Mind, Brain & Behaviour 1
Behavioural Neuroscience

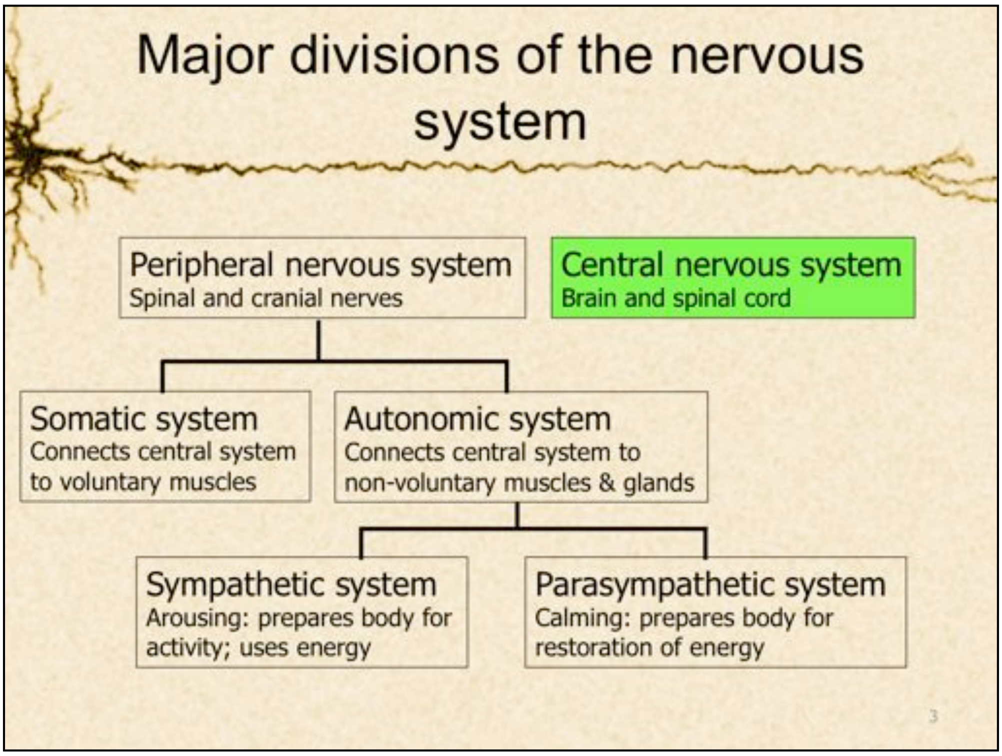
Structure and function of the human nervous system – Part 2

1

Learning objectives

- Describe the structure and function of the four lobes of the cerebral hemispheres
- Outline the roles of the corpus callosum, limbic system and basal ganglia in behaviour
- Describe the structure and function of the diencephalon, midbrain and hindbrain
- Describe the structure of the spinal cord and the role of the spinal nerves
- Understand the antagonistic functions of the two divisions of the autonomic nervous system

2



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:

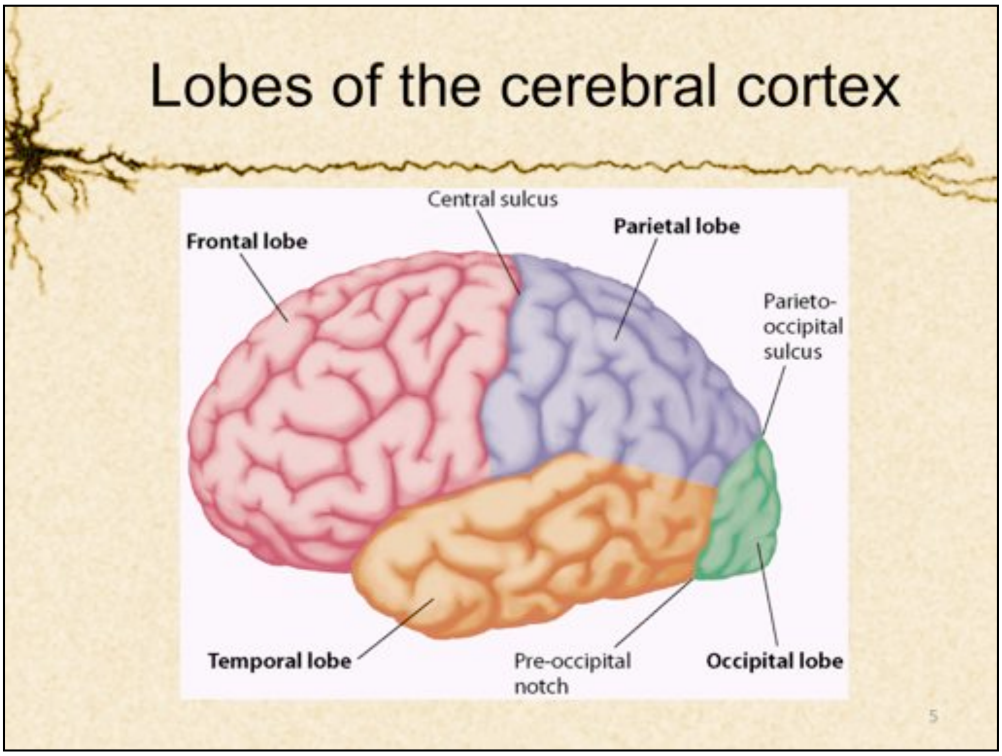
1) **Sympathetic system** (arousing; prepares the body for activity and therefore expends energy)
2) **Parasympathetic system** (calming; prepares the body for restoration of

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

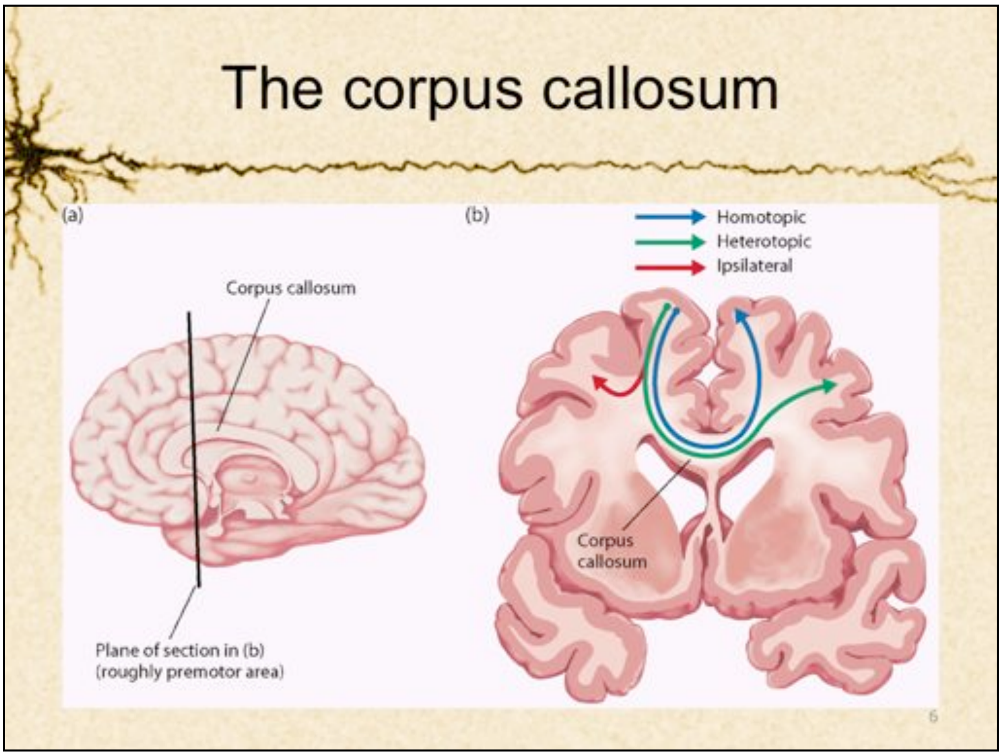
As mentioned in Lecture 4, all of the major structures of the brain can be associated with one of the three early precursors: the forebrain, midbrain and the hindbrain. Each of the precursors consists of a hollow chamber that will eventually form one of the ventricles. In the fully formed brain there 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.



The various gyri and sulci of the cortex can be grouped together into four **lobes**:

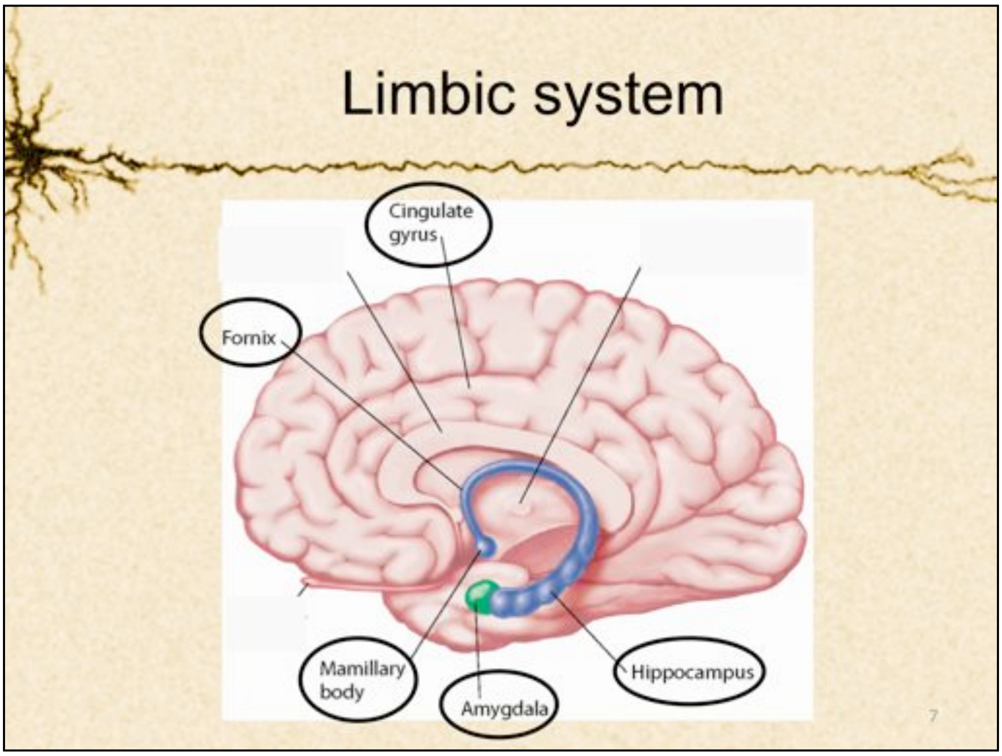
1) **Frontal lobe** – includes all the cortex anterior to the central sulcus. This region is especially large in humans, relative other animals, and is responsible for our unique ability to plan, to reason, and to reflect on our own behaviours. [Recall from Lecture 1 the profound changes to Phineas Gage after his accident with a tamping iron left him with extensive frontal lobe damage; recall also the effects of frontal leucotomy in psychiatric patients.]
2) **Parietal lobe** – includes cortex located behind the central sulcus, caudal to the frontal lobe and dorsal to the temporal lobe. In the left hemisphere this region plays a special role in aspects of language comprehension and mental arithmetic; in the right it is involved in representing the locations of salient objects in space.
3) **Temporal lobe** – includes cortex located ventral to the frontal and parietal lobes. In the left hemisphere this region plays a role in understanding the spoken and written word; in the right it may be particularly involved in recognising complex objects and faces.
4) **Occipital lobe** – includes the cortex at the back of the brain, caudal to the



Although the two cerebral hemispheres perform different functions, our perception, memory and thinking processes are unified. This is made possible because of a large bundle of axons that connects cortical areas of the two cerebral hemispheres, known as the **corpus callosum**. The corpus callosum contains about 200 million axons.

Some axons of the corpus callosum connect corresponding regions of cortex in the two hemispheres (**homotopic fibres**). Others connect different cortical regions of the two hemispheres (**heterotopic fibres**). Still others connect adjacent regions within the same hemisphere (**ipsilateral fibres**).

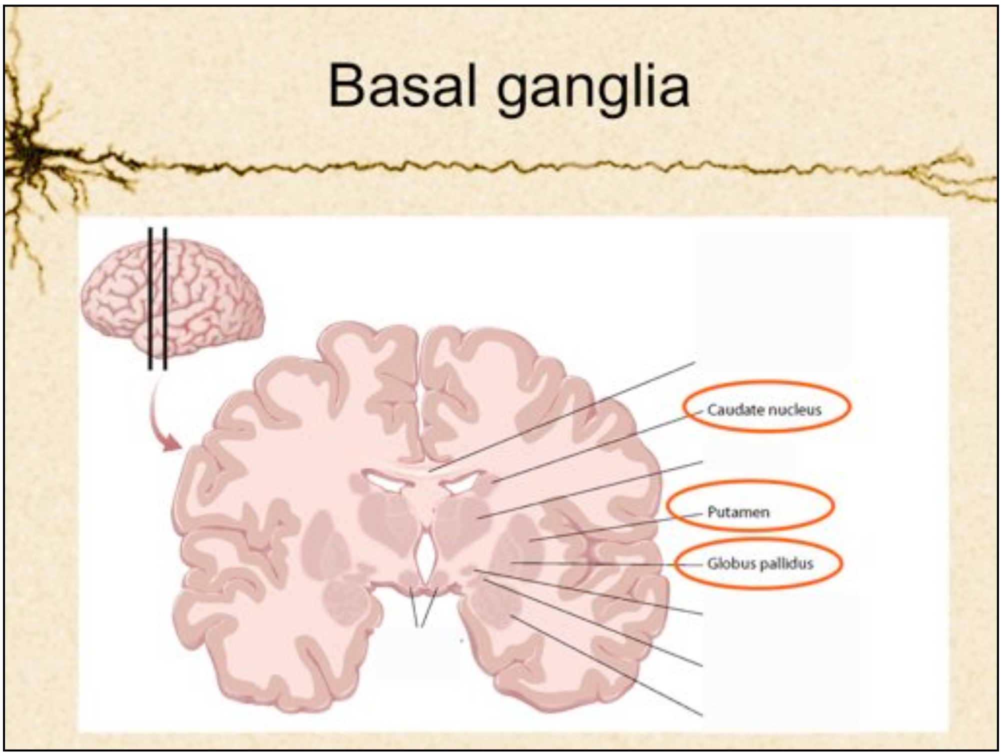
Patients with intractable epilepsy may have their corpus callosum surgically cut (**callosotomy**) to prevent abnormal electrical activity spreading from one hemisphere to the other. In such cases the two hemispheres essentially operate in isolation, with interesting consequences for behaviour.



Buried inside the medial portion of each hemisphere resides a set of structures known collectively as the **limbic system**. The functions of this system were originally described in detail by a neuroanatomist called **Papez (1937)**. He suggested that the limbic structures formed a circuit whose primary functions are **motivation** and **emotion**.

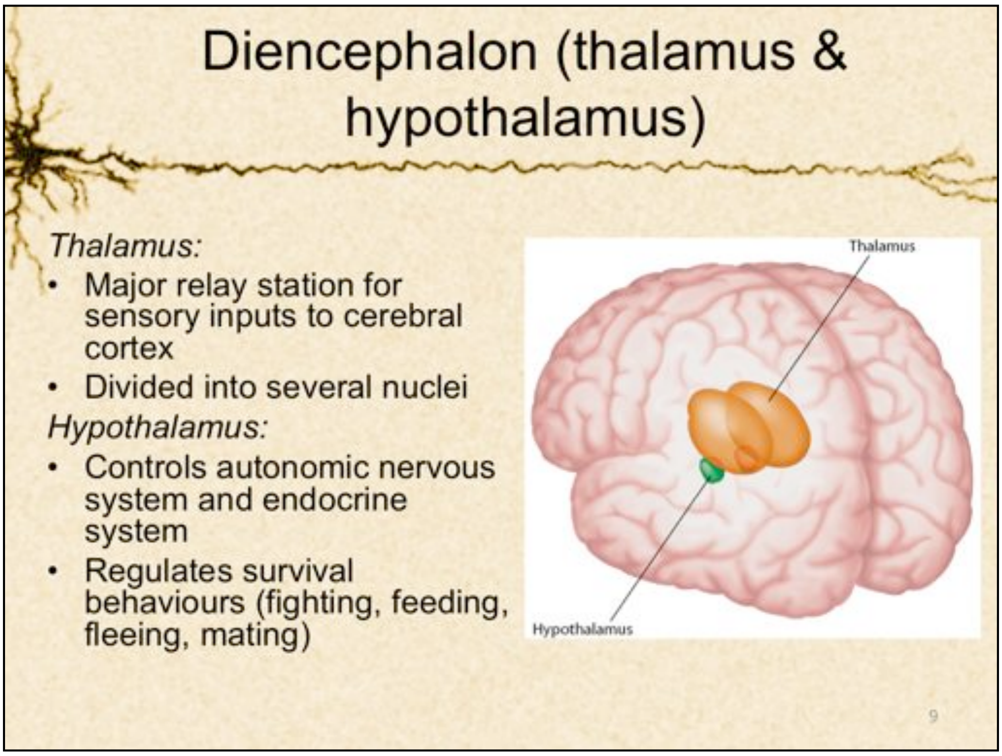
The most important parts of the limbic system are the **hippocampus** (‘seahorse’) and the **amygdala** (‘almond’), which are located adjacent to the lateral ventricle of each temporal lobe. A bundle of axons called the fornix connects these structures with other regions of the brain, most notably the **mammillary bodies**, two little nodules at the base of the brain that form part of the **hypothalamus** (described in detail later). A region of the cerebral cortex that lies above the corpus callosum, known as the **cingulate cortex**, is also considered part of the limbic system. This part of the limbic system controls many functions, one of which is the **emotional response to pain**.

Recent research has shown that the hippocampus and parts of the cortex that surround it are in fact involved in learning and memory rather than emotional behaviour. One of the most classic demonstrations of the role of the hippocampus and surrounding cortex in learning and memory comes from a



The **basal ganglia** (the word **ganglion** means 'a swelling') are a collection of nuclei buried deep within each hemisphere. They contain the cell bodies of collections of neurons, and thus are classified as grey matter even though they are not part of the cerebral cortex. The principal nuclei comprising the basal ganglia are the **caudate nucleus** ('nucleus with a tail'), the **putamen** ('shell') and the **globus pallidus** ('pale globe').

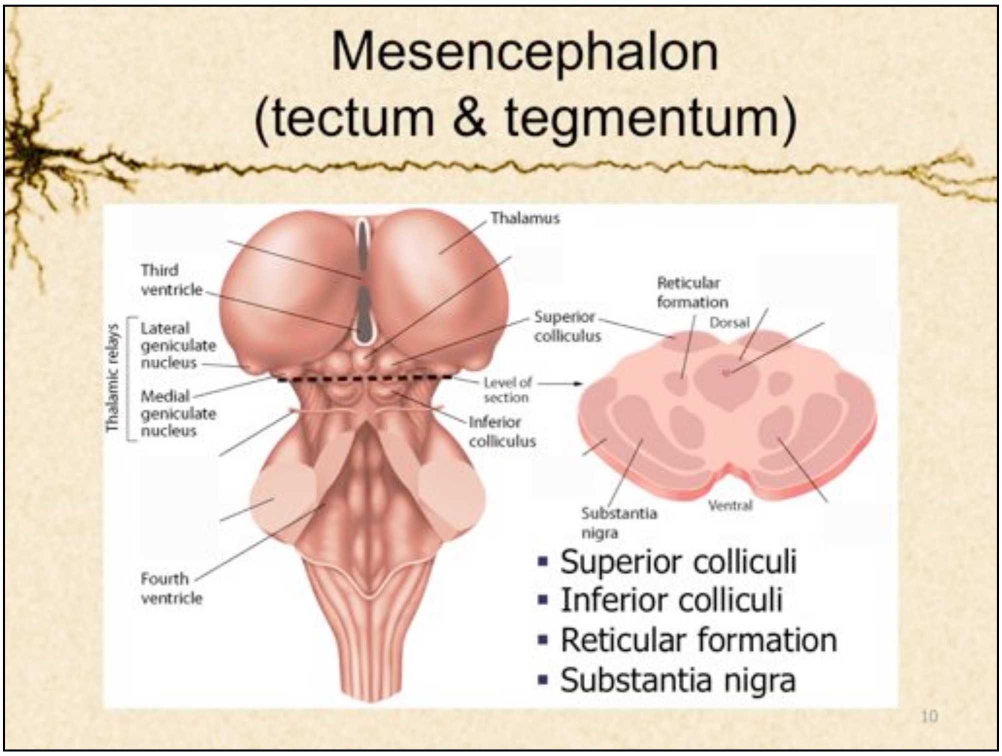
Together, the nuclei of the basal ganglia are responsible for controlling movement, particular those aspects that are highly automatised or involuntary (such as walking). The basal ganglia are dysfunctional in patients with **Parkinson's disease**, because of degeneration of neurons in a part of the midbrain (which we shall consider in a moment) that send their axons to the basal ganglia. Parkinson's disease is characterised by weakness, tremors, limb rigidity, poor balance and difficulty initiating movements.



The second major division of the forebrain is the **diencephalon**. It surrounds the third ventricle, in the middle of the brain, and consists of two major parts:

1) **Thalamus** – (‘inner chamber’) forms the dorsal part of the diencephalon. It is a major relay station for sensory information being conveyed to the cerebral cortex. The thalamus is divided into several smaller nuclei, each with a specific function. For example, the **lateral geniculate nucleus** receives information from the retina of the eye and sends axons to the primary visual cortex, whereas the **medial geniculate nucleus** receives information from the inner ear and sends axons to the primary auditory cortex.

2) **Hypothalamus** – (‘under the thalamus’) sits, as its name suggests, underneath the thalamus. The hypothalamus controls the autonomic nervous system and the endocrine system; it also regulates behaviours necessary for survival, such as fighting, feeding, fleeing and mating. The hypothalamus is also composed of several nuclei, each with its own specialised function.



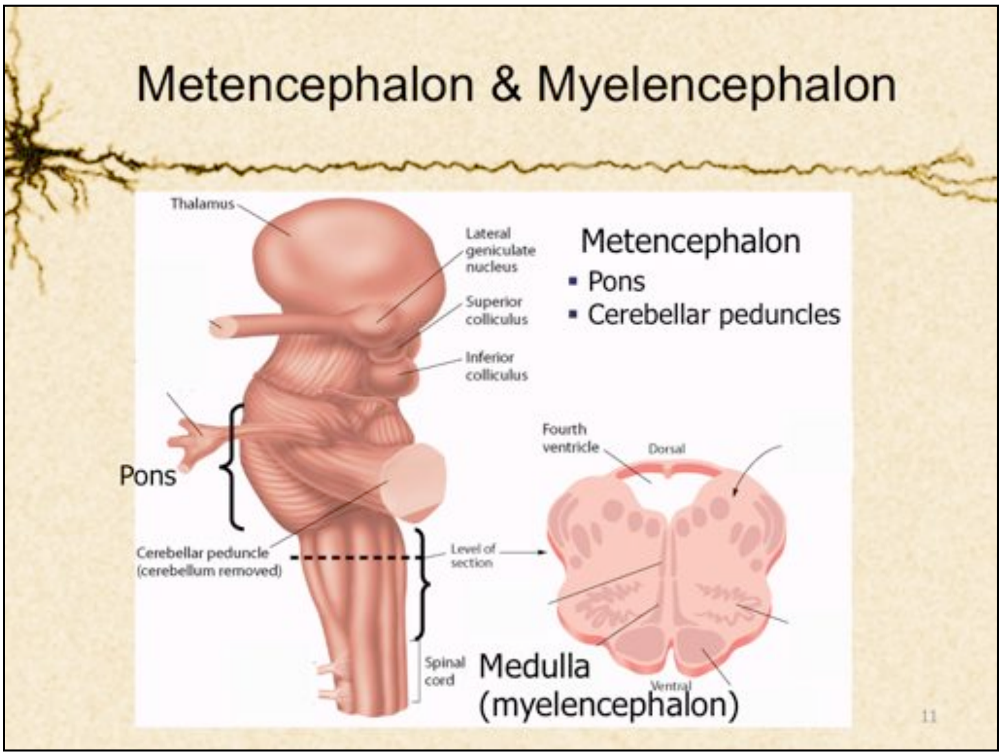
The **midbrain** (**mesencephalon**) is located toward the base of the brain, and is anatomically the junction between the cerebrum and the spinal cord.

The dorsal part of the midbrain is called the **tectum** ('roof'). It consists of the **superior** and **inferior colliculi** (singular: colliculus), which look like four little bumps on top of the **brainstem**. The brainstem is a generic term given to the set of structures that includes the diencephalon, the midbrain and the hindbrain, and is so named because of its (vague) resemblance to the stem of a plant.

The inferior colliculi play a critical role in auditory processing, and in particular in our ability to localise sounds in the environment. The superior colliculi have a role in both auditory and visual processing, and may also have an important role in spatial localisation.

The ventral part of the mesencephalon is the **tegmentum** ('covering'), and it is located beneath the tectum. It contains several nuclei that have different functions.

One cluster of nuclei in the tegmentum is known as the **reticular formation**,



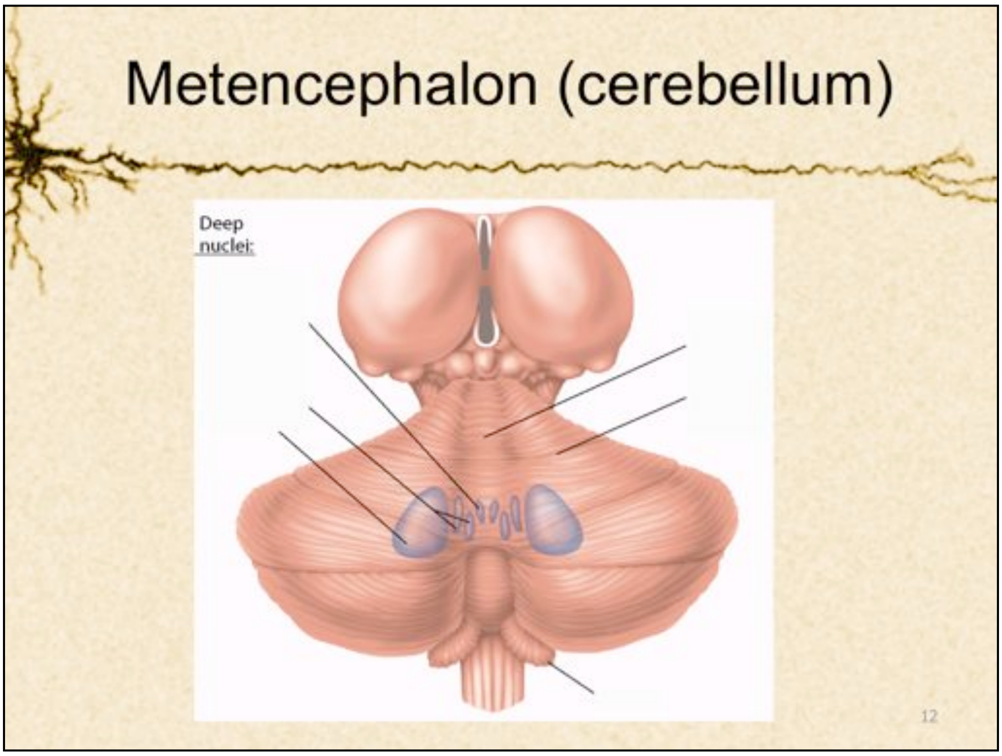
The hindbrain has two major divisions, the **metencephalon** and the **myelencephalon**.

The metencephalon consists of the **pons** and the **cerebellum**.

The pons lies on the ventral surface of the brainstem. It contains several nuclei important in regulating sleep and arousal; it also relays information from the cerebral cortex to the cerebellum, via the **cerebellar peduncles**.

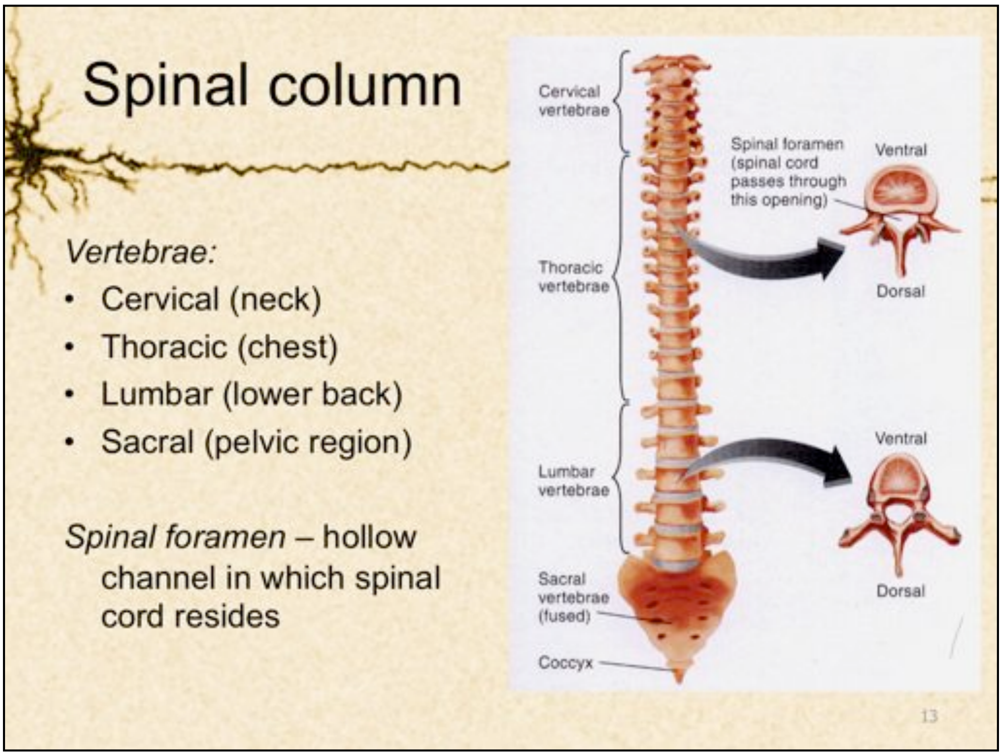
The myelencephalon is more commonly called the Medulla

The Medulla links the hindbrian to the spinal cord, and contains neurons important for autonomic functions like respiration and hear rate.



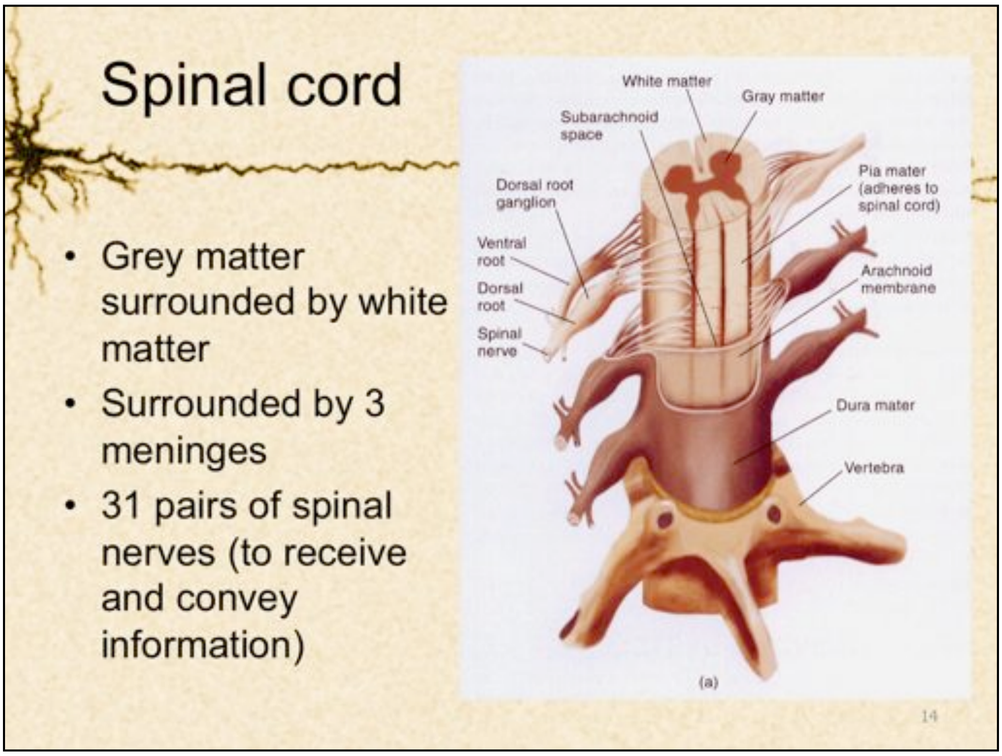
The other major division of the metencephalon is the **cerebellum** ('little brain'). It has two hemispheres, and in this sense it is like a small version of the cerebrum. It consists of an outer **cerebellar cortex** and several **deep nuclei**. The nuclei receive projections from the cerebellar cortex and send out projections from the cerebellum to the rest of the brain. As illustrated in the previous slide, bundles of axons called the **cerebellar peduncles** ('little feet') connect the cerebellum to the pons.

The functions of the cerebellum are only beginning to be understood. It plays a role in the coordination of movement, and damage to the cerebellum causes problems with walking, standing and other aspects of motor (movement) control. The cerebellum receives information from the visual, auditory, somatosensory and vestibular (balance) systems, and from areas involved in the control of muscles. It is therefore in a unique position to fine tune motor behaviour. Cerebellar damage, which may arise from a stroke (blockage or rupture of an artery) or from alcohol abuse, leads to jerky, poorly coordinated movements and problems maintaining balance.



The spinal cord is contained within the **spinal column**, which is composed of 24 individual vertebrae stacked on top of one another. These individual vertebrae are in the cervical (neck), thoracic (chest) and lumbar (lower back) regions. A further set of fused vertebrae make up the sacral and coccygeal portions, which are in the pelvic region.

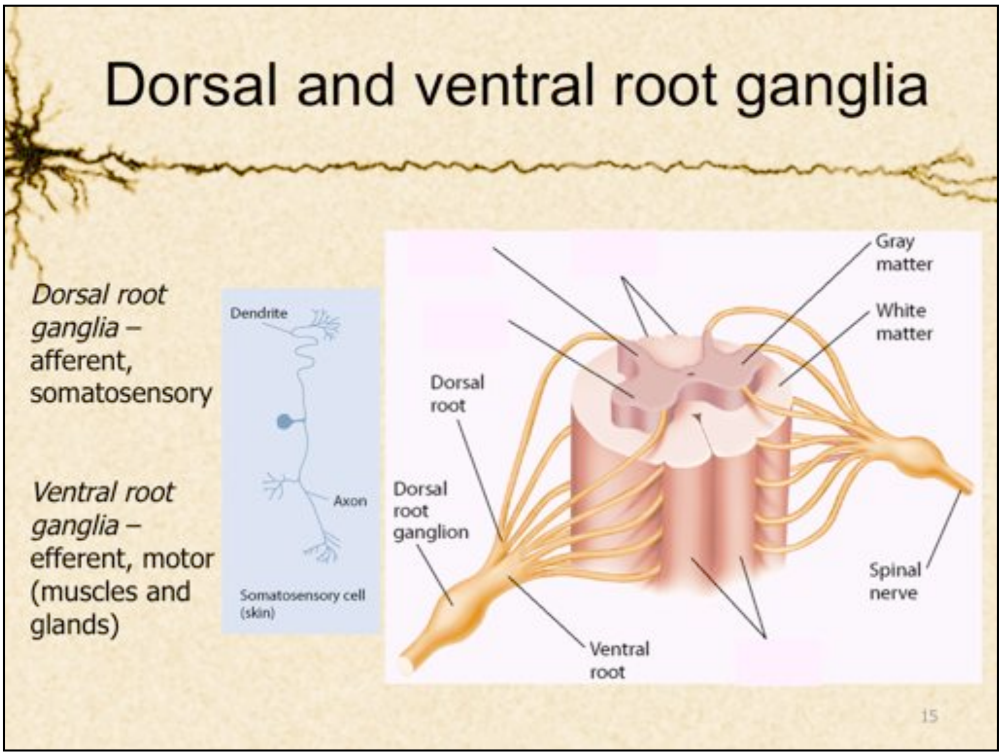
The spinal column surrounds and protects the **spinal cord**, which is a long rod of nerve tissue about the same diameter as our little finger. The spinal cord runs inside a hollow channel, known as the **spinal foramen** ('spinal opening'), which runs down the centre of the stacked vertebrae.



The purpose of the spinal cord is to transmit somatosensory information (touch, temperature and pain) from the body to the brain, and to distribute motor axons to the various organs (glands and muscles).

The spinal cord is sheathed by the three meninges. The spinal cord consists of **grey matter** (cell bodies) and **white matter** (axons), just like the brain, but with an important difference: in the spinal cord the white matter is on the *outside* and the grey matter is on the *inside*. The white matter consists of bundles of axons that ascend toward the brain, carrying sensory information, and bundles of axons that descend toward the body, carrying signals from the brain to the glands and muscles. The grey matter consists mostly of cell bodies and some short, unmyelinated axons.

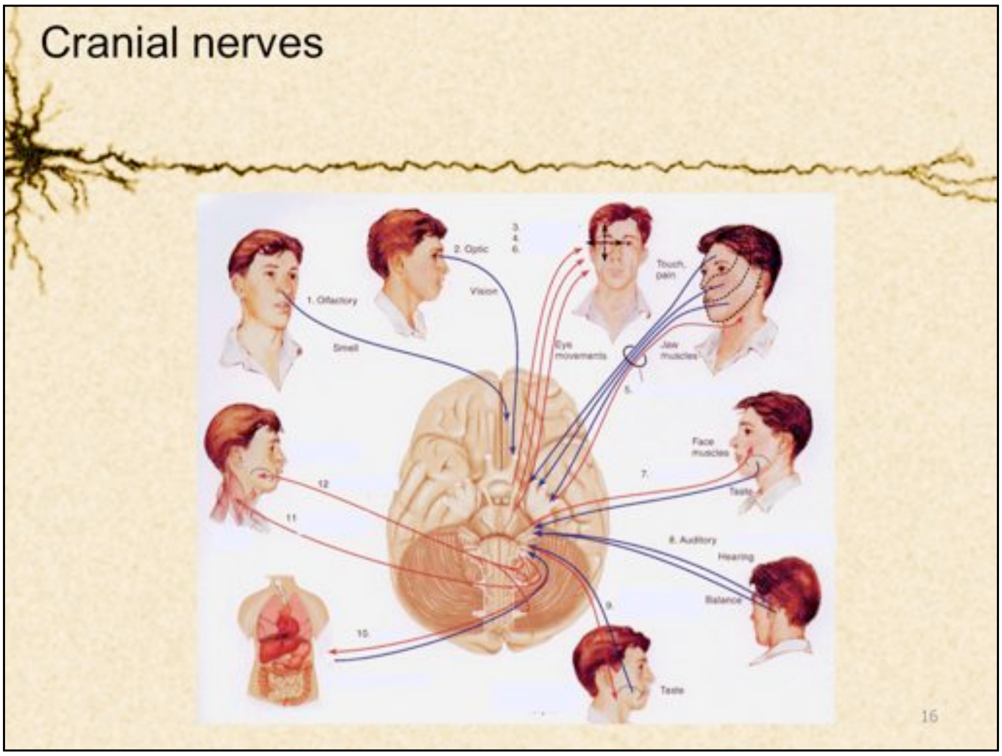
Small bundles of axons emerge in pairs from the sides of the spinal cord for much of its length. One member of each pair is called the **dorsal root** (so called because it emerges from the dorsolateral surface of the spinal cord), and the other member is called the **ventral root** (which emerges from the ventrolateral surface). The fibres contained within the pair of roots emerging from each side of the spinal cord join together as they exit from gaps in the vertebrae, and form an individual **spinal nerve**.



Let us consider in more detail the role of the dorsal and ventral roots in receiving and conveying information.

The cell bodies of neurons that receive sensory information are located outside the CNS; axons from these receptor neurons (called **afferent** neurons, because they ‘bear toward’ the CNS) are found in the dorsal roots, and the cell bodies that give rise to them reside in the **dorsal root ganglia** (the swelling being due to the cluster of cell bodies). These neurons are pseudounipolar (refer to Slide 8, Lecture 2), so that the axon divides close to the cell body and sends one branch into the spinal cord and the other out to a sensory receptor.

The cell bodies of neurons that convey information from the brain to the glands and muscles are located inside the grey matter of the spinal cord; axons from these neurons (called **efferent** neurons, because they ‘bear away from’ the CNS) are found in the **ventral root**.

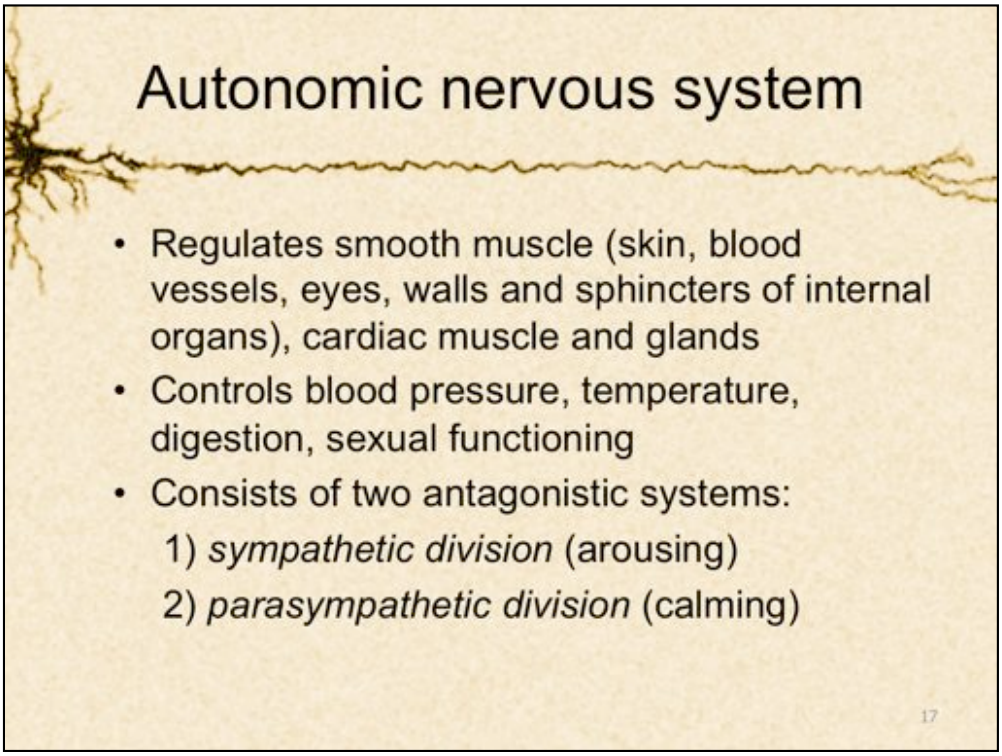


In addition to the 31 pairs of spinal nerves, there are a further 12 **cranial nerves** (so called because they arise from the ventral surface of the brain).

The cranial nerves serve the sensory and motor functions of the head and neck. Each of the cranial nerves has a name that denotes its function, as well as a number from 1 – 12. It is not necessary for current purposes to remember the names and numbers of all of these nerves (though there are plenty of mnemonics to help you do so if you wish), but it is instructive to know something about what functions they serve.

Some cranial nerves have a sensory function, some have a motor function, and some have both sensory and motor functions.

Some cranial serve functions are self-explanatory: the **olfactory nerve (I)** serves the sense of smell; the **optic nerve (II)** transmits visual information from the retina of the eye; the **facial nerve (VII)** serves the muscles of the face; the **auditory/vestibular nerve (VIII)** transmits information concerning sound and balance from the inner ear.



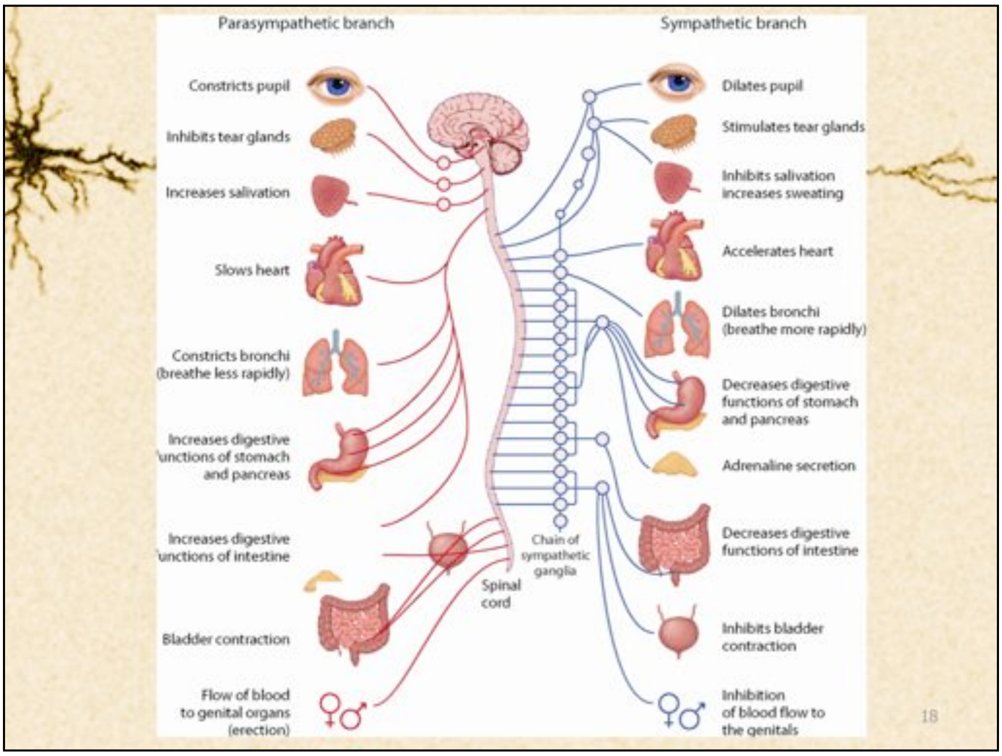
Recall that the PNS has two principal divisions: the somatic system, which we have just considered (control of movement of skeletal muscles and transmission of somatosensory information to the CNS); and the **autonomic nervous system (ANS)**, which we shall consider now.

The autonomic ('self governing') nervous system regulates the body's involuntary muscles and glands. Smooth muscle is found in the skin (in hair follicles), in blood vessels, in the eyes (to control pupil size and focusing of the lens), and in the walls and sphincters of the gut, gallbladder and urinary bladder. The ANS is thus involved in such functions as the control of blood pressure, body temperature and digestion.

The ANS consists of two antagonistic subsystems, the **sympathetic division** and the **parasympathetic** subdivision. Most organs of the body are innervated by both subdivisions, but with antagonistic (opposing) effects. For example:

Heart rate – increased by the sympathetic division, decreased by the parasympathetic division

Pupil of the eye – dilated by the sympathetic division, constricted by the



The sympathetic and parasympathetic branches of the ANS are distinct both functionally and anatomically.

The cell bodies of sympathetic motor neurons are located in the grey matter of the thoracic and lumbar regions of the spinal cord. The axons of these neurons exit the spinal cord via the ventral roots. They then pass to a chain of **sympathetic ganglia** that are connected to their neighbours above and below, thus forming the **sympathetic ganglia chain**, which runs parallel to the spinal cord.

The cell bodies of parasympathetic neurons are located in two regions: (1) the nuclei of some of the cranial nerves (the vagus (X) nerve in particular), and (2) the grey matter of the sacral region of the spinal cord.

Summary

- Forebrain – cortical lobes, limbic system, basal ganglia, diencephalon
- Midbrain – superior & inferior colliculi, reticular formation, substantia nigra
- Hindbrain – pons, cerebellum
- Somatic nervous system – spinal cord, dorsal and ventral roots, spinal nerves, cranial nerves
- Autonomic nervous system – sympathetic & parasympathetic divisions

19