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# Limbic System: Overview

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**Annotation:** The aim of literature review is to describe the historical evolution of the scientific understanding of interconnections between the human brain, behavior, and emotions.

**Keywords:** Limbic system, hippocampus, amygdala, hypothalamus, memory, emotions, motivation.

***Introduction:*** The limbic system was initially referred to as the rhinencephalon, a term derived from Greek that translates to "nose brain," as it was thought to be primarily linked to olfactory perception. In 1878, surgeon Paul Broca introduced the concept of "le grand lobe limbique," designating the term limbic from the Latin limbus, meaning "border," to describe the curved perimeter of the cerebral cortex. As research progressed, additional functions of the limbic system were progressively unveiled. The involvement of the limbic system in emotional processing was examined by physician James Papez and neuroanatomist Paul Yakovlev, who published their insights in 1937 and 1948, respectively. Paul D. MacLean later coined the term "limbic system" to encompass Broca's limbic lobe and its associated structures situated beneath the cortex. From an evolutionary perspective, the limbic system is recognized as one of the most ancient components of the human brain, being present in fish, amphibians, reptiles, and early mammals. Additionally, the neuronal architecture of the limbic system is comparatively less intricate than that of the cerebral cortex. The limbic system constitutes a complex assembly of structures located bilaterally adjacent to the thalamus, directly beneath the cerebral cortex, playing a crucial role in emotional reactions, memory formation, and various facets of behavior.

***Morphology***

The limbic system consists of several interconnected structures, each with specific roles:

1. *Amygdala*: The amygdala is an almond-shape structure that exists in two parts, each located in front of the corresponding hippocampus in its respective temporal lobe. The amygdala is integral to the regulation of various dimensions of emotional learning and behavior. It facilitates the assessment of the emotional significance of situations, identifies potential threats, and prepares the organism for fight-or-flight responses by elevating heart and respiratory rates. Given its anatomical proximity to the hippocampus, the amygdala also plays a role in the modulation of memory encoding, particularly for memories associated with intense emotions. Lesions or damage to the amygdala may lead to heightened levels of aggression, increased irritability, impaired emotional regulation, and diminished capacity to recognize emotional expressions. Moreover, such impairment can compromise an individual's ability to detect fear, resulting in a propensity for more risk-taking behavior.

2. *Hippocampus*: The hippocampus is part of the limbic system, which manages the functions of feeling and reacting. It resembles the shape of a curvy seahorse and is essentially the memory center of our brains. Here, our episodic memories are formed and catalogued to be filed away in long-term storage across other parts of the cerebral cortex. Connections made in the hippocampus also help us associate memories with various senses. The hippocampus is also play a key role in spatial orientation and our ability to navigate the world.

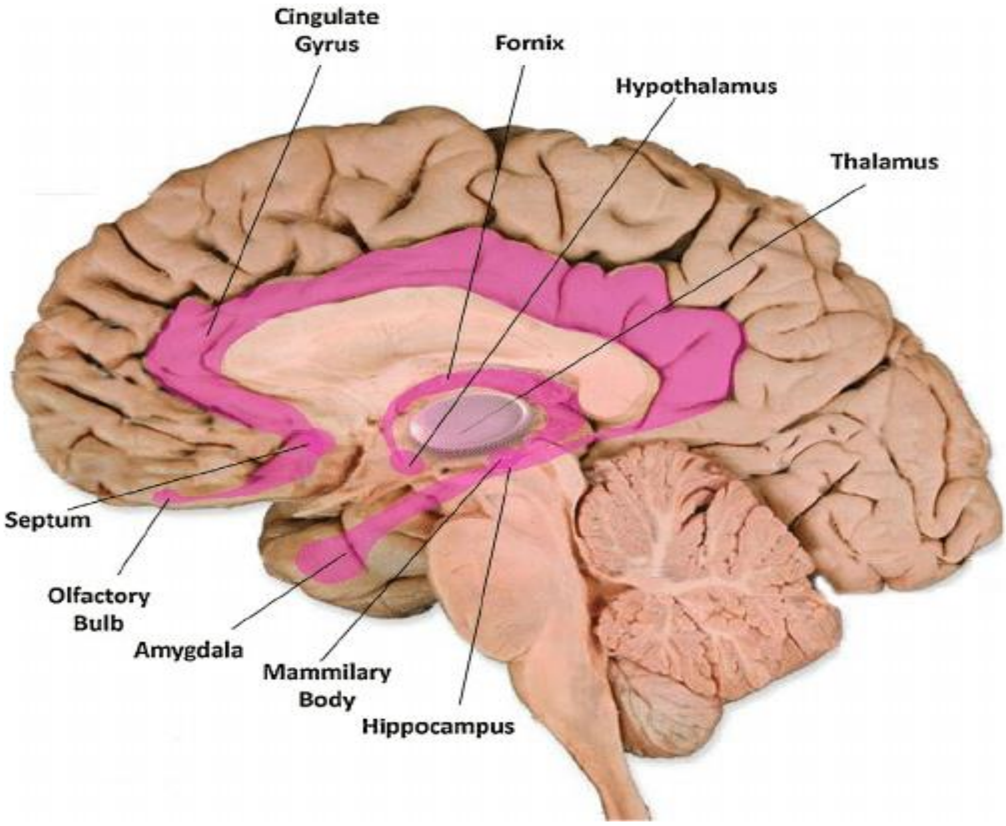
3. *Cingulate Gyrus*: The cingulate gyrus is a major limbic area and part of the Papez circuit (the medial or hippocampal limbic circuit), which begins at the hippocampus, continues as the fimbria and fornix,

and ends in the mammillary body. From the mammillary body, the mammillothalamic tract reaches the anterior nuclear group of the thalamus and then the cingulum (the white matter core of the cingulate gyrus), which turns around the splenium of the corpus callosum to end as the radiation of the cingulum into the hippocampus and uncus of the temporal lobe, thus completing the circuit; this is in contradistinction to the basolateral or amygdaloid limbic circuit. This curved structure is involved in emotional regulation and processing. It also plays a role in decision-making and impulse control.

4. *Hypothalamus:* While not traditionally classified solely as part of the limbic system, the hypothalamus is critical for hormonal regulation and maintaining homeostasis. It influences various autonomic functions, such as hunger, thirst, and the fight-or-flight response. This interface has been described as the “limbic-motor interface,” it is a model for the initiation of actions by limbic forebrain structures and helps explain how the “emotive brain” and “cognitive brain” operate together to initiate a response.

5. *Thalamus:* This structure acts as a relay station for sensory and motor signals to the cerebral cortex, and it also has roles in regulating consciousness, sleep,alertness and directs a person’s attention to sensory events. Damage to the thalamus can cause motor impairments, tremors, attention problems, insomnia, memory loss, vision loss or light sensitivity, and disorders of the motor systems. Severe damage can result in a coma.

6. *Mammillary Bodies:* Each mammillary body consists of two groups of nuclei: the medial mammillary nuclei and the lateral mammillary nuclei. They have direct connections to the hippocampus, thalamus and tegmental nuclei. They are also part of the medial limbic circuit as they relay impulses from the hippocampal formation to the anterior thalamic nuclei via the mammillothalamic tract. These small structures are involved in memory processing. They connect to the hippocampus via the fornix.




### *Function*

While the limbic system was initially suggested to be the sole neurological system involved in regulating emotion, it is now considered only one part of the brain to regulate visceral, autonomic processes. In general, the limbic system assists in various processes relating to cognition; including spatial memory, learning, motivation, emotional processing, and social processing. The limbic system's functions are diverse but can be broadly categorized into several key areas:

1. *Emotion Regulation:* The limbic system is central to processing emotions, such as fear, pleasure, and anger. The amygdala, in particular, assesses emotional responses and helps orchestrate reactions both psychologically and physiologically.

2. *Memory Formation*: The hippocampus is vital for the encoding, storage, and retrieval of memories. It facilitates the consolidation of information from short-term to long-term memory and plays a role in associating memories with emotions.

3. *Motivation and Reward:* The limbic system is involved in the brain's reward circuitry, influencing motivation and reinforcing behaviors that fulfill basic needs, such as food and social interaction. This system is also implicated in the pursuit of pleasurable activities

4. *Behavioral Responses:* The limbic system influences various behaviors, including aggression, maternal instincts, and responses to stress. It plays a role in how individuals interact with their environments and manage challenges.

5. *Homeostasis*: Through connections with the hypothalamus, the limbic system helps to maintain bodily homeostasis, regulating hunger, thirst, temperature, and sleep patterns.

***Clinical Significance***

The hypothalamus is involved in numerous functions critical for maintaining homeostasis. Nevertheless, its contribution to the limbic system has not been thoroughly explored. Established connections exist among the hypothalamus, nucleus accumbens, ventral tegmental area, hippocampus, and amygdala. The neural interactions between these structures are fundamental for behaviors associated with food-seeking, as well as evasion and fear responses to predators. This neural connectivity has been referred to as the "limbic-motor interface," serving as a framework for understanding how limbic forebrain structures initiate actions. It elucidates the cooperative functioning of the "emotive brain" and "cognitive brain" in generating appropriate responses.

The olfactory bulbs play a critical role in the sensory perception of olfaction. They transmit olfactory data to the amygdala, orbitofrontal cortex, and hippocampus for further processing. Subsequently, the amygdala interprets this information and employs it for associative learning purposes. For instance, it encodes odor cues that are linked to either favorable or unfavorable tastes.

The hippocampus is an allocortical structure that is important for the consolidation of information, including short-term, long-term, and spatial memory. People with extensive bilateral hippocampal damage are likely to have anterograde amnesia, as demonstrated in the infamous case of "H.M." Schizophrenic patients have been reported to have reductions in the size of their hippocampi. The parahippocampal gyrus is the cortical region surrounding the hippocampus with roles in scene recognition, and memory encoding and retrieval.Like the hippocampus, the parahippocampal gyrus has been observed to be asymmetrical in patients with schizophrenia.

The fornix constitutes the principal efferent pathway of the hippocampus. Although its precise function remains ambiguous, studies indicate that lesions affecting the fornix can lead to impairments in recall memory. The columns of the fornix terminate at the mammillary bodies, which possess limbic connections with the amygdala, hippocampus, and anterior thalamic nuclei. The mammillary bodies are crucial for the encoding and retrieval of episodic memory. Thiamine deficiency is notably associated with damage to the mammillary bodies, commonly resulting in Wernicke-Korsakoff syndrome.

The amygdala is a subcortical structure of the limbic system, located in the medial temporal lobe, whose role involves processing emotional responses- specifically fear, anxiety, and aggression. Additionally, the amygdala further processes memory and decision-making. Fear conditioning processing takes place in the lateral nuclei of the amygdalae where memories form associations with the adverse stimuli through long-term potentiation. Damage to the amygdalae has resulted in the impairment of fear conditioning. Kluver-Bucy syndrome is another rare condition observed after bilateral lesions to the amygdalae occur. Symptoms include amnesia, docility, hyperphagia (both pica and overeating normal foods), hyperorality and visual agnosia.

The cingulate gyrus is a cortical structure situated directly above the corpus callosum. Its principal afferent inputs are derived from both the thalamus and the neocortex. Similar to other components of the limbic system, the cingulate gyrus plays a pivotal role in the processes of emotional expression, learning, and memory formation. It serves to integrate behavior with motivational outcomes. Research has indicated that the cingulate gyri, particularly the anterior cingulate cortex, exhibit morphological differences in individuals diagnosed with mood disorders and schizophrenia.

The entorhinal cortex is located in the medial temporal lobe and is the main gateway between the hippocampus and neocortex. The EC-hippocampus system is an essential part of the limbic system responsible for declarative memories, spatial memories, memory formation, and memory consolidation. Clinically, in those who have Alzheimer's disease, magnetic resonance imaging has shown a loss of volume in the entorhinal cortex.

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