THE LIMBIC SYSTEM

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INTRODUCTION

In 1878, the French neurologist Paul Broca called attention to a group of distinct sub-cortical structures surrounding the thalamus in the mammalian brain. He called these interconnected neuronal components the limbic lobe (limbic, from the Latin, 'limbus', meaning surrounding, as in encircling) (Figure A). This was later to be called the **limbic system** by Paul Maclean. The limbic system is a loosely defined anatomical grouping of sub-cortical/cortical nuclei that, acting together, increase our chances of survival from predators. The limbic system generates both a heightened state of awareness and attention and, when required, activates other brain systems to enable our bodies to run or fight. In addition, it amplifies information processing and memory encoding that relates to a threat so that stimuli that recall the original learning moment are easily retrieved. It lowers the threshold for salience and increases vigilance when danger is sensed, allowing us to seek out a predator so that we can avoid becoming prey. In a moment of danger the limbic system prunes the number of options under consideration. In short, the limbic system is a coordinator of changing perceptions so that we make the correct response to a perceived threat.

The nuclei that comprise the limbic system have been preserved throughout mammalian evolution. In the human, however, the enlarged neocortical structure called the frontal lobe specifically expands our emotional range and our cognitive storage space. The anatomical components usually assigned to the limbic system by Sitoh include (See Figure A):

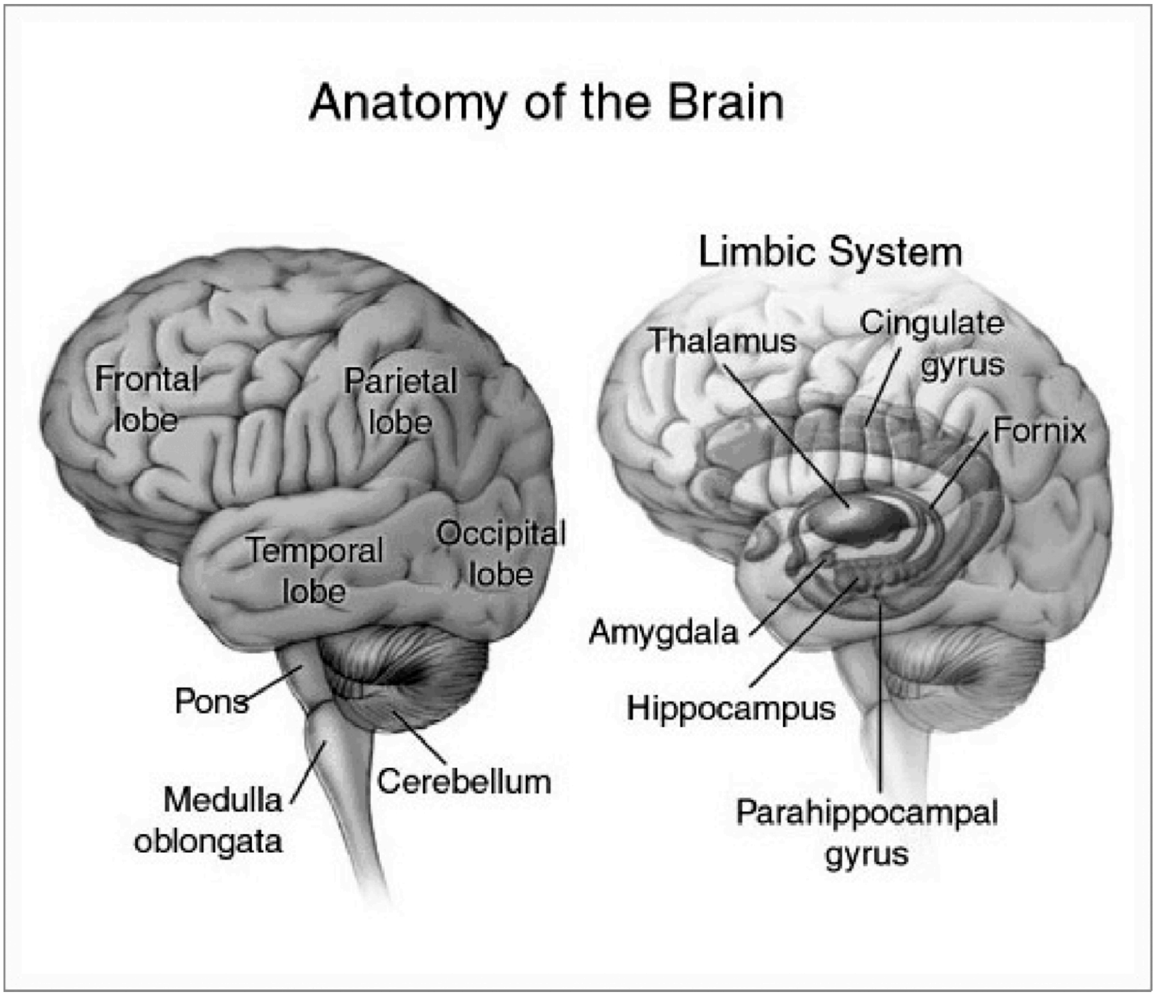


Figure A. The Anatomy of the Limbic System (Medical Illustration provided courtesy of Alzheimer's Disease Research, a program of American Health Assistance Foundation, © 2000-2010, http://www.ahaf.org/alzheimers/.)

Components of the Limbic System

Amygdala

Hippocampus

Fornix

Thalamus

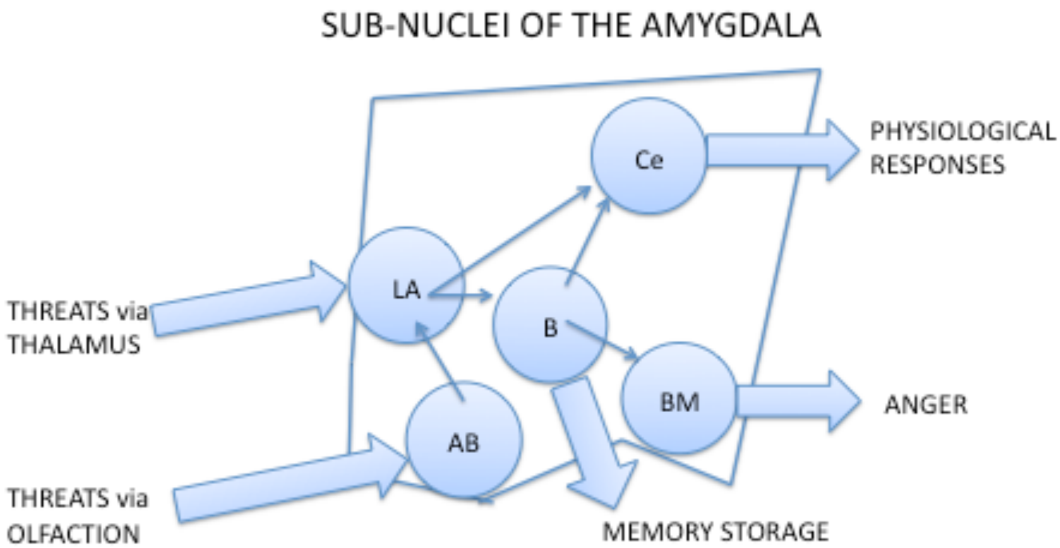
Cingulate gyrus
Hypothalamus
Frontal lobe
Olfactory bulb

The **amygdala** is the key player in the limbic system. It has connections to other limbic structures and to other areas traditionally not considered to be a component of this group. The amygdala (a complex grouping of sub-nuclei that perform different functions) is critical for generating the emotional and physiological response to these stimuli. It modulates the storing and subsequent retrieval of the narrative as well as the event's autonomic and somatic components. This is accomplished through powerful reciprocal pathways between the amygdala and the **hippocampus**. The hippocampus is involved with memory storage and retrieval. The hippocampus and the amygdala connect to **fornix,** which then connects to the mammillary bodies. These in turn send signals to the thalamus that are involved with the recognition of a stored memory, specifically smell. The **fornix** also connects to septal nuclei, areas of the brain involved with pleasure and reward.

The **cingulate gyrus** connects to the amygdala and regulates our emotional reaction to pain and aggressive behavior. It is also important for attentiveness. The **parahippocampal gyrus** receives input from the cortex and is important for scene recognition and recall (the context). The **olfactory bulb** (not shown), unlike other senses, has a direct pathway amygdala. This provides for long distance sensing as early detection increases the number of escape options. The **frontal lobe**, while not belonging to the traditional limbic circuit, has intense bidirectional connections with the other limbic nuclei, most importantly the amygdala and the thalamus. The prefrontal cortex is, in essence, an inhibitor of our limbic system and is involved with the evaluative aspects of a threat. The **hypothalamus** (not shown)**,** which connects to the pituitary gland, is simultaneously activated during a threat and causes the release of the stress neurochemical cortisol, critical for encoding emotional information and preparing us for action.

We now know that fear is generated as a consequence of limbic activation. Aggressive behavior and rage are modulated by the limbic system as well. These two primitive emotional states, fear and rage, are associated with physiological changes that involve the viscera, the soma and the endocrine system. How does this occur?

Threatening stimuli (we call unconditioned threat stimuli, UTS) enter the thalamus through our senses and activate the **amygdala** (as mentioned earlier, smell can go directly to the amygdala) (Figure B). These UTS are innately hard-wired, that is, no learning is required.



LA is Lateral Nucleus / AB is Accessory Basal Nucleus / B is Basolateral Nucleus
BM is Basomedial Nucleus / Ce is Central Nucleus

Figure B

THE ROLE OF THE LIMBIC SYSTEM IN TRAUMATIZATION

The limbic system in humans is critically involved with the phenomenon of traumatization. Traumatization, the permanent encoding of a threatening event, leads to many somatic, behavioral, and cognitive disorders. These include phobias, panic, post-traumatic stress, somatization and chronic pain. Traumatization also increases the risk for other problems including substance abuse, depression, obesity and other disorders. How is trauma encoded and what is the neurobiology of its encoding?

All traumatization requires an intense emotional response associated with a permissive neurochemical landscape and perceived inescapability. At the onset of encoding, the thalamus receives sensory input that is associated with an unconditioned threat stimulus (UTS). The thalamus relays this to the lateral nucleus of the amygdala, where the pathways leading to the experience of an encoded trauma begin. The lateral amygdala (LA) projects to the basolateral (B) and central nucleus (Ce) activating the physiological response we call fear (See Figure B).

UTS/ Sensory Stimulus→ Thalamus→LA→B and Ce→Fear

The Ce amygdala connects directly to other non-limbic areas (see **Table 1**) enabling us to respond to a threat.

AMYGDALA CONNECTIONS

Brain Area	Response
Sympathetic plexus	Prepares us for Flight Or Fight
Nucleus Accumbens	Motivate us to Action
Ventral Tegmentum	Increases Salience
Locus Coeruleus	Increases Vigilance
Central Gray	Causes Freezing
Insula	Mediates Pain Perception

Table 1

The B is involved with the memory storage of the components of the encoded moment.

If a traumatization is encoded, the co-encoded sensory stimuli now behave as a UFS, activating a response pathway in the amygdala that recapitulates the original experience. This sensory stimulus causes the release of stress neurochemicals and the individual experiences some or all of the components present during the traumatizing event. Traumatization also prevents the prefrontal cortex from interfering with the response to associated stimuli and possibly allowing for the maintenance of the memory. On occasion some cognitive components involved with the trauma are not stored normally. This occurs under two conditions. First, when the hippocampus is not yet functional, generally felt to be before the age of four, the memories being stored in the dorsal striatum (considered by some to be part of the limbic system). Second, when an immensely huge biological response to an event causes hippocampal dysfunction. This leads to an aspect of traumatization called dissociation. Here a narrative is unavailable and abnormal retrieval of the event occurs in the form of nightmares, intrusive thoughts and flashbacks.

Traumatization cannot occur without a functional limbic system. Recent research by Harper and colleagues suggest that pathways involving glutamate AMPA receptors in the LA and B are activated during encoding and reactivation. An enzyme called phosphokinase M zeta maintains these glutamate receptors. It now appears that these glutamate receptors become subject to disruption when activated, providing a potential mechanism for disrupting an encoded event. In summary, under ordinary circumstance, the limbic system is used to protect us from predation. Under conditions of traumatization, an event appears to be encoded as an immutable engram, forever affecting our lives. To be able to de-encode this has the potential to mitigate much of human suffering.

Further Readings

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