Mind, Brain & Behaviour 1
Behavioural Neuroscience

Structure and function of the human nervous system – Part 1

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Learning objectives

- Understand the terms denoting directions in the nervous system
- Describe the major divisions of the nervous system
- Understand the structure and function of the meninges, ventricles and cerebrospinal fluid
- Outline the mechanisms of neural migration in development of the cerebral cortex
- Describe the structure and function of the primary sensory and motor cortical regions

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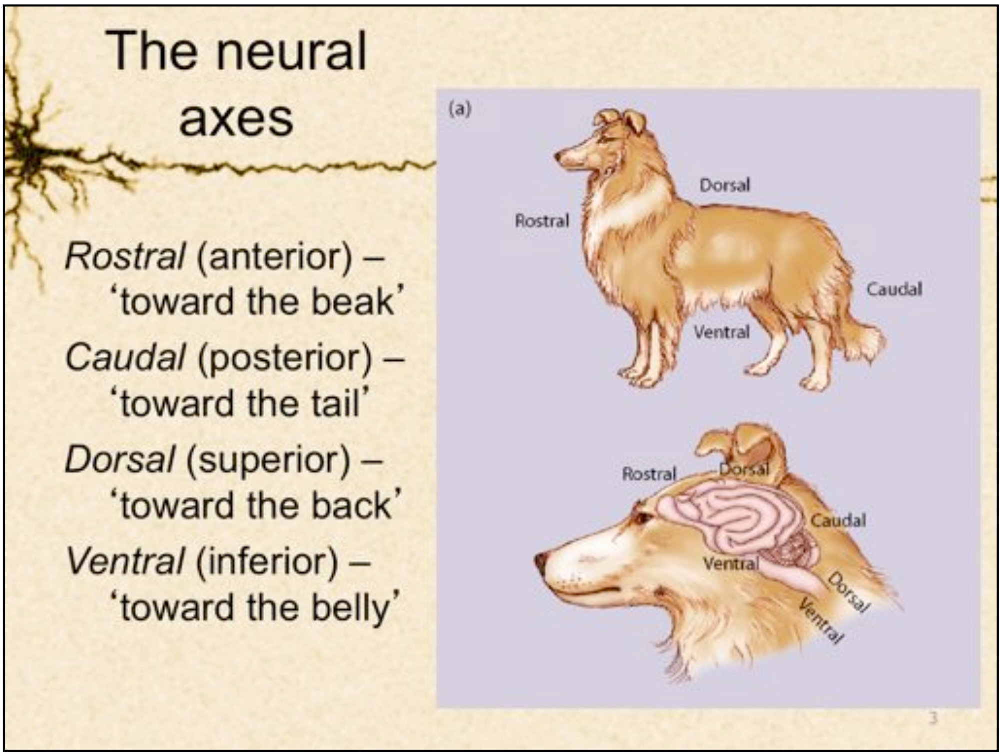
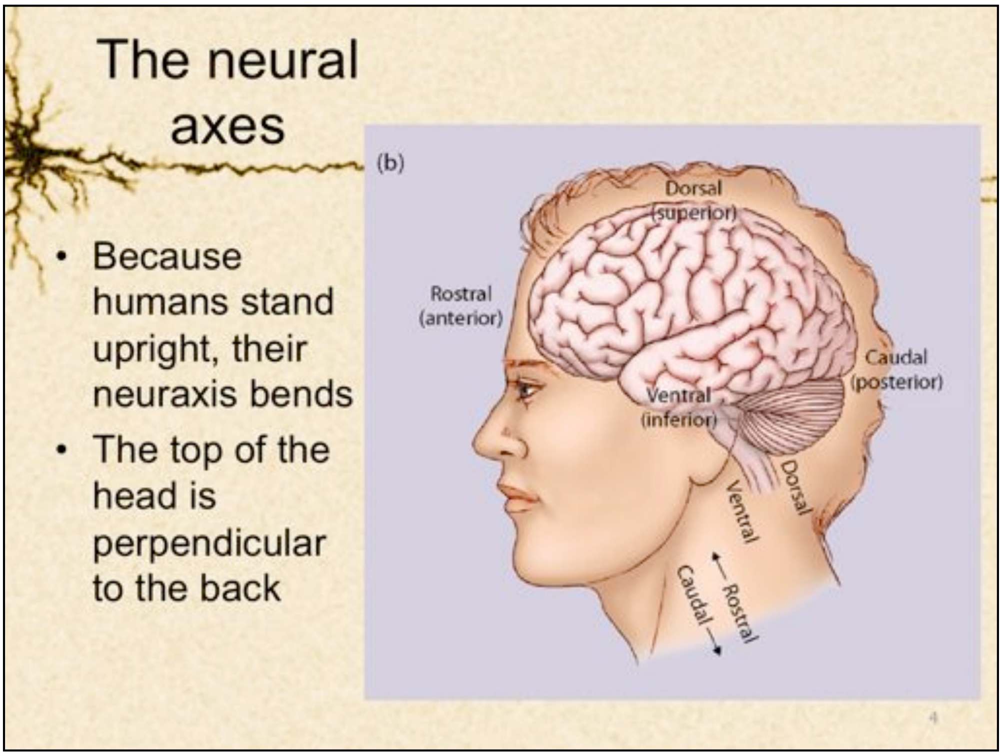


Terms denoting directions are used to locate structures within the nervous system. These directions are normally described in terms of the **neuraxis**, which is an imaginary line drawn through the spinal cord toward the front of the brain. It is easiest to begin with an animal that has a relatively straight neuraxis, as is the case for most four legged animals (e.g., dogs).

The key terms are as follows:

Rostral (anterior) – ‘toward the beak’
Caudal (posterior) – ‘toward the tail’
Dorsal (superior) – ‘toward the back’
Ventral (inferior) – ‘toward the belly’



In humans the neuraxis is slightly more complicated because it has a bend where the spinal cord meets the brain.

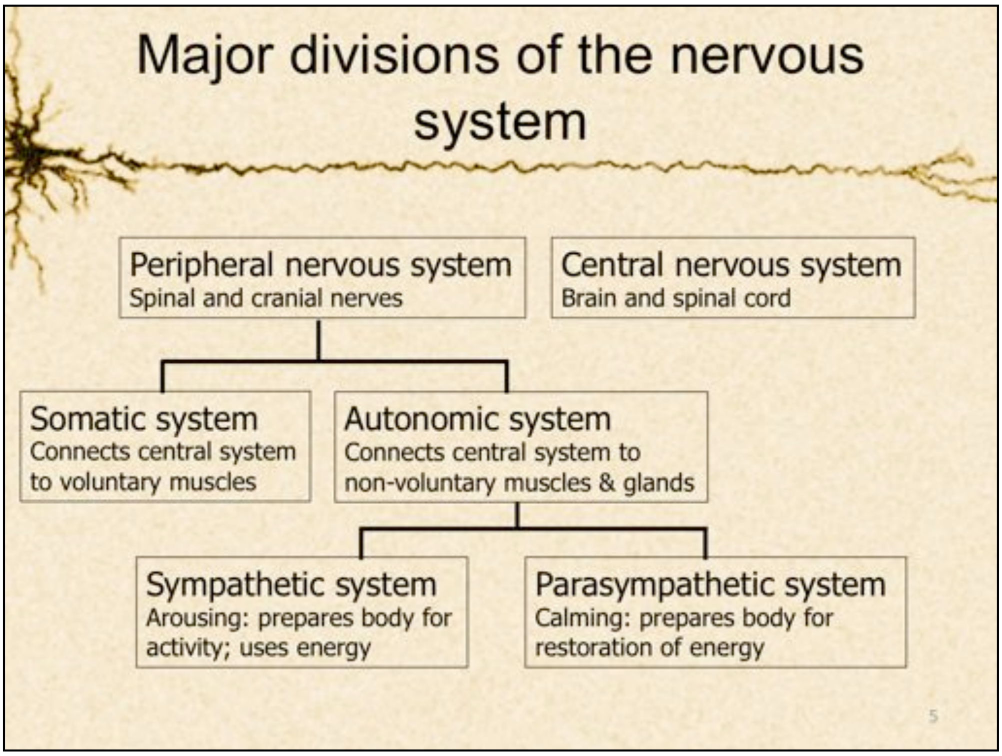
In addition to the terms just introduced, we can add four more that are important for defining positions of structures in the nervous system:

Lateral – toward the side

Medial - toward the midline

Ipsilateral – structures on the same side of the body (in Latin *ipse* means 'same')

Contralateral - structures on the opposite side of the body (in Latin *contra* means 'against')



The nervous system has two major divisions:

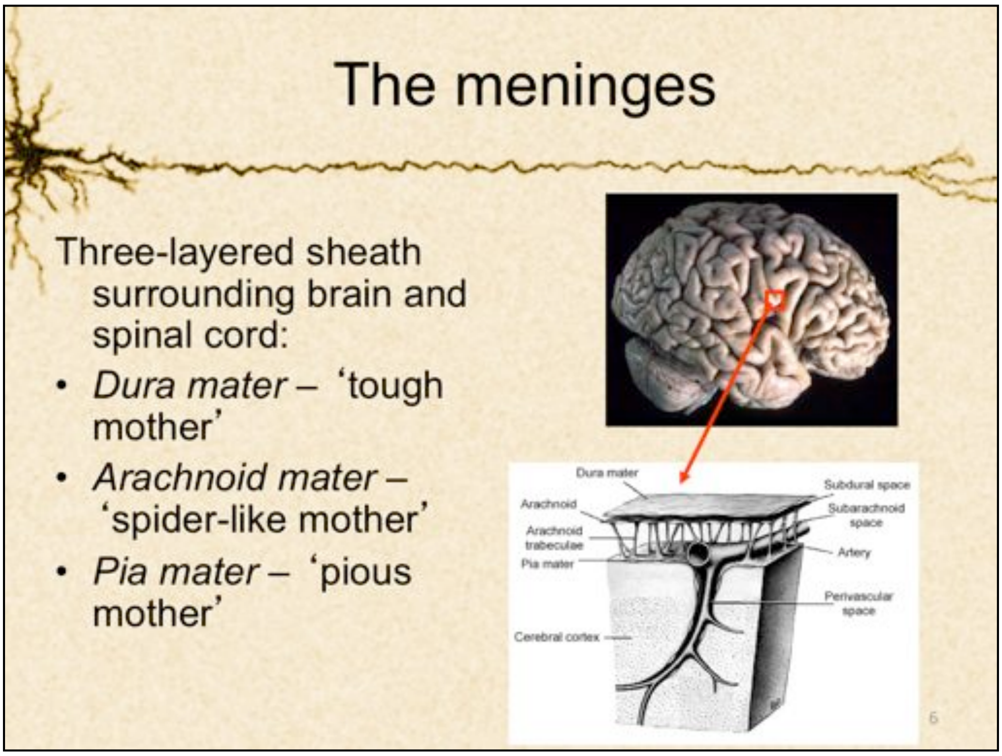
1) **Central nervous system** (CNS; includes the brain and spinal cord)
2) **Peripheral nervous system** (PNS; includes the cranial nerves, spinal nerves and peripheral ganglia)

The PNS is further divided into subcomponents:

The **somatic system** connects the CNS to voluntary muscles, whereas the **autonomic nervous system** connects the CNS to non-voluntary muscles and glands.

The autonomic nervous system is also subdivided into two systems that tend to operate in opposition:

1) **Sympathetic system** (arousing; prepares the body for activity and therefore expends energy)
2) **Parasympathetic system** (calming; prepares the body for restoration of



The entire nervous system (CNS and PNS) is covered by a protective sheath of connective tissue.

The protective sheaths around the brain and spinal cord are called the **meninges** (plural). In the CNS there are three layers:

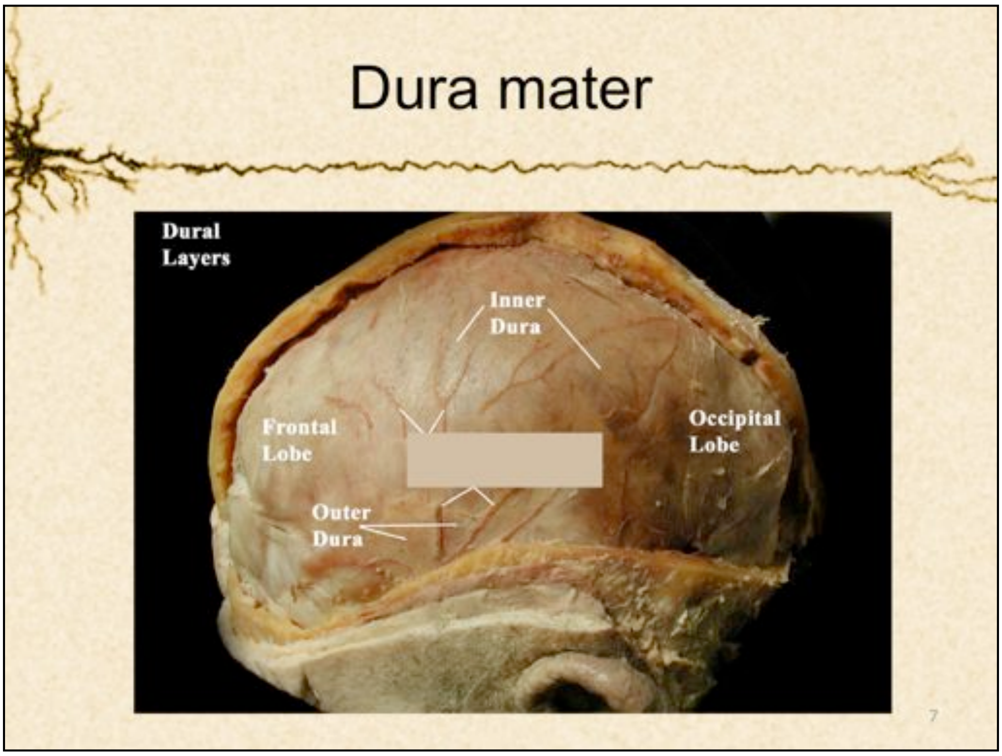
1) **Dura mater** ('tough mother') - the thick outer layer

2) **Arachnoid mater** ('spider-like mother') – the middle layer, which has a weblike appearance due to the protrusions called arachnoid trabeculae, and is soft and spongy.

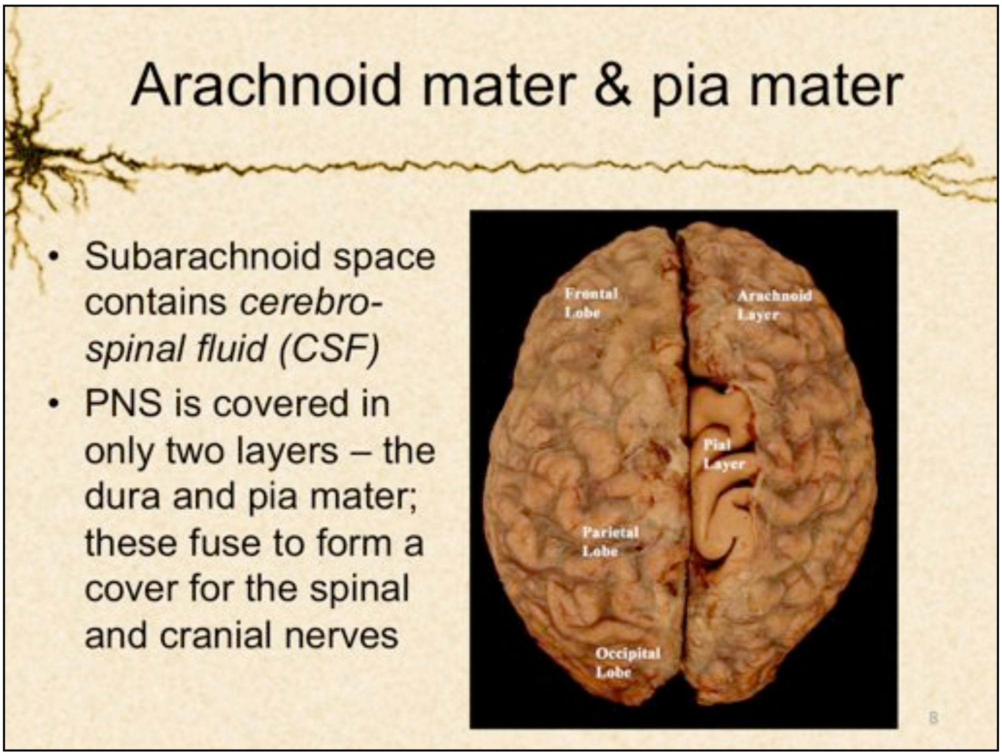
3) **Pia mater** ('pious mother') – delicate inner layer, which follows every fold of brain tissue.

Lying between the arachnoid mater and the pia mater is the **subarachnoid space**, which holds the fluid that bathes the brain and spinal cord, and which contains the main arteries that cover the surface of the brain and spinal cord.

Important note: The PNS has only **two** protective sheaths, the dura mater and



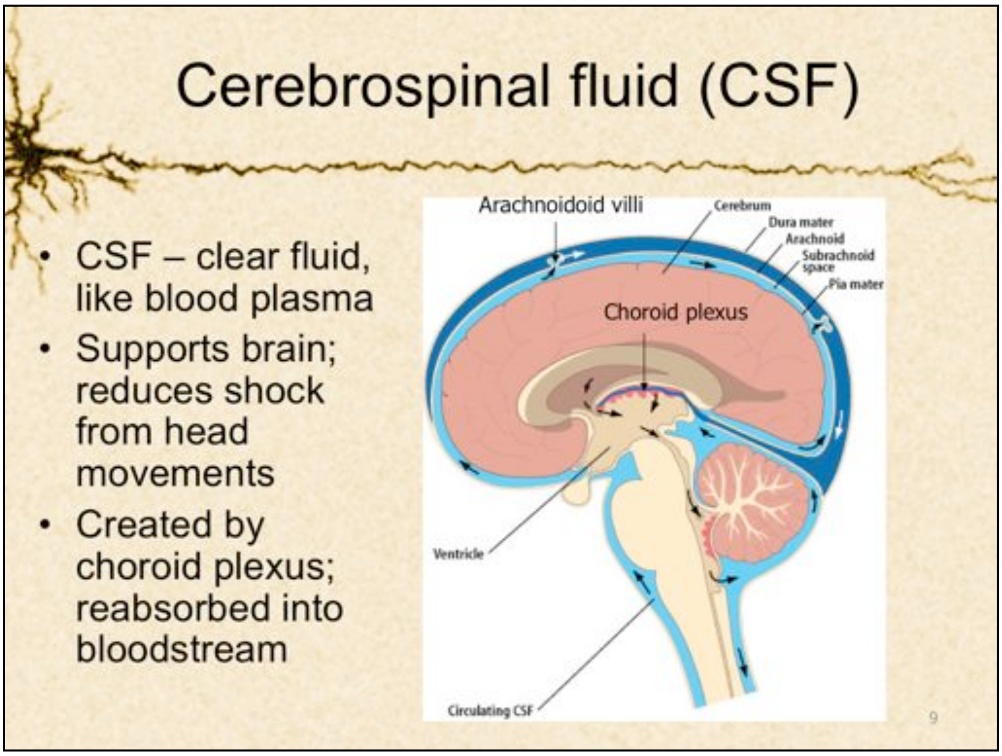
This skull dissection shows the **dura mater** (tough mother) beneath the skull, covering the brain beneath.



This brain dissection shows the **arachnoid mater** (spider-like mother) containing the major arteries that cover the surface of the brain.

A small region has been exposed to reveal the transparent **pia mater** beneath (in this photograph the covering is so thin and delicate it is invisible).

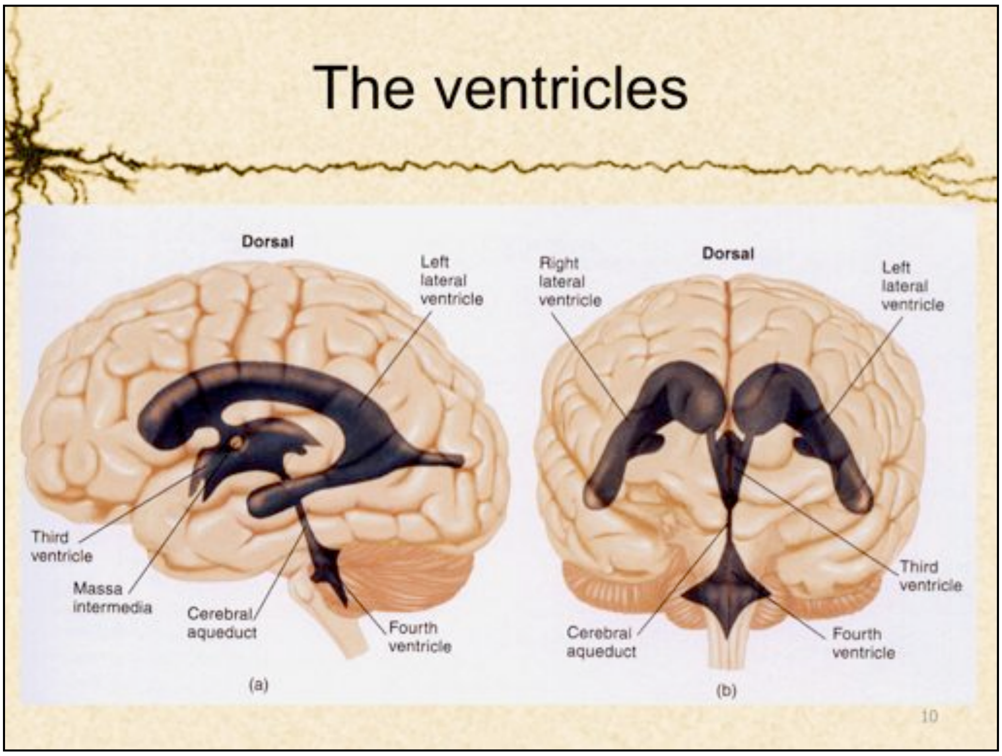
Neurological disorders such viral meningitis and meningococcal disease attack the meninges and impair the CNS.



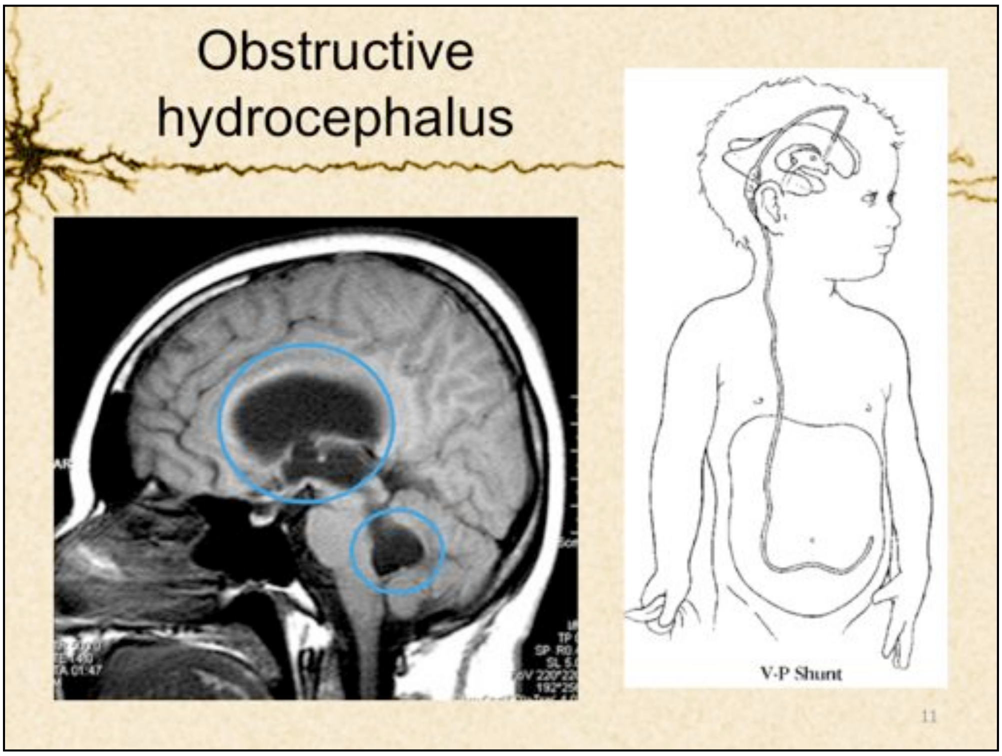
The brain is a bit like a jelly in a lunchbox. At an average weight of 1400 grams it needs to be supported inside the bony cavity of the skull. This is achieved by bathing the brain in a protective raft of fluid, called **cerebrospinal fluid (CSF)**. The CSF supports the brain, and reduces its net weight to about 80 grams.

CSF is a clear fluid similar to blood plasma. It resides in the subarachnoid space around the outside of the brain and spinal cord, and also fills the hollow, interconnected chambers inside the brain known as the **ventricles** (remember that many early philosophers and physicians, from Hippocrates through to Descartes, believed the ventricles were the seat of the mind).

CSF is produced by the **choroid plexus**, a structure rich in tiny blood vessels located in the **lateral ventricles** (there are two of these, one in each brain hemisphere). From the lateral ventricles CSF flows down to the **third ventricle**, then through the **cerebral aqueduct** to the **fourth ventricle**. From here it exits via a set of openings into the subarachnoid space, before being reabsorbed back into the bloodstream via the **arachnoid villae**.



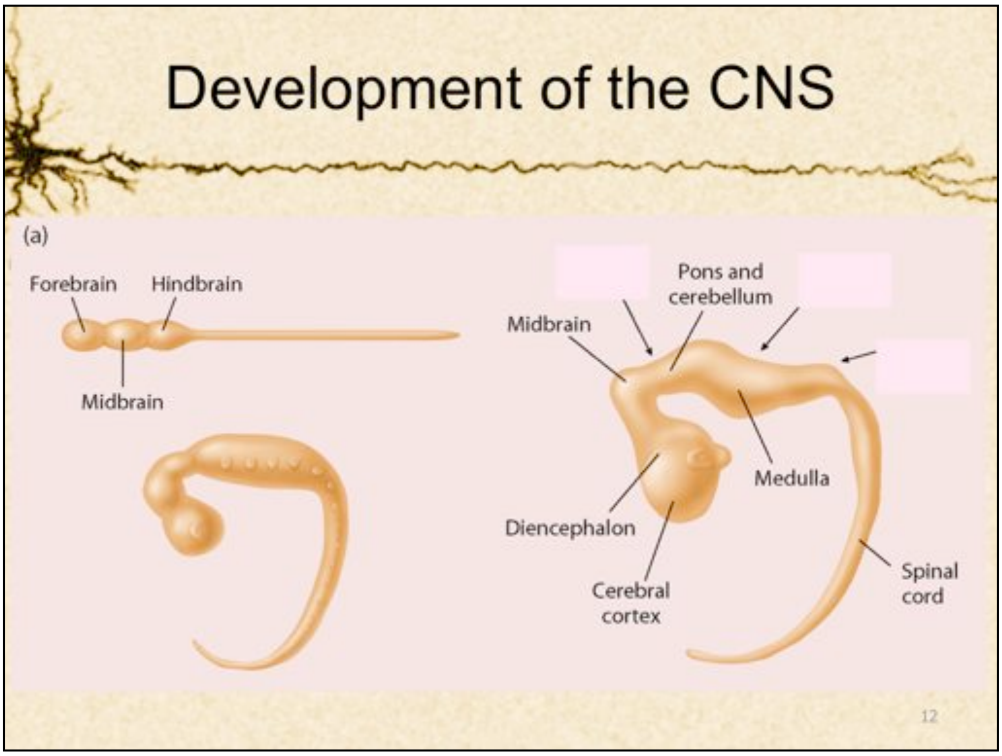
The ventricular system in the brain consists of a set of linked, fluid-filled chambers. The **lateral ventricles** are located within each hemisphere (one on each side). These are linked centrally with the **third ventricle**, which is located in the midline of the brain. A long tube called the **cerebral aqueduct** connect the third ventricle to the **fourth ventricle**, which sits immediately beneath the **cerebellum** (‘little brain’).



Occasionally the flow of CSF is blocked somewhere in its journey between the choroid plexus within the lateral ventricle and the arachnoid villi within the subarachnoid space which channel it back into the bloodstream.

Such blockages cause a condition called **hydrocephalus** ('water head'), in which CSF accumulates within the ventricles because it is not reabsorbed into the bloodstream. This raises pressure inside the skull, and can damage brain tissue and occlude arteries, leading to permanent (sometimes fatal) brain damage.

Hydrocephalus can be treated by inserting a ventriculo-peritoneal (VP) shunt. A hole is drilled in the skull (under anaesthesia of course!) and a fine tube is inserted into one of the ventricles. The tube runs beneath the skin, down into the person's abdominal cavity (the peritoneum), from where it can be reabsorbed into the bloodstream. When pressure starts to increase in the ventricles, a release valve in the tube opens and the excess CSF is allowed to flow out.



The nervous system begins to develop around 18 days after conception. The embryo begins as a plate of cells, whose edges form ridges that curl toward one another and fuse, forming a tube (the neural tube) that extends longitudinally from rostral to caudal.

At about 28 days after conception to neural tube has differentiated to form three interconnected chambers. These chambers are destined to become the ventricles, and the surrounding tissue will form the three main components of the adult brain: the **forebrain**, the **midbrain** and the **hindbrain**. The 'tail' connected to the hindbrain chamber will form the spinal cord.

Later in development the tissue of the forebrain, midbrain and hindbrain differentiate to form the precursors of the major structures present in the adult brain. The chamber of the forebrain divides to form the two lateral ventricles and the third ventricle. The chamber inside the midbrain narrows to form the cerebral aqueduct, and the chamber inside the hindbrain becomes the fourth ventricle.

Anatomical subdivisions of the brain

Major Division	Ventricle	Subdivision	Structures
Forebrain	Lateral	Telencephalon	Cerebral cortex
			Basal ganglia
			Limbic system
	Third	Diencephalon	Thalamus
			Hypothalamus
Midbrain	Cerebral aqueduct	Mesencephalon	Tectum/Tegmentum
Hindbrain	Fourth	Metencephalon	Cerebellum
			Pons
		Myelencephalon	Medulla oblongata

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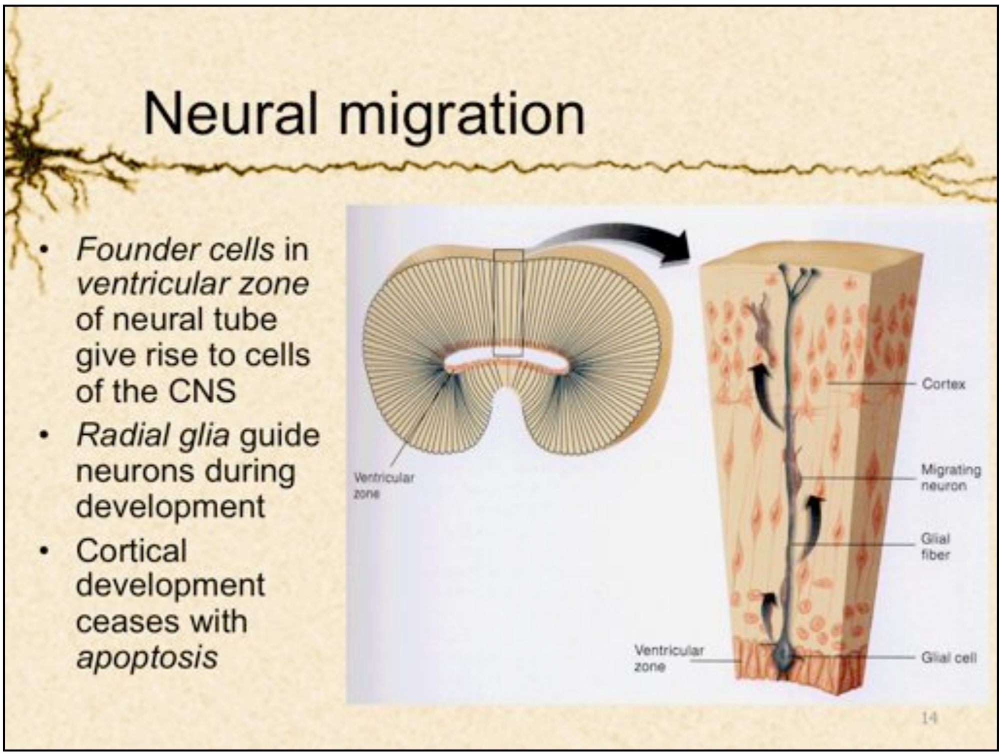
All of the major structures of the brain can be associated with one of the three early precursors, the forebrain, midbrain and hindbrain. As mentioned earlier each of the precursors consists of a hollow chamber that will eventually form one of the ventricles. In the fully formed brain there are five major subdivisions: **telencephalon**, **diencephalon**, **mesencephalon**, **metencephalon** and **myelencephalon** (the word *cephalo* means brain), and the prefixes denote positions (e.g., telencephalon means 'end brain', because it is at the rostral end of the neural tube). In this lecture and throughout this lecture series we will typically refer to structures by their common names (e.g., the cerebral cortex), but it can be helpful to remember what subdivision of the brain the structure belongs to.

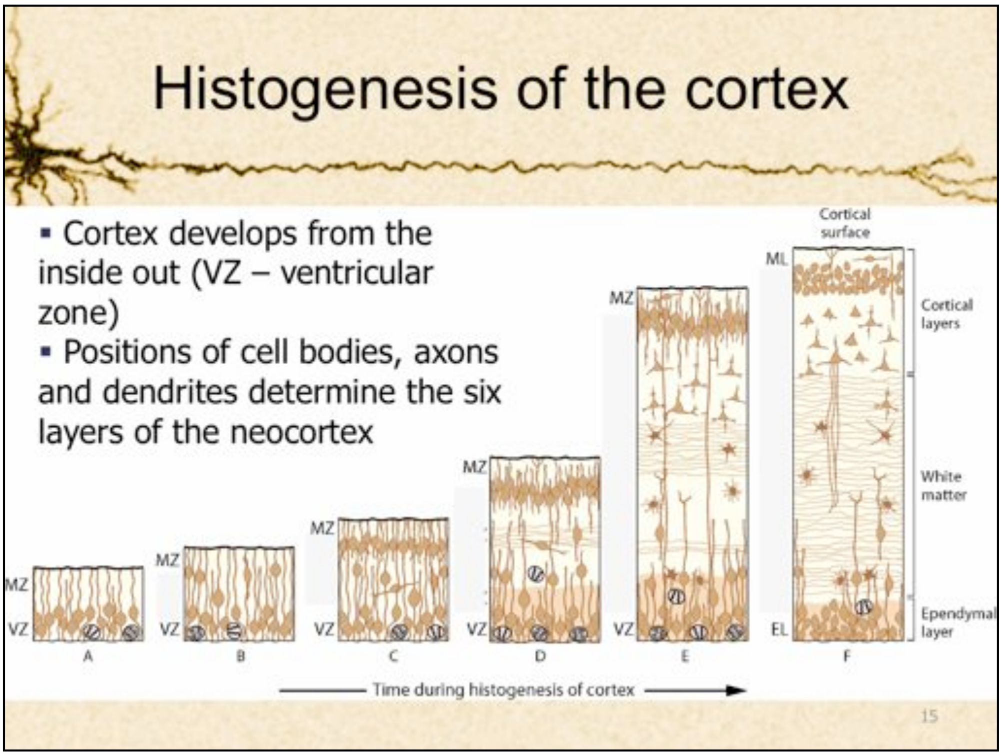


How does a structure that begins as a tiny hollow tube grow to become the most complex structure in the known universe? Scientists are only beginning to understand the complexities of neural development, but some of the general principles are known.

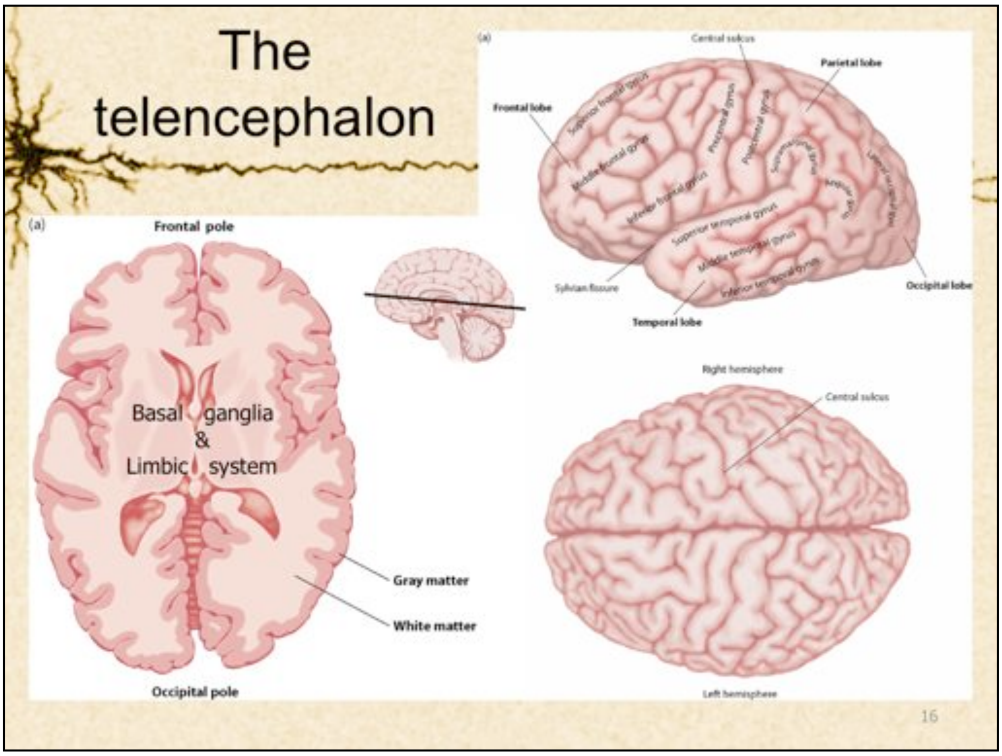
Those cells that line the inside of the neural tube – a region known as the **ventricular zone** - give rise to the cells of the nervous system. These precursor cells are called **founder cells**, and they can become either neurons or glial cells. Founder cells divide and migrate away from the centre of the tube toward the periphery.

Here we shall consider development of the important outer layer of the brain, called the **cerebral cortex**. This structure develops from the inside out. The first cells to grow out from the ventricular zone travel only a small distance and establish the first layer of the cortex. The next cells grow through the first layer to form a second layer, and so on until six layers have been created.

How do neurons know where to migrate to in the developing brain? They are guided by a special type of glial cell called **radial glia**. These cells extend fibres outward from the ventricular zone, and their cuplike endings attach to



The positions to which different types of neurons migrate during development determines the layered structure of the mature cortex. The layers are defined by the **types of cells** in them and by the **structures** of the neurons that are present (e.g., cell bodies, axons). The mature neocortex in humans consists of six distinct layers.

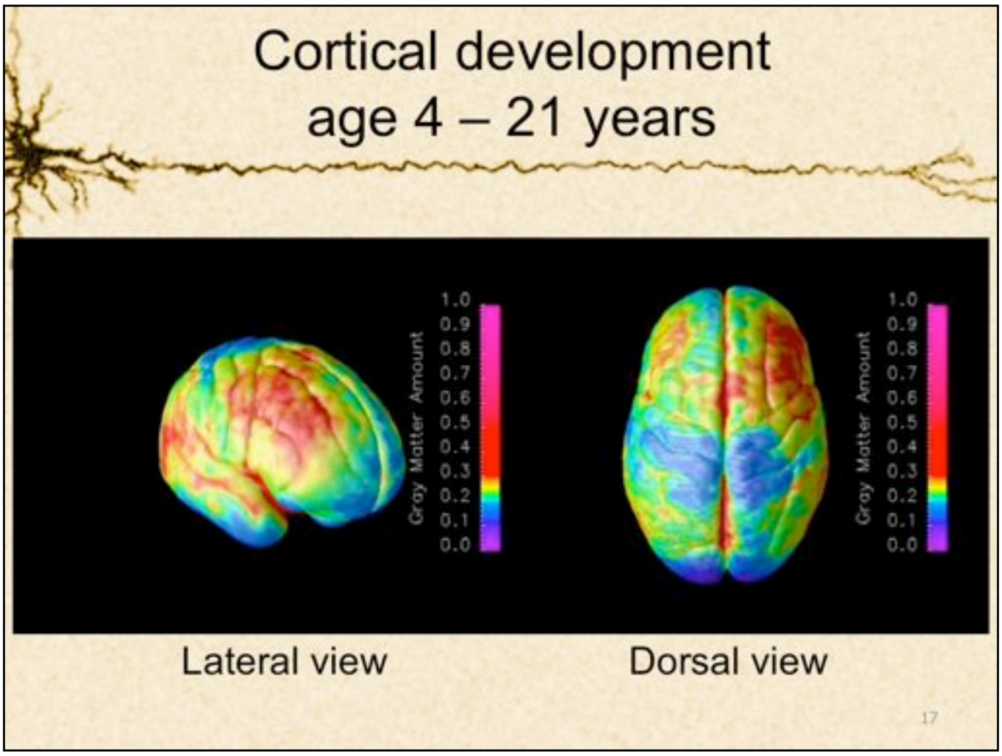


The forebrain has two subdivisions, the telencephalon and the diencephalon. We shall first consider the important features of the telencephalon.

The telencephalon is composed of the two **cerebral hemispheres**, which together form the **cerebrum**. The hemispheres comprise an outer layer called the **cortex** (‘bark’), and an inner (subcortical) region that contains the **basal ganglia** and **limbic system**.

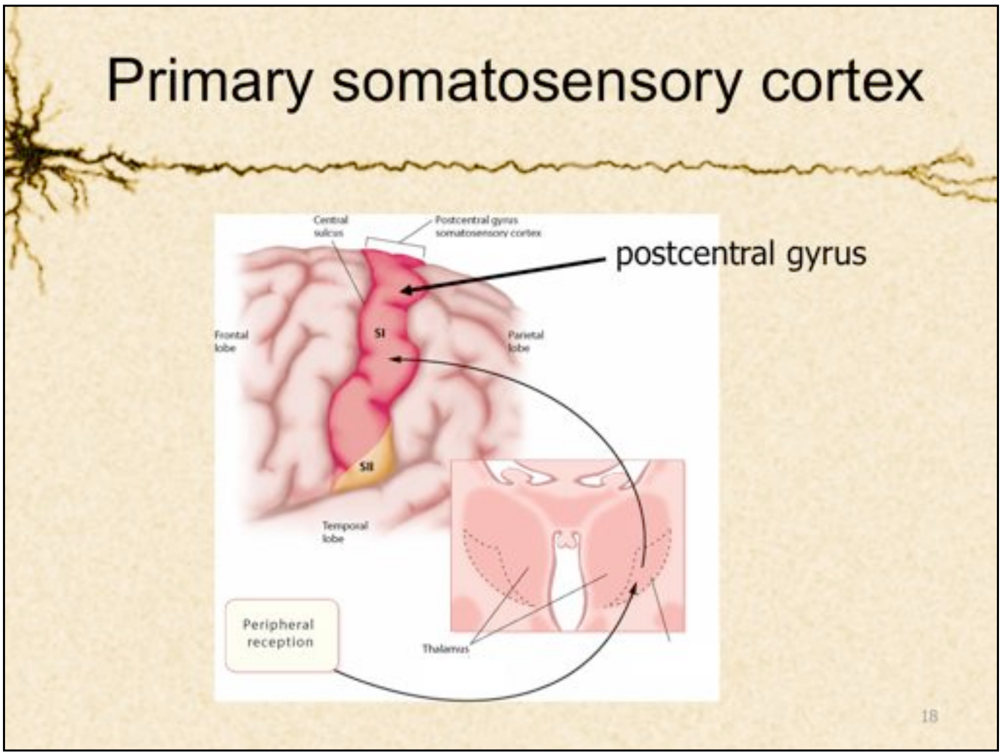
In humans the cerebral cortex is highly convoluted (folded). It is characterised by large, deep grooves called **fissures**, smaller grooves called **sulci** (singular: **sulcus**), and bulging regions of tissue between the folds called **gyri** (singular: **gyrus**). The convolutions of the cerebral cortex allow a large amount of tissue to fit into a relatively small space (the cranial cavity). The cortex consists predominantly of the cell bodies and associated dendrites of neurons, together with the supporting glial cells. This region, which is around 3 mm thick, is sometimes called the **grey matter**, because of its greyish-brown appearance.

Beneath the cortex run the axons of the neurons of the cortex, which connect these cells to those located elsewhere in the brain. The axons are covered in

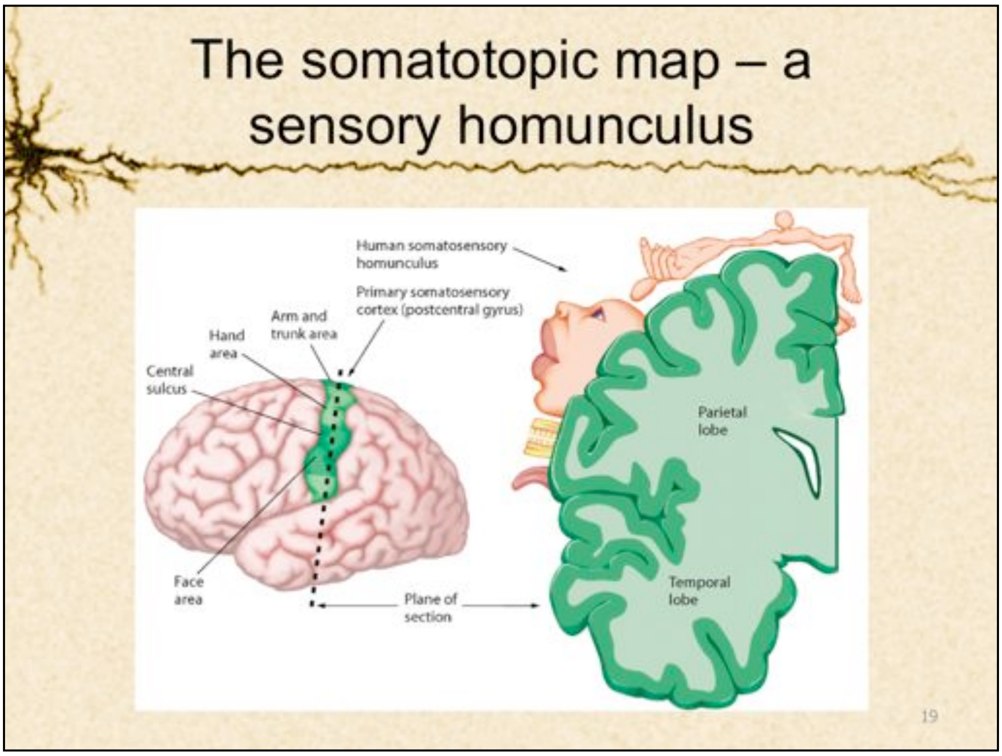


Once neurons reach their destinations they begin to form connections with other neurons. Many more neurons are produced during development than are needed, and so those that have been created must compete to exist (some have called this 'neural Darwinism' because the process resembles the process of natural selection). Only those neurons whose axon makes contact with another neuron will survive; they receive a chemical message from the postsynaptic cell that keeps them alive. Those neurons (around 50% of the total) that do not form synapses with another cell do not receive this message and so die by apoptosis. Although this seems like a wasteful strategy, it seems to be a safer strategy than trying to create exactly the right number of neurons during development.

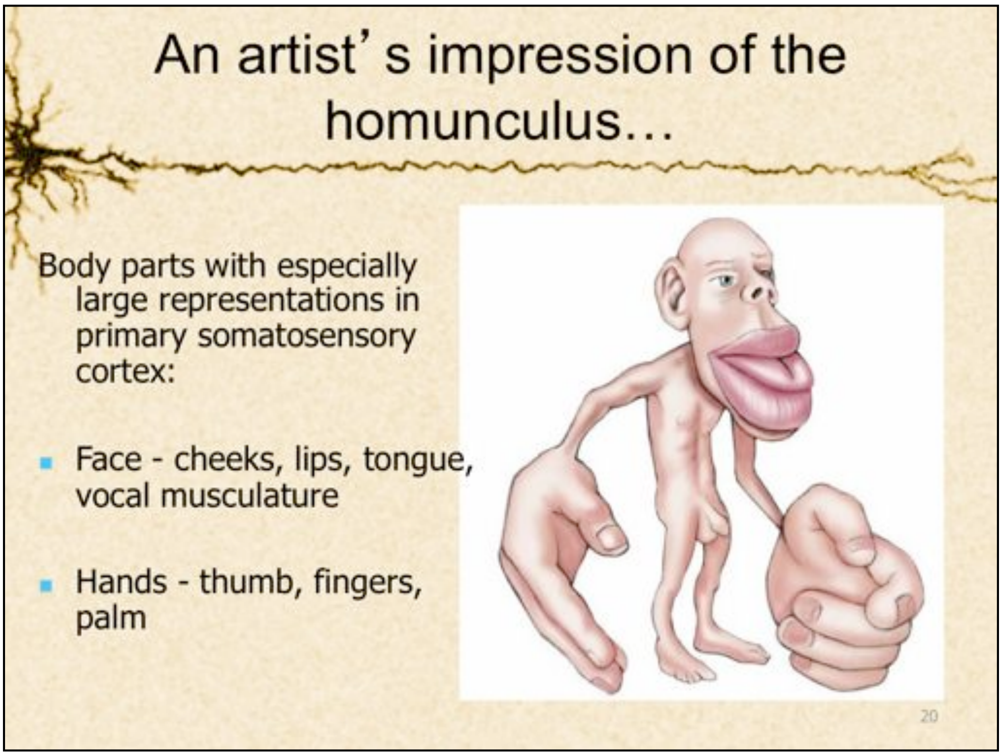
These animations illustrate the pattern of cortical development as it occurs between the ages of 4 and 21 years. Yellow and red colouration represents relatively 'immature' areas of the cortex, whereas blue and purple colouration represents more 'mature' areas. Note that some areas reach a mature state relatively early in life: these include the primary motor area (responsible for controlling body movement), the primary somatosensory area (responsible for our skin senses of touch, pain and temperature), and the primary visual area (responsible for vision). Other areas do not mature until much later in life (in some cases right through to early adulthood: these include areas like the



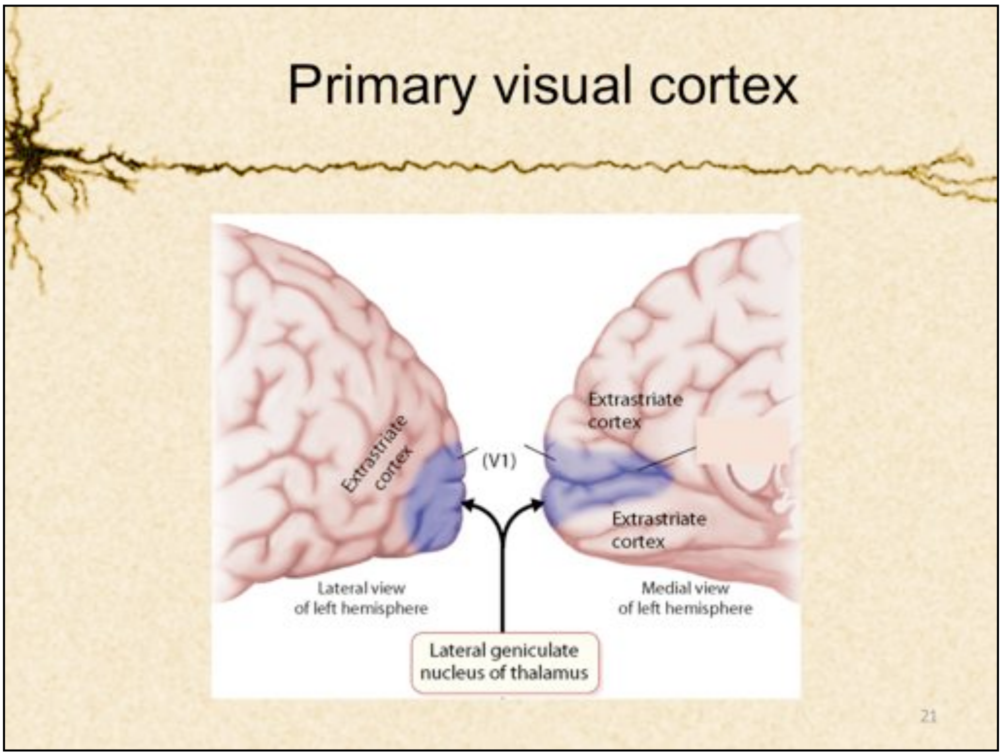
Primary somatosensory cortex – a vertical strip of cortex located immediately posterior to the central sulcus, called the **postcentral gyrus**. It receives sensory information from the skin (temperature, touch and pain). Different regions of the skin surface are represented by different areas along the strip of cortex, forming a **somatotopic map**.



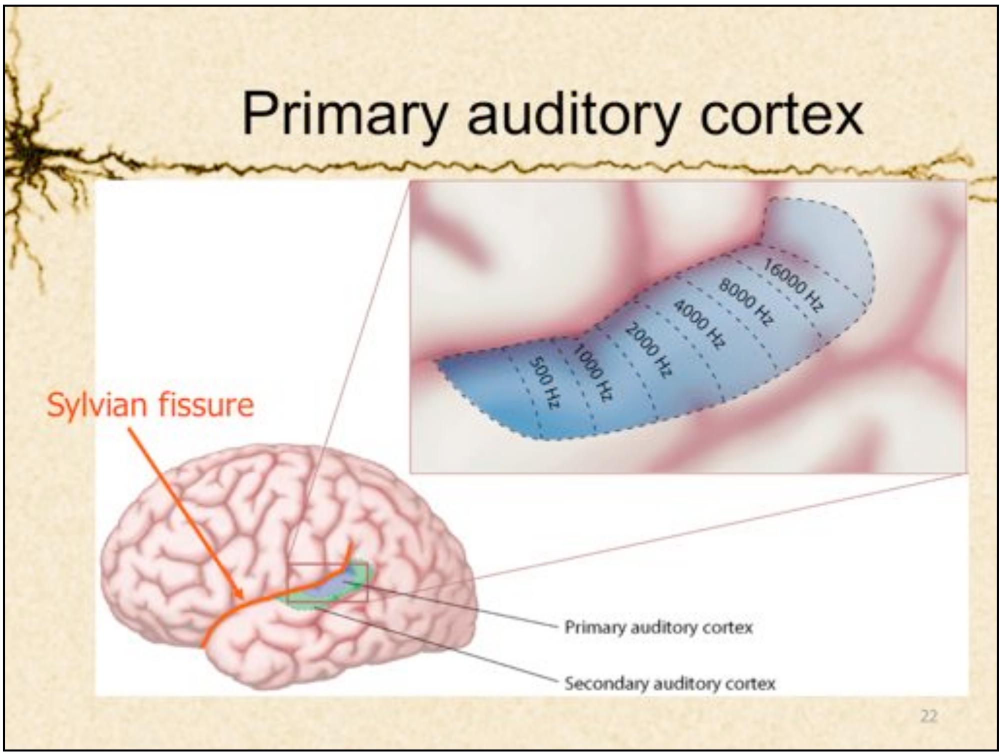
The somatotopic map of the primary somatosensory cortex is organised in a peculiar fashion. The amount of cortex allocated to a body part is proportional to its functional significance rather than to the size of the body part. Thus, for example, the lips, mouth, face and hands occupy a substantial portion of the primary somatosensory cortex, whereas the trunk of the body occupies a rather small portion.



The somatotopic map is sometimes called the **sensory homunculus** ('little man'), because it recreates a map of the body in the brain. Here is an artist's impression of how the human somatosensory cortex represents our various body parts; oversized body parts indicate that a disproportionately large amount of cerebral cortex is devoted to representing that part.

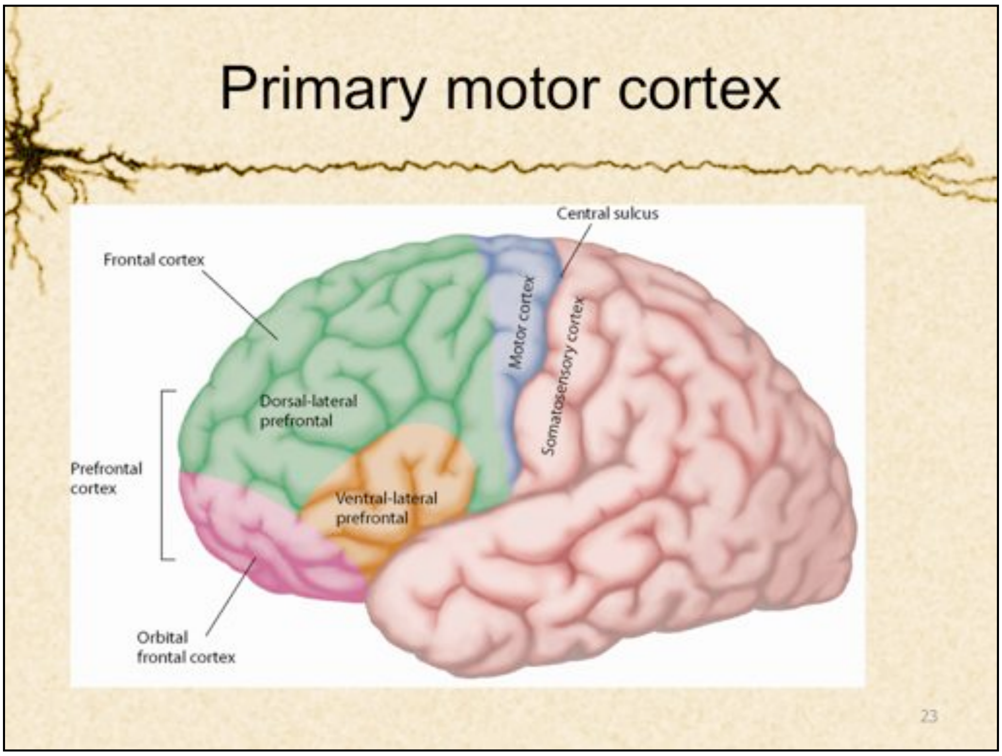


Primary visual cortex – an area of cortex that occupies the medial and lateral parts of the **occipital cortex** at the back of the brain. It receives sensory information from the **retina** (the photosensitive layer at the back of the eye). Different regions of the retina are represented by different areas within the primary visual cortex, forming a **retinotopic** map.



Primary auditory cortex – an area of cortex that occupies the superior part of the **temporal cortex**, as well as a patch of cortex that is buried within the **Sylvian fissure**. It receives sensory information from the **cochlea** (part of the inner ear concerned with hearing). Sounds of different frequencies (e.g., low versus high tones) are represented by different areas within the primary auditory cortex, forming a **tonotopic** map.

With the exception of the senses of smell (olfaction) and taste (gustation), sensory information from the body or environment tends to be represented in the primary sensory cortex of the opposite (**contralateral**) hemisphere. Thus, for example, a touch on the skin of the right hand is processed by the primary somatosensory cortex of the left hemisphere; similarly, visual information occurring toward the viewer's left side is represented by primary visual cortex of the right hemisphere. In audition each ear sends sensory information to the cortex of both hemispheres, but the connections to the contralateral hemisphere are stronger.



Primary motor cortex – a vertical strip of cortex located immediately anterior to the central sulcus, called the **precentral gyrus**. Different parts of the primary motor cortex send signals that control different groups of voluntary muscles (e.g., hands, feet, lips). Like the primary sensory cortices, the primary motor cortex controls muscles on the opposite (contralateral) side of the body.

Those parts of the cortex not involved in the initial reception of sensory information or the control of voluntary muscles are responsible for all other aspects of perception, learning, memory, planning, acting and feeling. These are called **association areas**.

Summary

- Terminology – directions and names of parts
- Basic features of the nervous system – meninges, CSF, ventricles
- Major divisions of the nervous system
- Cortical development – histogenesis and the process of neural migration
- Primary sensory and motor cortex - structure and function

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