DIVISIONS OF HUMAN FOREBRAIN

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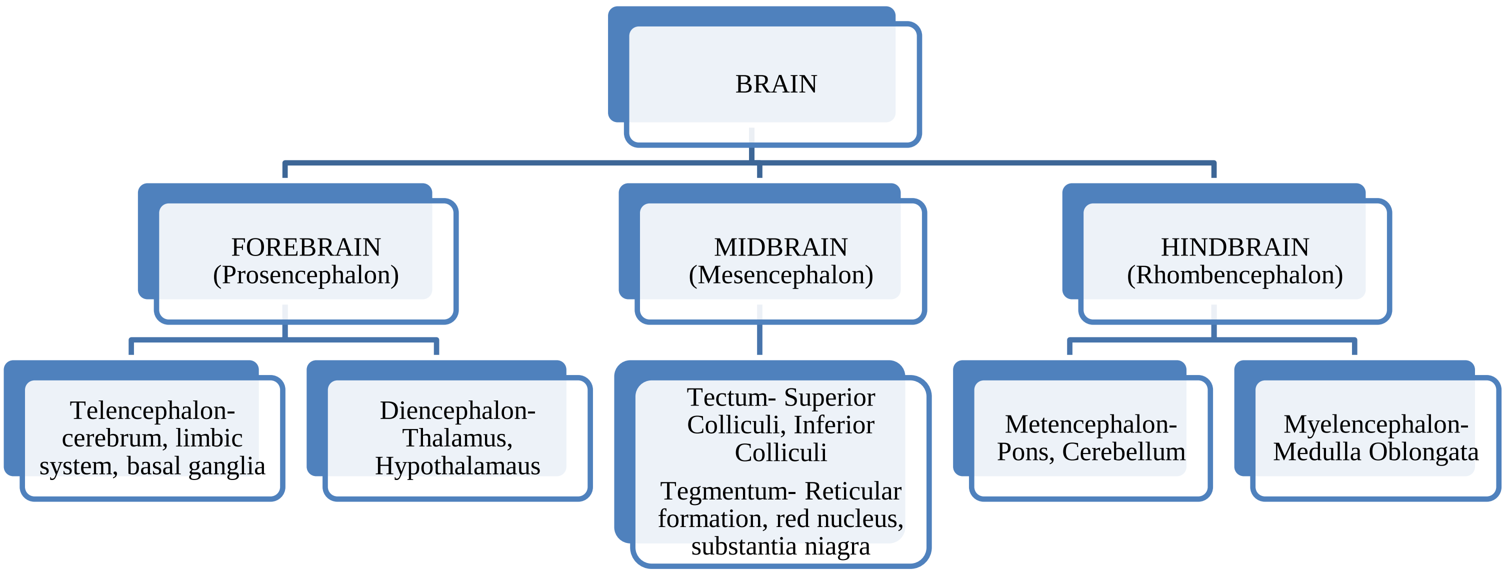
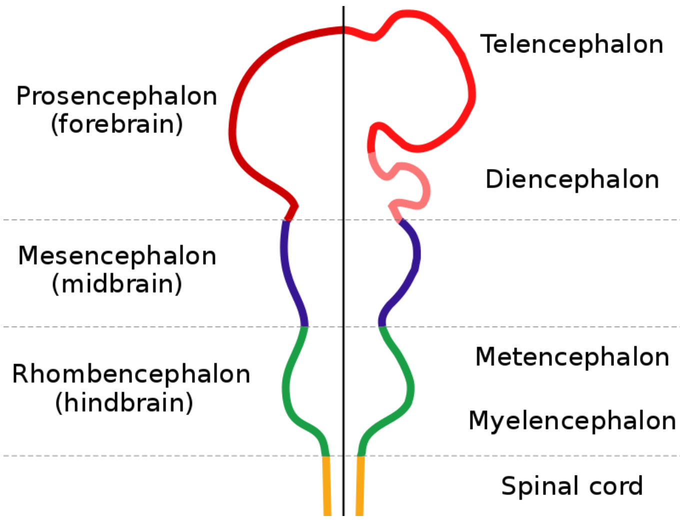


CLASSIFICATION OF BRAIN

Central nervous system consists of brain and spinal cord taken together which occupies the central axis of the body. The CNS developes from an infold of the outer layer of the embryo known as ectoderm immediately above the notochord. The infolding ectoderm form a dorsal, hollow, neural tube running the length of the organism, the first indication of the developing brain being three swellings that occur at the anterior end of this fluidfilled tube. These three swellings eventually develop into the forebrain,midbrain and hindbrain. Before birth, the initial 3 swellings in the neural tube become five because the forebrain grows into two more swellings. From anterior to posterior, the five swellings are:

1. Telencephalon
2. Diencephalon
3. Mesencephalon (Midbrain)
4. Metencephlon
5. Myelencephalon.



ANATOMY OF THE DEVELOPING BRAIN

TELENCEPHALON : CEREBRUM, LIMBIC SYSTEM AND BASAL GANGLIA

1. CEREBRUM

The cerebrum (4/5th of the brain weight) is divided into two cerebral hemispheres covered by a film of tissue known as cerebral tissue. The surface of the cerebrum is deeply convoluted (to increase overall volume and enable greater accomodation of neurons). The rich convolutions are marked by ridges called *gyri* (singular: gyrus) and depressions called *sulci* (singular: sulcus) and paticularly serve as convenient landmarks for dsitinguishing subdivisions of the cerebral lobes. The cerebral hemispheres are divided by a deep fissure called *longitudinal fissure* and connected by a sheet of nerve fibres called *corpus callosum*.

Each cerebral hemisphere is further divided into lobes namely *frontal lobe*, *parietal lobe*, *temporal lobe* and *occipital lobe* and *insula*. A *central fissure* demarcates the frontal lobe from parietal lobe, a *parieto-occippital fissure* demarcates the parietal lobe from ocipital lobe and a *sylvian fissure* sets the temporal lobe apart from the frontal and parietal lobes. The cerebral cortex is the highest centre for many sensations and functions. The cerebral hemsipheres enclose the four interconnected cavity called *ventricles* which produces the cerebrospinal fluid for transmission of nerve impulses. It also has the *primary sensory areas* that are important regions of reception of sensory information. However, the perception, integration and storage of sensory information are accomplished by the *sensory association cortex*. Similarly, the *primary motor cortex* (premotor cortex) is involved in strategic planning of movements and the *motor association cortex* controls behaviour.

Neocortex (new layers in evolutionary context) forms the six layered surface of the different lobes of the brain while *Allocortex* forms the four layered surface of the hippocampus and olfactory system in the sub-cortical region.

Functions of cerebrum:

1. Cerebrum is the seat of **highest intellectual faculties** governing mental tasks like thinking, reasoning, decision making, learning, memory and controls will, emotion and speech. It is also the seat of consciousness and self-awareness.

2. A widely accepted theory regarding the function of the brain's prefrontal cortex is that it serves as a store of **short-term memory**. This idea was first formulated by Jacobsen, who reported in 1936 that damage to the primate prefrontal cortex caused short-term memory deficits. Once the concept of **working memory** was established in contemporary neuroscience by Alan Baddeley (1986), these neuropsychological findings contributed to the theory that the prefrontal cortex has an integral role in working memory.

3. Speech and language are mainly attributed to the parts of the cerebral cortex. **Wernicke's area** is involved in the comprehension of written and spoken language in contrast to **Broca's area** that is involved in the motor production of language. Damage to the Broca's area results in expressive aphasia (telegraphic speech) while damage to Wernicke's area results in receptive aphasia (fluent but not meaningful).

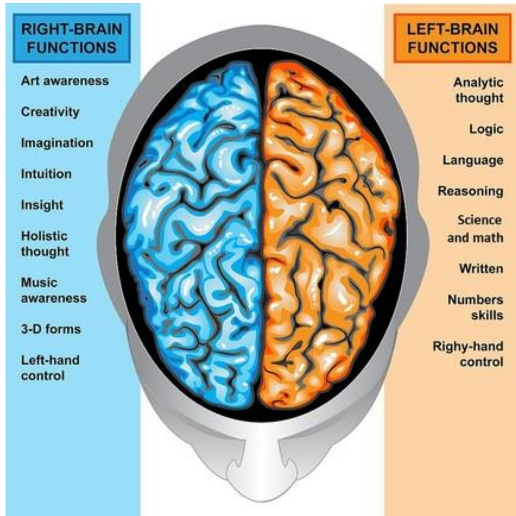
4. The olfactory bulb, responsible for the sense of smell, takes up a large area of the cerebrum in most vertebrates. However, in humans, this part of the brain is much smaller and lies underneath the frontal lobe. Damage to the olfactory bulb results in a loss of olfaction (the sense of smell).

5. The cerebrum directs the conscious or volitional motor functions of the body. These functions originate within the primary motor cortex and other frontal lobe motor areas where actions are planned.

FRONTAL LOBE

The frontal lobes are considered our emotional control centre. There is no other part of the brain where lesions can cause such a wide variety of symptoms (Kolb & Wishaw, 1990). The frontal lobes are involved in motor function, problem solving, spontaneity, memory, language, initiation, judgment, impulse control, and social and sexual behaviour.

There are important asymmetrical differences in the frontal lobes. The left frontal lobe is involved in controlling language related movement, whereas the right frontal lobe plays a role in non-verbal abilities.



BRAIN LATERALIZATION

Disturbance of motor function is typically characterized by loss of fine movements and strength of the arms, hands and fingers (Kuypers, 1981). Complex chains of motor movement also seem to be controlled by the frontal lobes (Leonard et al., 1988). Patients with frontal lobe damage exhibit little spontaneous facial expression, which points to the role of the frontal lobes in facial expression (Kolb & Milner, 1981). Broca's Aphasia, or difficulty in speaking, has been associated with frontal damage by Brown (1972).

An interesting phenomenon of frontal lobe damage is the insignificant effect it can have on traditional IQ testing. Researchers believe that this may have to do with IQ tests typically assessing convergent rather than divergent thinking. Frontal lobe damage seems to have an impact on divergent thinking, or flexibility and problem solving ability. There is also evidence showing lingering interference with attention and memory even after good recovery from a traumatic brain injury (Stuss et al., 1985).

One of the most common characteristics of frontal lobe damage is difficulty in interpreting feedback from the environment. Perseverating on a response (Milner, 1964), risk taking, and non-compliance with rules (Miller, 1985), and impaired associated learning (using external cues to help guide behaviour) (Drewe, 1975) are a few examples of this type of deficit.

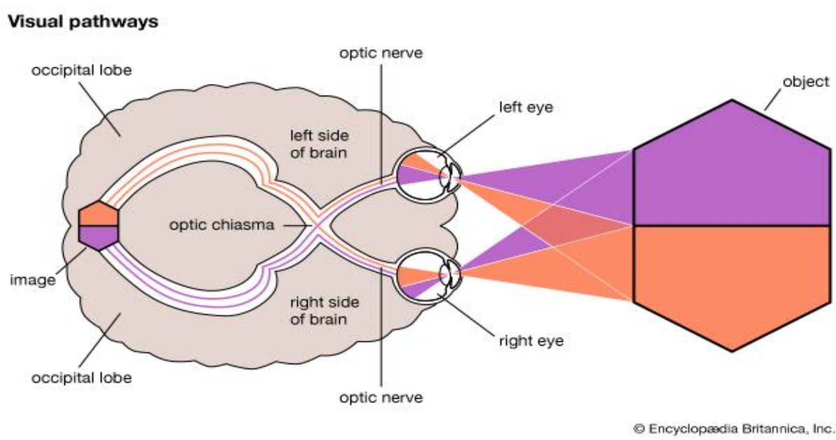
The frontal lobes are also thought to play a part in our spatial orientation, including our body's orientation in space (Semmes et al., 1963).

PARIETAL LOBE

It is forward of the occipital lobe and includes area that registers the sense of touch called primary somato-sensory area. The finer sensations of touch and temperature, sense of position and movements are regulated by this area. The cortex at the lower end of the somesthetic sensory area (tongue and face) is the area for taste. Lesions in this area are responsible for pricking sensations, pins and needles.

OCCIPITAL LOBE

It includes the cortical area where most visual signals are sent and visual processing is initiated. This area is called primary visual cortex. Axonal fibres leaving the back of each eye from the optic nerve travel to the optic chiasm and cross over to project to the opposite half of the brain. After reaching the optic chiasm, the nerve fibres diverge along two pathways. The main pathway projects into thalamus. After initial cortical processing of visual input takes place, signals maybe shuttled to the temporal and parietal lobes for additional processing. The second visual pathway from the optic chiasm branches off to an area in the midbrain called superior colliculus before travelling through thalamus and occipital lobe.



PROCESS OF VISUAL SENSATION

TEMPORAL LOBE

The temporal lobe is involved in primary auditory perception, such as hearing, and holds the primary auditory cortex. The primary auditory cortex receives sensory information from the ears and secondary areas process the information into meaningful units such as speech and words. The superior temporal gyrus includes an area where auditory signals from the cochlea first reach the cerebral cortex. It is important for the processing of semantics in both speech and vision in humans. Wernicke's area, which spans the region between temporal and parietal lobes, plays a key role (in tandem with Broca's area in the frontal lobe) in speech comprehension. The areas associated with vision in the temporal lobe interpret the meaning of visual stimuli and establish object recognition. Lesion of this lobe may result in disturbances of speech (aphasia), auditory disorders, disturbances in smell and taste, feeling of unreality and auditory hallucinations.

These are the four major parts of the cerebral cortex controlling and regulating sensations and behaviours in human physiology.

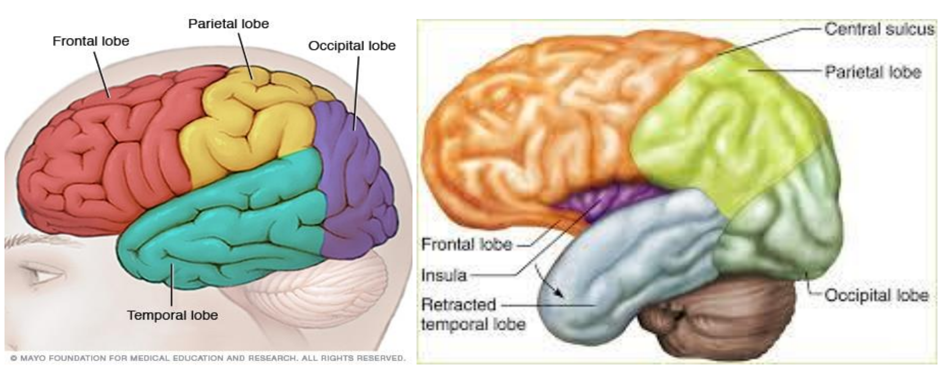
INSULA

The insular cortex is a portion of the cerebral cortex folded deep within the lateral sulcus (the fissure separating the temporal lobe from the parietal and frontal lobes). The insulae are believed to be involved in consciousness and play a role in diverse functions usually linked to emotion or the regulation of the body's homeostasis. These functions include perception, motor control, self-awareness, cognitive functioning, and interpersonal experience.

The anterior insula processes a person's sense of disgust both to smells and to the sight of contamination and mutilation — even when just imagining the experience.

The insula is active during social decision making. Tiziana Quarto et al. (2016) measured emotional intelligence (EI) (the ability to identify, regulate, and process emotions of themselves and of others) of sixty-three healthy subjects. Using fMRI EI was measured in correlation with left insular activity. The subjects were shown various pictures of facial expressions and tasked with deciding to approach or avoid the person in the picture. The results of the social decision task yielded that individuals with high EI scores had left insular activation when processing fearful faces. Individuals with low EI scores had left insular activation when processing angry faces.[58]

The insular cortex, in particular its most anterior portion, is considered a limbic-related cortex. The insula has increasingly become the focus of attention for its role in body representation and subjective emotional experience. In particular, Antonio Damasio has proposed that this region plays a role in mapping visceral states that are associated with emotional experience, giving rise to conscious feelings. In terms of function, the insula is believed to process convergent information to produce an emotionally relevant context for sensory experience.



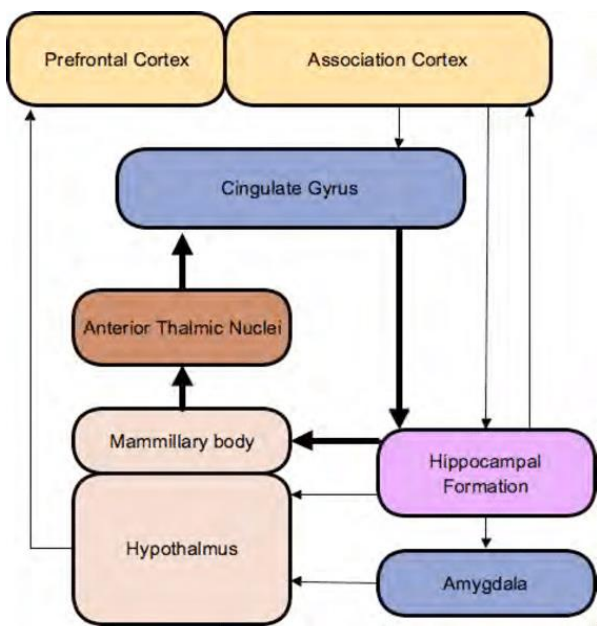
POSITION OF LOBES OF THE BRAIN (with and without INSULA)

2. LIMBIC SYSTEM

According to a theory proposed by Papez (1937), a neural circuit (named after Papez) made up of some interconnected structures is present at the sub-cortical part of the brain for the expression of emotions. This was later revised by Paul MacLean who coined the term limbic system. This system comprises of the following important structures:

(a) *Hippocampus*- A brain component playing important role in memory consolidation and storage.
(b) *Amygdala* – A cluster of nuclei playing a role in processing of memory and emotional responses.
(c) *Fornix* – A bundle of axons connecting the hippocampus with other brain regions
(d) *Mammillary bodies* – Small round bodies connecting to the hypothalamus and having a role in storage of episodic memory.
(e) *Septum*: This region of the limbic system receives information from the olfactory bulbs, the hippocampus and the reticular formation, sending the altered signals to the hypothalamus, hippocampus, and amygdala. The septal region may be involved in controlling maternal behaviours.

Damage to any component of the Papez circuit can directly result in memory disorders like Alzheimer's, Parkinson's disease, Semantic dementia, Korsakoff syndrome and Transient Global Amnesia.



SIMPLIFIED DEMONSTRATION OF PAPEZ CIRCUIT

3. BASAL GANLGLIA

The basal ganglia are a group of structures found deep within the cerebral hemispheres. The structures generally included in the basal ganglia are the following:

(a) *dorsal striatum* consisting of the *putamen* (functions include motor planning, learning, and execution motor preparation, specifying amplitudes of movement and movement sequences) and *caudate nucleus* (integrates spatial information with motor behaviour formulation and helps in speed and accuracy of direction in movements)
(b) *globus pallidus* (involved in the regulation of movements that occur on the subconscious level; its inhibitory action balances the excitatory action of the cerebellum attaining smooth controlled movements)
(c) *red nucleus* (lower motor neurons controlling gait in vertebrates)
(d) *substantia nigra* in the midbrain
(e) *subthalamic nucleus* in the diencephalon.

The basal ganglia are most often linked to the initiation and execution of movements. One popular hypothesis suggests that the basal ganglia act to facilitate desired movements and inhibit unwanted and/or competing movements. Damage to basal ganglia results in tremors, jerks and poor balance. Parkinson's disease is most often clinically related to lesion in this region.

[Ref: Basal Ganglia 3-D tour: https://youtu.be/s-6sOscx8-E]

DIENCEPHALON – THALAMUS AND HYPOTHALAMUS

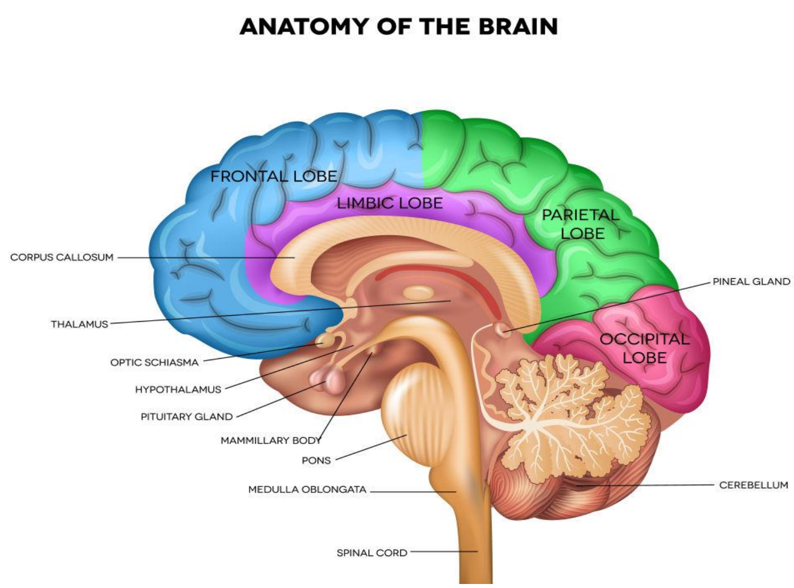
THALAMUS: It is the relay station of sensory impulses of the brain located in the dorsal part of diencephalon. It is crude centre of sensation and perception as every sensory region has a thalamic nucleus that receives sensory signals and then them to associated primary cortex. For the visual system, for example, inputs from the retina are sent to the lateral geniculate nucleus of the thalamus, which in turn projects to the visual cortex in the occipital lobe. Therefore, it is associated with integration of sensory and motor functions. The thalamus plays a major role in regulating arousal, the level of awareness, and activity (sleep and wakefulness). Damage to the thalamus can lead to permanent coma.

HYPOTHALAMUS: This is the part lying underneath the thalamus containing a number of nuclei that produce different hormones to link the nervous system to the endocrine system. These hormones stimulate or inhibit the secretion of hormones from the pituitary gland in the brain. Some of the most important hormones produced in the anterior region include:

- *Corticotropin-releasing hormone (CRH)* - CRH is involved in the body's response to both physical and emotional stress. It signals the pituitary gland to produce a hormone called adrenocorticotropic hormone (ACTH). ACTH triggers the production of cortisol, an important stress hormone.

- *Thyrotropin-releasing hormone (TRH)* - TRH production stimulates the pituitary gland to produce thyroid-stimulating hormone (TSH). TSH plays an important role in the function of many body parts, such as the heart, gastrointestinal tract, and muscles.
- *Gonadotropin-releasing hormone (GnRH)* **-** GnRH production causes the pituitary gland to produce important reproductive hormones, such as follicle-stimulating hormone (FSH) and luteinizing hormone (LH).
- *Oxytocin* -This hormone controls many important behaviors and emotions, such as sexual arousal, trust, recognition, and maternal behavior. It's also involved in some functions of the reproductive system, such as childbirth and lactation.
- *Vasopressin* **-**Also called antidiuretic hormone (ADH), this hormone regulates water levels in the body. When vasopressin is released, it signals the kidneys to absorb water.
- *Somatostatin* - Somatostatin works to stop the pituitary gland from releasing certain hormones, including growth hormones and thyroid-stimulating hormones.

The anterior region of the hypothalamus also helps in *homeostatic balance*. It regulates body temperature (thermoregulation), maintains circadian rhythms, sexual urges, thirst and appetite. These are physical and behavioural changes that occur on a daily cycle for basic survival. Hunger and fullness signals come from two nerve centres within the hypothalamus that help control eating behaviour: the *lateral hypothalamus* and the *ventromedial hypothalamus*. The lateral hypothalamus responds to any internal or external stimulation that causes hunger while the ventromedial hypothalamus sends signals indicating when to stop, thus regulating ones eating behaviour.



OVERLAY OF THE LOCATION OF THALAMUS AND HYPOTHALAMUS

[Ref: Neuroanatomy of Diencephalon https://youtu.be/5BvVjjs664w]