Limbic system

The limbic system is a group of brain areas involved in *feeling emotions* such as fear, anger and happiness; *motivating* behaviours driven by primitive drives, such as aggression, pleasure-seeking and sexual urges; and even *learning* and *memory*. The Latin term 'limbus' is translated as 'edge' or 'border'. This system takes its name from the location of these regions, which are buried under the surface where the *edge* of the cerebrum (the largest part of the brain, split into two hemispheres) sits just above the brain stem.

Because the limbic system controls the basic emotions and urges which drive our behaviour, it is fundamental to survival. Dysfunction in any of these brain regions, or the connections between them, is believed to underlie the distress and difficulties suffered by individuals with psychiatric illnesses such as depression and anxiety. Abnormalities in the limbic system are also implicated in the symptoms of developmental disorders, such as autism. The main regions involved are introduced below before we return to consider the consequences of damage to the limbic system.

Key players of the limbic system

There is some disagreement about which brain structures are included in the limbic system but by popular consensus, it includes several structures in the cerebral cortex (such as the *cingulate gyrus* and the *hippocampus*) and the diencephalon (the *hypothalamus* and *thalamus*). It also includes some subcortical structures such as the *amygdala* and the *basal ganglia*.

Other brain regions, such as the *orbitofrontal cortex* and the *olfactory bulb*, also play an important role in motivation and emotion, and are sometimes considered to be part of the limbic system.

The amygdala

Located deep within the medial aspect of the temporal lobe, the amygdala plays a central role in decision-making and emotional responses. This is reflected in the wealth of its connections with other brain and limbic areas. Electrical stimulation of this area can produce uncontrollable bursts of fear, anxiety, sadness or aggression. The amygdala lends emotional colouring to our speech, and is believed to contribute to the recognition of emotions in others.

At the level of brain evolution, the amygdala is very old and arguably crucial for human survival. Damage to the amygdala prevents an individual from learning from unpleasant experiences (so-called 'fear conditioning'). If cell activity in the amygdala is disrupted or the structure is lesioned, humans and animals do not learn to avoid painful or dangerous stimuli.

The amygdala is also believed to alert us to potential dangers in our environment, diverting attention to detected threats. It triggers the fight or flight response through its inputs to the hypothalamus and the brain stem. A famous neuropsychological case-study, S. M., is totally unmoved by stimuli that most people would find extremely threatening. With severe bilateral damage to the amygdala, she has been dubbed “the woman without fear”.

For many years, the amygdala was specifically associated with fear. However, it is now believed to be responsive to a range of emotions, including positive ones. Disruption of the amygdala also prevents humans and animals from learning positive associations. Normally pleasant stimuli, like food, cease to be rewarding and to motivate behaviour.

The hippocampus

The hippocampus and surrounding areas are crucial for memory. One of the most famous cases in neuropsychology, a man known as H.M., experienced a catastrophic disability when he underwent bilateral removal of the hippocampus. The surgery successfully alleviated H.M.’s epilepsy but left him bereft of the ability to form new long-term memories. H.M. retained some memories from his past, which suggests that older memories may be less dependent on the hippocampus. His inability to lay down new memories, however, left him adrift in a perpetual moment of immediate consciousness, ungrounded by the hours, days or weeks preceding it.

The amygdala interacts with the hippocampus to give memories their ‘emotional flavour’. It also affects how memories are laid down, making emotional memories easier to recall. Memories laid down by the hippocampus also affect the amygdala: having heard about someone else’s painful experience with the dentist, you may feel anxious yourself when going.

In cases where the hippocampus is damaged but the amygdala is spared, people learn to associate stimuli with emotions such as fear – but they have no idea why they’re frightened.

Cingulate gyrus

The cingulate is a ‘belt’ *(cingulum)* of grey matter which surrounds the corpus callosum, the thick fibre tract which connects the two hemispheres. This large area is normally considered to have posterior and anterior aspects with differential roles, although these are still under investigation.

The anterior part of the cingulate is connected not only to many of the cortical regions involved in complex mental processes, but also to the amygdala, the nucleus accumbens and other nodes in the limbic system. In patients with treatment-resistant forms of depression or obsessive-compulsive disorder, severing the fibres of the anterior cingulate produces a remarkable reduction in distress and emotional reactivity. As the cingulate is also involved in interpreting and experiencing pain, this procedure may also be used to treat chronic pain when all else fails.

The hypothalamus and the thalamus

Located together in the part of the brain known as the diencephalon, the thalamus and the hypothalamus control and regulate many basic functions for supporting life.

The hypothalamus maintains the body in a state of homeostasis, regulating temperature, the sleep-wake cycle, sex drive, appetite and satiation. It controls the autonomic nervous system and thus is responsible for increasing heart rate and blood pressure if the fight or flight response is initiated by the amygdala. It also controls the endocrine (hormone) system, which influences mood and behaviour.

Like a kind of hub, the thalamus relays sensory (visual, auditory, tactile) and motor information to the cerebral cortex. It also regulates consciousness and sleep.

The basal ganglia

The basal ganglia are a group of subcortical structures, located at the base of the forebrain, which play a multitude of roles. The parts of the basal ganglia most strongly associated with emotion and motivation are the nucleus accumbens, the ventral pallidum and the ventral tegmental area. Rewarding (or reinforcing) behaviours, like eating, having sex or taking drugs, activate dopamine neurons in the ventral tegmental area. Dopamine is a neurotransmitter, a chemical messenger in the brain, and is central to this reward and pleasure pathway: these signals project to the nucleus accumbens and the behaviour is experienced as pleasurable.

The extended limbic system: orbitofrontal cortex and olfactory bulb

The orbitofrontal cortex, located immediately above the eyes, is crucial for decision making. Whilst the amygdala and the hippocampus appear to be important in learning emotional associations with stimuli, the orbitofrontal cortex controls behaviour so that these are taken into account. Patients with damage to orbitofrontal cortex have difficulty learning from the (negative) consequences of their behaviour. They struggle to inhibit their impulses and are often aggressive, hypersexual and socially inappropriate.

It may be unsurprising that smells can evoke powerful emotions and memories. Because of this, and its connections to the other regions of the limbic system, the olfactory bulb is sometimes included in this system.

The limbic system in disarray

As it regulates emotion, dysfunction in the limbic system causes extremely distressing symptoms. Problems with limbic brain regions appear to contribute to many psychiatric illnesses.

Phobias are an instance where the typical fight or flight response is hijacked. Perceiving a threat in harmless objects, the amygdala initiates a full-blown threat response – even if the phobic stimuli is only mentioned in conversation or seen in a picture. This dysfunction in the amygdala is impervious to rational thinking and so is beyond the control of sufferers. However, people can be helped to reduce their phobias in therapy, which results in normalising amygdala activity to the phobic object.

Abnormalities in the function of the anterior cingulate are common in several disorders, including depression, schizophrenia and post-traumatic stress disorder. The cingulate is also implicated in obsessive-compulsive disorder, as are the basal ganglia and the thalamus. In this condition, some researchers suggest that typical communication between the orbitofrontal cortex, the thalamus and the striatum (which includes the basal ganglia) breaks down, leaving behaviour distressingly out of control.

Many recreational drugs, like opiates, nicotine, amphetamines and cocaine, flood the brain's reward/pleasure circuitry (the basal ganglia, particularly the nucleus accumbens) with dopamine. These substances evoke 2-10 times the amount of dopamine activity evoked by food or sex – hence why they produce such euphoric feelings and are so addictive. The brain tries to adapt to such an influx of dopamine by reducing dopamine activity in the limbic system. Unfortunately this has the effect of reducing *any* feelings of pleasure, such that the addicted individual tries to bring their dopamine levels back to normal by taking the drug; no longer necessarily chasing a high, but just to try to feel OK.

The limbic system functions differently in some developmental disorders, too, notably those characterised with difficulties in social communication and emotion processing. Autism is characterised by abnormality in key limbic regions and in the connections between them. The amygdala has historically been of particular interest due to some of the similarities between people with autism and people with brain damage to this area. Whilst people with autism certainly experience fear, they can be less aware of potential dangers, less able to recognise emotions, and may show a lack of vocal or facial emotion themselves, much like sufferers of traumatic brain injury.

People with developmental and intellectual disorders often suffer from additional psychiatric illnesses. It can be difficult to determine whether abnormalities in the limbic system, in these cases, are a feature of the developmental/intellectual disorder itself, or a feature of a mental illness.

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See also:

Aggression, depression, obsessive-compulsive disorder, phobias, substance use, basal ganglia, cerebral cortex, cingulate gyrus, frontal lobes, hormones, neurotransmitters

Further reading:

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