It is recommended that more studies be carried out on the anatomical structures that are associated with memory.

Key words: Brain, neuroscience, amnesia, hippocampus, cerebellum, amygdala, frontal lobe, temporal lobe.

INTRODUCTION

Memory has been defined as the process of encoding, storing, consolidating, and retrieving information. It is an emergent process in our brain, resulting from complex interactions between the biochemistry of neurons and their electrical activity in specific anatomical structures (García-Lázaro et al., 2012).

Studies in cognitive neuroscience have demonstrated that memory is a dynamic property of the brain as a whole, rather than being localized to any single region. New advances in magnetic resonance imaging (MRI) have allowed neuroscientists to obtain morphologic and functional evidence of the different brain structures involved in memory networks, which form interconnections across the entire brain. Because memory depends on several brain systems working in concert across many levels of neural organization, modern neuroscientists can innovatively use MRI to determine the architecture of memory systems (García-

Lázaro et al., 2012).

It is aimed that this review will contribute to the body of knowledge concerning the anatomical structures associated with memory and stimulates more interest in researchers to carry out further studies in the anatomical structures that are associated with memory and indeed the whole concept of memory.

JUSTIFICATION OF THE REVIEW

Memory is critical to humans and all other living organisms. Practically all of our activities; talking, understanding, reading and socializing - depend on our having learned and stored information about our environments. Memory allows us to retrieve events from the distant past or from moments ago. It enables us to learn new skills and to form habits. Without the ability to

access past experience or information, we would be unable to comprehend language, recognize our friends and family members, find our way home, or even tie a shoe lace. Life would be a series of disconnected experiences each one new and unfamiliar. Without any sort of memory, humans would quickly perish (Roediger, 2009). Therefore the understanding of memory will be an important tool not only to Neuroscientists and Neurologist but the parent, clinical Psychologist, the Teacher and of course the Neuroanatomist.

HISTORY OF MEMORY

Aristotle (335 BC) famously mistook the heart as the organ of thought and thought that the brain was merely for cooling the blood (Squire and Zola-Morgan, 1991). In 1793, the possibility of testing experimentally whether mental exercise can induce growth of brain was discussed (Winkler, 2002). The science of memory began in 1885 when Hermann Ebbinghaus announced the study – test method and experimental results obtained with it (Roediger, 2009). Soon after Ebbinghaus's studies, an American investigator Mary Calkins (1894) introduced the method of paired – associates learning (Madigan and O'Hara, 1992).

Three important developments have occurred in the area of memory during the past decade. The first was the recognition that there is more than one kind of memory. The second important development was the establishment of an animal model of human amnesia in the monkey. The third development was the emergence of new technologies for studying anatomy and function in living objects (Squire and Zola-Morgan, 1993).

CLASSIFICATION OF MEMORY

Memory has been classified into many subtypes depending on its persistence, the contents of its stored material, and the presence or not of consciousness during learning and memory. In accordance with its persistence, memory was first separated into three sequential major systems, *the sensory, short-term, and long-term memory* systems. Sensory memory allows for the recording of sensations and their storage in cortical structures. Short-term memory was initially proposed as a precursor to long-term memory. However, it was later noted that not all information stored in short-term memory passes into long-term memory. In fact, one kind of short-term memory refers to information used exclusively for executing or developing other complex cognitive processes. Long-term memory has been divided based on whether the material is stored in episodic memory or semantic memory. Episodic memory is defined as recollections of previous experiences from one's personal past, especially if focused on events that constitute our

autobiographic memory. Semantic memory refers to general knowledge of facts and concepts regarding the world. This knowledge is not located in a specific time or place. Based on the contents of their operating characteristics, the kinds of information they process, and the purpose they serve, all memory systems have been classified as *declarative* and *non-declarative*. Declarative memory refers to memories that can be consciously recalled, such as facts and events. It is divided into episodic and semantic memory. In contrast, non-declarative memory does not afford awareness of any memory content but does require consciousness, and it includes procedural memory, priming, simple classical conditioning, and non-associative learning (García-Lázaro et al., 2012).

ANATOMICAL STRUCTURES ASSOCIATED WITH MEMORY

In the last few decades, memory has come to be seen as networks of interconnected cortical neurons, formed by associations that contain our experiences in their connective structures. Likewise, we now believe that memory networks overlap and interact profusely with one another such that a cellular assembly can be engaged in many memory networks. These networks are integrated by specific anatomical structures (Figure 1) such as the hippocampus, cerebellum, amygdala, frontal lobes, temporal lobes, entorhinal cortex, and basal ganglia (García-Lázaro et al., 2012).

The conclusion that the hippocampal region (Figure 2) is essential for normal recognition memory is entirely consistent with many current ideas about the role of the hippocampus in declarative memory. Thus, it is often suggested that the Hippocampal region and the medial temporal lobe system to which it belongs is essential for the normal acquisition of information about relationships, combinations, and conjunctions among and between stimuli. Furthermore, the anatomy of this system is consistent with the idea that the hippocampus extends and combines the functions performed by the adjacent perirhinal and parahippocampal cortices, which are positioned earlier in the information-processing hierarchy. Recognition memory tests ask whether an item that has recently been presented subsequently appears familiar. The recognition (or familiarity) decision requires that the stimulus presented in the retention test be identified as what was presented during learning. At the time of learning a link must therefore be made between the to-be remembered stimulus and its context or between the stimulus and the animal's interaction with it. It is this process of forming associations and the ability to retain relational information across time that many have supposed is at the heart of declarative memory and in turn is the function of the Hippocampal region in both humans and animals (Zola et al., 2000).

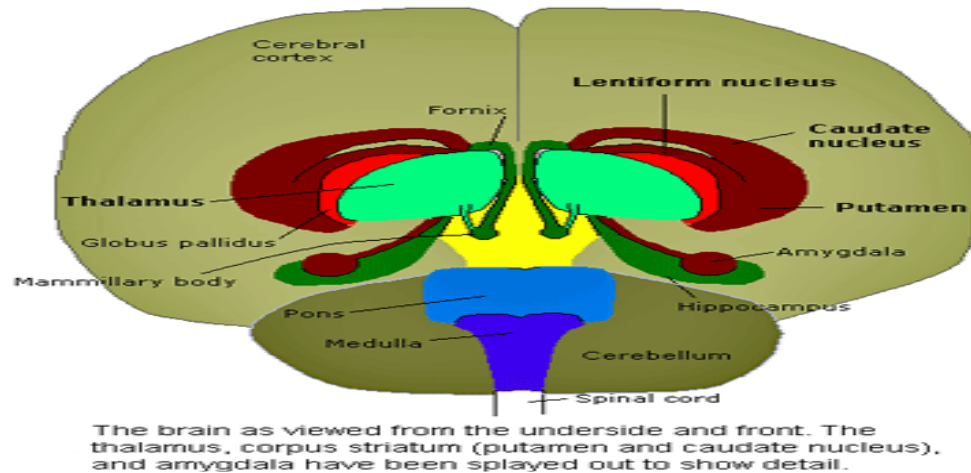


Figure 1. The anatomical structures associated with memory; (Source: <http://mybrainnotes.com/memory-brain-stress.html>).

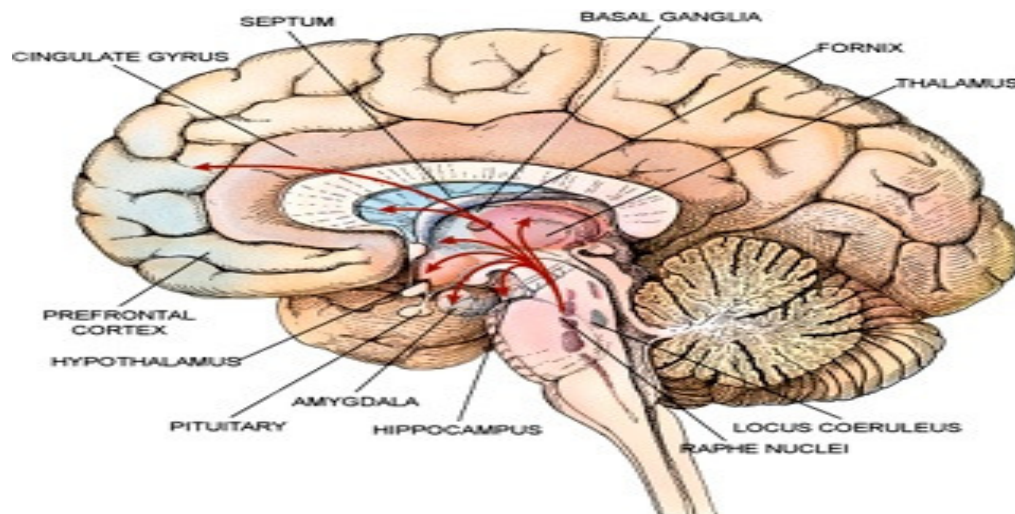


Figure 2. The Hippocampus and other structures; (Source: www.rmcybernetics.com/images/main/cyber/brain_diagram.jpg).

It has been suggested that the cerebellum is involved in the fundamental cognitive process of working memory, and the lobular activation patterns serve as a prediction of where damage to the cerebellum is most likely to affect working memory. The interpretation of cerebellar activation reflects cerebellar computations that are qualitatively similar to those hypothesized to occur during skilled limb movements as well as simpler forms of motor learning (Desmond et al., 1997). However, recent studies have found some important points of divergence. First, the superior cerebellum should be functionally subdivided into at least two regions, a superio-medial region involved in more motor-speech based processes and a superio-lateral region that is more specific to working memory processing. Second, that the inferior sector of the

cerebellum is right-dominant, but the activation is not exclusive to the right hemisphere nor does the pattern of lateralization differ from that observed in the other sectors of the cerebellum. Finally, it may be important to reconsider the role of covert speech in working memory and how it may be mediated and detected in the brain (Durisko and Fiez, 2009).

Previous reports suggested that the amygdala (Figure 3) may be a brain region critically involved in memory consolidation. Subsequent studies demonstrated that amygdala stimulation delivered after inhibitory avoidance training can enhance as well as impair memory consolidation. For example, low intensity foot shock with low intensity amygdala stimulation produces memory enhancement. The evidence that post training amygdala

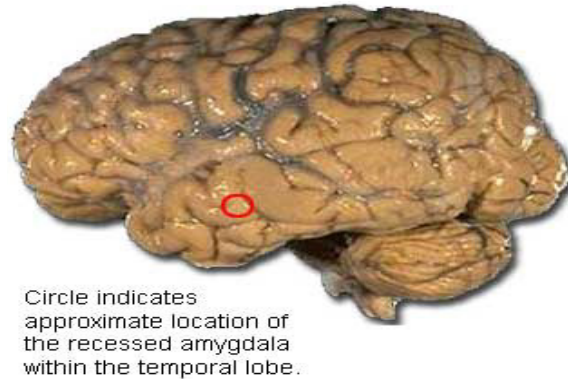


Figure 3. The approximate location of the amygdala in the brain (Source: <http://mybrainnotes.com/memory-brain-stress.html>).

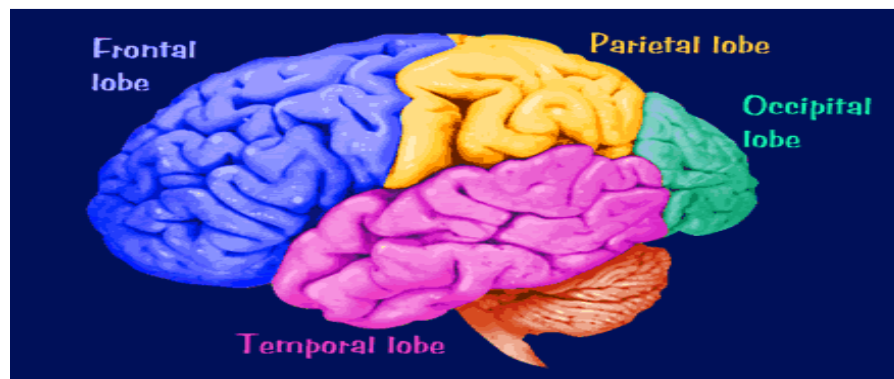


Figure 4. The lobes of the cerebral hemisphere; (Source: <http://www.brainmuseum.org/>)

stimulation can either enhance or impair memory clearly indicates that alteration of activity in the amygdala does not simply disrupt local neural circuits involved in memory consolidation. Rather, such findings suggest that the amygdala modulates the consolidation of recently acquired information (McGaugh et al., 2002).

In recent years, frontal lobe (Figure 4) function has become almost synonymous with working memory. Evidence that the frontal lobes play an important role in working memory goes back more than half a century, to early reports that frontal lobe damage in nonhuman primates causes an inability to remember the location of hidden food after a brief delay. More recent electrophysiological recording studies in monkeys have further strengthened this link by demonstrating that some neurons in the frontal lobes fire only during the delay period of a working memory task. Furthermore, some of these neurons fire during spatial working memory tasks, whereas others fire during non spatial working memory tasks, consistent with the idea of a multicomponential nature of working memory (Thompson-Schill et al., 2002).

The temporal lobe (Figure 4) underpin the declarative memory system, including episodic memory (memory

unique to individual events), and semantic memory (established knowledge about concepts, facts, objects and word meanings). In children with temporal lobe epilepsy, dissociation between episodic and semantic memory for verbal material was recently reported, although the neural substrates for this dissociation were not indicated. Previous research has documented a partial division of labour for memory within the temporal lobe: the hippocampus and medial temporal structures are emphasized in supporting episodic memory, whereas anterior ventral and lateral temporal cortices are implicated in semantic memory (Skirrow, 2014).

Distinguishing the roles of specific Medial Temporal Lobe structures in long-term memory is a major goal in the study of memory. The hippocampus is the most studied of these regions as it serves a primary role in the encoding and time-limited retrieval of both object and spatial memory. The most prominent pathway into the hippocampus is the perforant pathway initiated in the entorhinal cortex. Anatomical connectivity of the hippocampus, parahippocampal cortex, perirhinal, and entorhinal cortices with the dorsal and ventral processing streams suggests that different neural circuits exist for

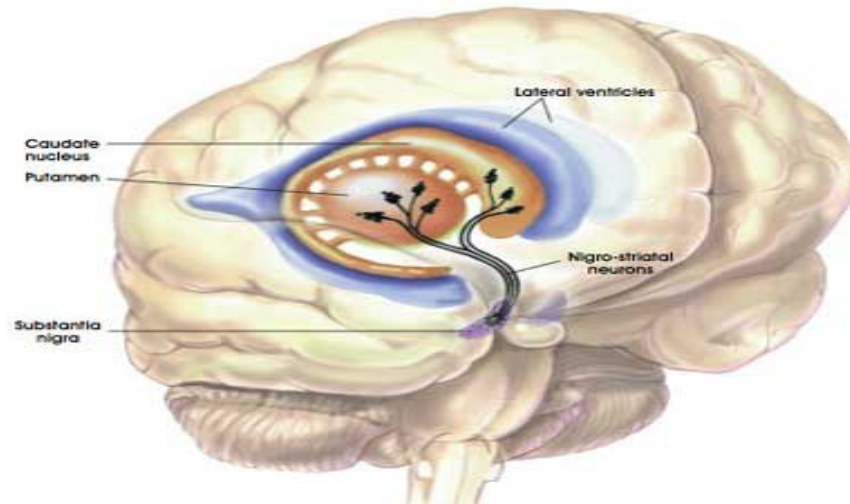


Figure 5. The basal ganglia; (Source: <http://mybrainnotes.com/memory-brain-stress.html>)

processing object (ventral stream) and spatial (dorsal stream) memories. Using the same stimuli and procedure, it has previously been reported that activity in the most anterior portion of the parahippocampal cortex, posterior to the perirhinal cortex, was greater for spatial than object encoding, while activity in the perirhinal cortex was equal for both object and spatial encoding (Bellgowan et al., 2014).

Decades of research on the anatomy, neurochemistry, and neurophysiology of the basal ganglia have refined our understanding of the role of this brain region in motor behavior. However, the idea that the basal ganglia (Figure 5) function strictly as a motor system is no longer supported by neurobehavioral research. Extensive evidence now indicates that one behavioral function of the basal ganglia involves participation in learning and memory processes. In particular, several lines of evidence are consistent with the hypothesis that the basal ganglia (specifically the dorsal striatum) mediate a form of learning in which associations between stimuli and responses (i.e., S-R habits) are acquired. Neuropsychological studies of humans with Parkinson's and Huntington's disease, as well as human neuroimaging studies, have provided some support for the role of the basal ganglia in S-R habit learning. Finally, evidence suggests that in a given learning situation, basal ganglia and medial temporal lobe systems are activated simultaneously, and recent studies have begun to examine the nature of the interaction between these brain regions in learning and memory (Packard and Knowlton, 2002).

METHODS OF IMPROVING MEMORY

Memory improvement techniques are known as

mnemonic devices or simply mnemonics. Three of the most common mnemonic techniques are: the method of loci, the Pegword method and the PQ4R method (Roediger, 2009).

The Method of Loci is one of the oldest mnemonic techniques (loci is a Latin word meaning 'places'). The method involves forming vivid interactive images between specific locations and items to be remembered. First step is to learn a set of places, then use them to encode experiences for later recall e.g. making a grocery list as bread on the front sidewalk, milk on the front porch, bananas hanging on the front door and so on (Roediger, 2009).

Pegword method also relies on the power of visual imagery. These are variations on the Pegword method but they are all based on learning a series of words that serve as "pegs" on which memories can be hung. Example, the peg words could be made to rhyme with numbers to make the words easier to remember. One is gun, two is shoe, three is tree, four is door, five is a hive, six is sticks, seven is heaven, eight is a plate, nine is wine, and ten is a hen (Roediger, 2009).

PQ4R method is a mnemonic technique used for remembering text material. The name is itself a mnemonic device for the steps involved. Firstly Preview the information by skimming quickly through the chapter and looking at the headings. Then Questions about the information should be formed e.g. What are the ways to improve memory? The third step is to Read the text carefully, trying to answer the questions. Then Reflect on the material, e.g. create your own examples of how the principles could be applied. Next, Recite the material after reading it; i.e. put the book aside and try to recall what you have read. Finally, Review the material by going through it again and trying to recall and to summarize its main points (Roediger, 2009).

Other techniques of improving memory involve spacing out study sessions which help improve memory. That is, if you are going to read a chapter twice before a test, retention is better if you allow some time to pass between readings, instead of reading the chapter twice in one sitting (Roediger, 2009).

SOME PHENOMENA IN MEMORY

These are puzzling phenomena of retrieval that nearly everyone has experienced. These include the following: *Déjà vu*, *Jamais vu*, Flashbulb memories and Tip-of-the-tongue State.

The sense of *déjà vu* (French word for 'seen before') is the strange sensation of having been somewhere before or experienced your current situation before, even though you know you have not. One possible explanation of *déjà vu* is that aspects of the current situation act as retrieval cues that unconsciously evoke an earlier experience, resulting in an eerie sense of familiarity (Roediger, 2009).

Another puzzling phenomenon is the sense of *Jamais vu* (French word for 'never seen'). This feeling arises when people feel they are experiencing something for the first time, even though they know they have never experienced it before. Here, the cues of the current situation do not match the encoded features of the earlier situation (Roediger, 2009).

A flashbulb memory is an unusually vivid memory of an especially emotional or dramatic past event. For example, the death of Princess Diane in 1997 created a flashbulb memory for many people (Roediger, 2009).

Tip-of-the-tongue State refers to the situation in which a person tries to retrieve a relatively familiar word, name, or fact, but cannot quite do so. Although the missing item seems almost within grasp, its retrieval eludes the person for some time (Roediger, 2009).

DISORDERS OF MEMORY-AMNESIA

Amnesia means loss of memory. There are different types of amnesias, but they fall into two major classes according to their causes: Functional amnesia and Organic amnesia. Another type of amnesia is infantile amnesia, which refers to the fact that most people lack specific memories of the first few years of their life (Roediger, 2009).

Functional amnesia

This refers to memory disorders that seem to result from psychological trauma, not due to injury to the brain.

Dissociative amnesia

Dissociative amnesia is a condition usually characterized

by severely impaired retrograde memory functioning in the absence of overt brain damage or a known neurological etiology. The amnesic state, also known as functional or psychogenic amnesia, mainly comprises deficits in retrieving autobiographical episodic memories (personal context-based events) and in the majority of cases to a lesser degree autobiographical semantic (personal non-context-based facts) and general semantic knowledge (facts) (Brand et al., 2009).

Dissociative fugue

Dissociative fugue is characterized by a sudden and unexpected travel away from home, geographical location, and experiences of impaired recall of past events and personal identity. People with dissociative fugue are sometimes referred to as schizophrenics, alcohol and substance abusers, or people with criminal tendencies (Gwandure, 2008).

Dissociative identity disorder

Dissociative identity disorder (DID), formerly known as multiple personality disorder, is defined as the presence of two or more identities or personality states that recurrently take control of a person's behaviour. These identities are accompanied by amnesia beyond that of ordinary forgetfulness, termed interidentity amnesia (Kong et al., 2008).

Organic amnesia

Organic amnesia is a neurological disorder that affects learning and memory but leaves other mental abilities relatively preserved (Shimamura, 1992). Organic amnesia is usually caused by brain disorders, tumours, strokes, degenerative diseases, chronic usages of select drugs, temporal lobe surgery, or electroconvulsive therapy. Organic amnesia may be temporary or permanent (Madan, 2011).

Anterograde amnesia

It means the inability to remember new information and events that occurred after the amnesia.

Retrograde amnesia

It is the inability to remember events before the onset of a brain insult (Shimamura, 1992).

Korsakoff syndrome

The best studied example of memory pathology is alcohol

Korsakoff syndrome, which develops after years of alcohol abuse and is characterized by symmetrical lesions along the wall of the third and fourth ventricles. The memory impairment associated with Korsakoff syndrome includes severe Anterograde amnesia (impaired learning ability) and a severe and extensive retrograde amnesia (impairment of remote memory) (Shimamura, 1986).

Alzheimer disease

The hallmark feature of Alzheimer disease is the dramatic memory deficit that occurs early in the disease. This deficit is presumed to result from neuropathological changes (intracellular neurofibrillary tangles and extracellular amyloid plaques) in Medial Temporal Lobe regions that are critical for declarative memory (Kensinger et al., 2004).

Parkinson disease

This is a neurodegenerative disorder characterized by resting tremors, rigidity, bradykinesia, and postural instability. This neurological disease results in a loss of nerve cells in the substantia nigra and a subsequent depletion of dopamine levels in the striatum, a structure that is known to be heavily interconnected with the frontal cortex. In several studies, researchers have reported that patients with Parkinson disease perform poorly on a number of verbal working memory tasks. However, the exact nature of this deficit remains unclear (Gilbert et al., 2005).

Infantile amnesia

Infantile amnesia, also called childhood amnesia, is the absence or scarcity of memories about very early life events. This phenomenon has been investigated for more than a century and by now, a large body of research conducted with adults concurs that there is very little recall for events from before the ages of 3–4 years. This boundary is not absolute, however (Peterson et al., 2011).

CONCLUSION

We are what we are not only because we think but also because we can remember what we have thought about. Every thought we have, every word we speak, every action we engage in –indeed, our very sense of self and our sense of connectedness to others- we owe to our memory, to the ability of our brains to record and to store our experiences. Memory is the glue that binds our mental life, the scaffolding that holds our personal history

and that makes it possible to grow and change throughout life; *Larry R. Squire and Eric R. Kandel (Memory: from Mind to Molecules, 1999).*

RECOMMENDATION

It is recommended that more studies be carried out on the anatomical structures associated with memory since life would be a series of disconnected experiences each one new and unfamiliar and that without any sort of memory, humans would quickly perish.

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