4 THE NERVOUS SYSTEM IS HIGHLY ORGANISED

UNIT 3 CONTENT

SCIENCE INQUIRY SKILLS

» select, use and/or construct appropriate representations, including diagrams, models and flow charts, to communicate conceptual understanding, solve problems and make predictions

SCIENCE UNDERSTANDING

Central and peripheral nervous system

» structure and function of the divisions of the nervous system can be observed and compared at different levels in detecting and responding to the changes in the internal and external environments, including:
  - central–peripheral
  - afferent–efferent
  - autonomic–somatic
  - sympathetic–parasympathetic

» the parts of the central nervous system, including the brain (cerebrum, cerebellum, medulla oblongata, hypothalamus, corpus callosum) and spinal cord, have specific roles in the co-ordination of body functions and are protected by the meninges and cerebro-spinal fluid

Source: School Curriculum and Standards Authority, Government of Western Australia

The trillions of cells that make up the human body work together in an integrated and coordinated way. To achieve integration and coordination, cells must communicate with one another. The **nervous system** is the communication network and control centre of the body and is made up of the brain, spinal cord and nerves. While it can be divided into parts, or divisions, on the basis of their structure and functions – the **central nervous system (CNS)** consists of the brain and spinal cord; and the **peripheral nervous system (PNS)** is made up of the nerves that connect the CNS with the receptors, muscles and glands – these all work together in a coordinated way.

4.1 CENTRAL NERVOUS SYSTEM

The central nervous system is where incoming messages are processed and outgoing messages are initiated.

Protection of the central nervous system

The brain and the spinal cord are very delicate and vital parts of the body. Therefore, it is important that they are well protected. Three structures protect the CNS:

- bone
- membranes called meninges
- cerebrospinal fluid.

Cranium and vertebrae

The outermost protective layer is bone. The brain is protected by the **cranium**, the part of the skull that houses the brain, while the spinal cord runs through the **vertebral canal**, an opening in the vertebrae. These bones provide a strong, rigid structure to protect the structures underneath.

FIGURE 4.1 The central nervous system – brain and spinal cord

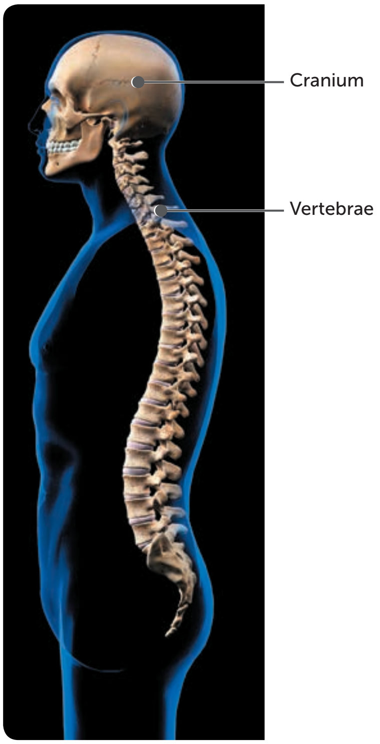

FIGURE 4.2 The cranium and vertebrae protect the brain and spinal cord

Meninges

Inside the bones, and covering the surface of the brain and spinal cord (i.e. the entire CNS), are three layers of connective tissue forming membranes called the **meninges**.

- The outer meningeal layer, the **dura mater**, is tough and fibrous, and therefore provides a layer of protection for the brain. It sticks closely to the bones of the skull, but on the inside of the vertebral canal it is not so close fitting. This outer membrane has been described as having a texture and thickness similar to a household rubber glove.
- The middle meningeal layer, the **arachnoid mater**, is a loose mesh of fibres.
- The inner layer, the **pia mater**, is far more delicate. It contains many blood vessels and sticks closely to the surface of the brain and spinal cord.

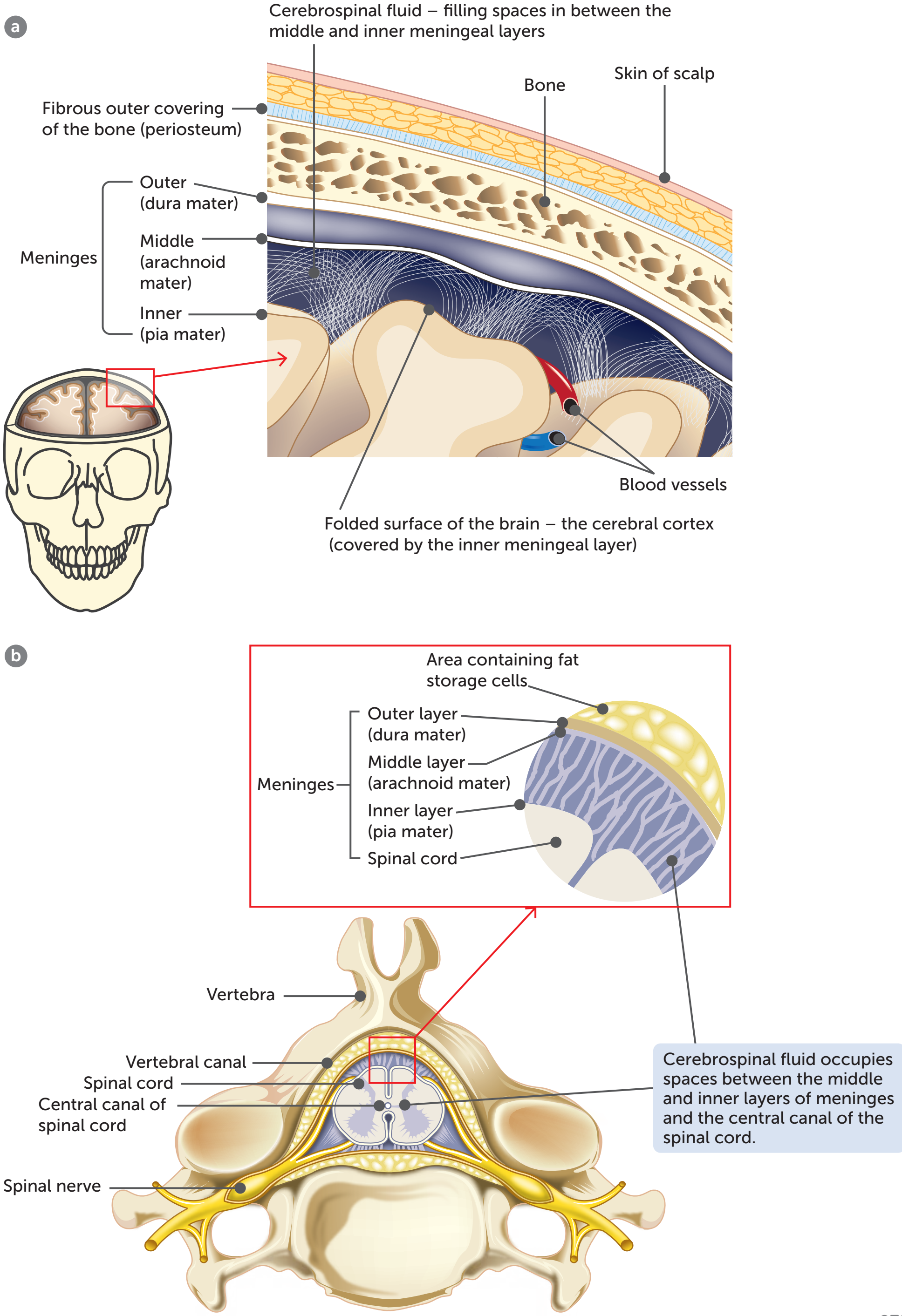

FIGURE 4.3
a Structures that protect the brain; **b** Structures that protect the spinal cord

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Cerebrospinal fluid

The third protective structure is **cerebrospinal fluid (CSF)**, which occupies a space between the middle and inner layers of meninges. It also circulates through cavities in the brain and through a canal in the centre of the spinal cord. The CSF is a clear, watery fluid containing a few cells and some glucose, protein, urea and salts.

The CSF has three functions:

- *Protection:* the CSF acts as a shock absorber, cushioning any blows or shocks the CNS may sustain.
- *Support:* the brain is suspended inside the cranium and floats in the fluid that surrounds it.
- *Transport:* the CSF is formed from the blood, and circulates around and through the CNS before eventually re-entering the blood capillaries. During its circulation it takes nutrients to the cells of the brain and spinal cord and carries away their wastes.

Key concept

The central nervous system is protected by bones, meninges and cerebrospinal fluid.

The brain

The brain is a very complex organ, both in structure and function. Much of the brain's workings are still a mystery and new discoveries are constantly being made. In this section we will deal only with those parts of the brain that have major functions, but it is important to remember that the brain works as an integrated whole.

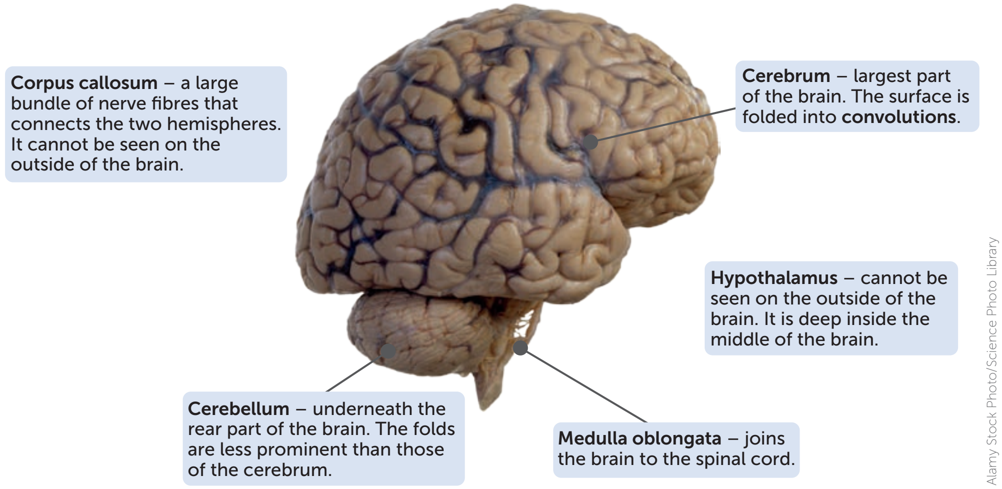

FIGURE 4.4 External view of the brain

Cerebrum

The **cerebrum** is by far the biggest part of the brain. It consists of an outer surface about 2–4 mm thick of **grey matter** known as the **cerebral cortex**. The grey matter consists of neuron cell bodies, dendrites and unmyelinated axons. Below the cortex is **white matter**, which is made up of myelinated axons. The fatty nature of myelin gives the white matter its colour and texture. Deep inside the cerebrum is additional grey matter called the **basal ganglia**.

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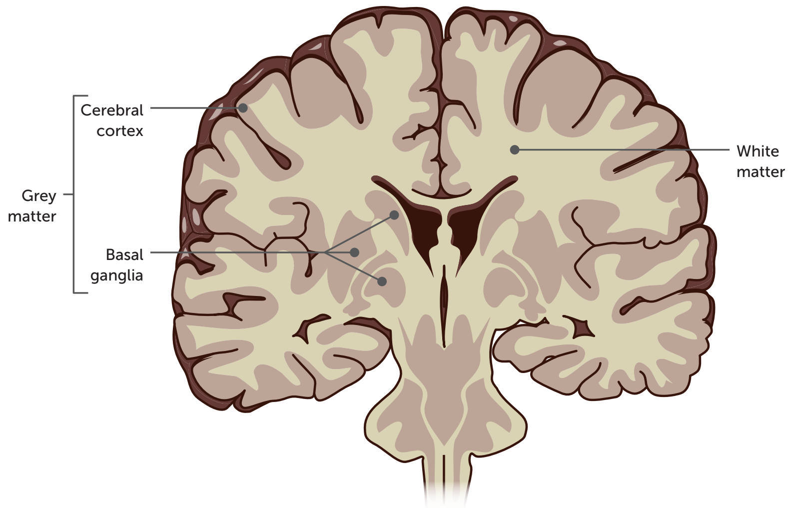


FIGURE 4.5 Cross-section of the cerebrum

The cerebral cortex is folded in patterns that greatly increase its surface area. In this way the cortex contains 70% of all the neurons in the central nervous system. The folding produces rounded ridges called **convolutions** (or gyri; singular: **gyrus**). The convolutions are separated by either shallow downfolds called **sulci** (singular: sulcus) or deep downfolds called **fissures**.

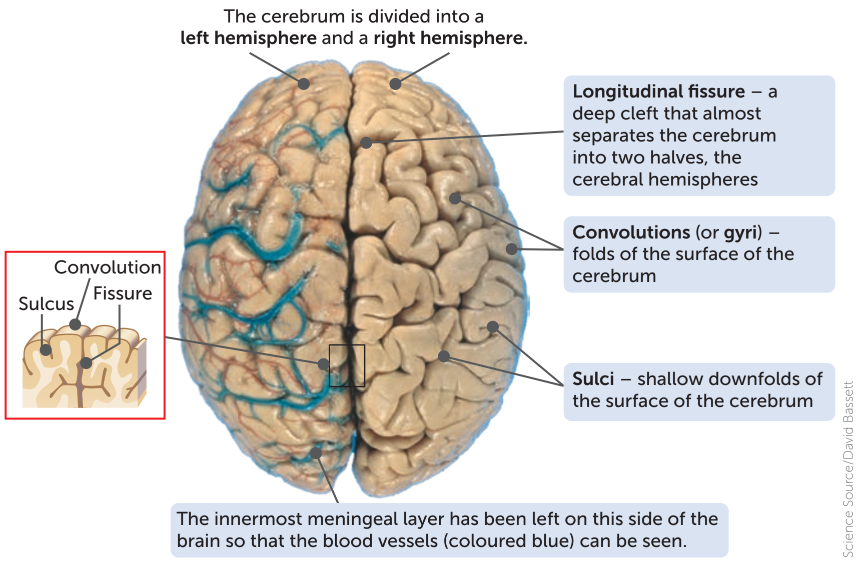


FIGURE 4.6 Convolutions, sulci and fissures of the cerebrum, as seen from above

TABLE 4.1 Functions of the lobes of the cerebral cortex

LOBE	FUNCTION
Frontal lobe	Thinking, problem solving, emotions, personality, language, and control of movement
Parietal lobe	Processing temperature, touch, taste, pain and movement
Temporal lobe	Processing memories and linking them with senses; receives auditory information
Occipital lobe	Vision
Insula	Recognition of different senses and emotions, addiction and psychiatric disorders

The deepest fissure, the **longitudinal fissure**, almost separates the cerebrum into two halves – the left and right **cerebral hemispheres**. Joining the two hemispheres, at the base of the longitudinal fissure, is an area of white matter consisting of a large bundle of transverse fibres known as the corpus callosum.

The patterns of folding of the cerebral cortex vary from person to person. However, certain fissures and sulci are fairly constant and are used to further subdivide each cerebral hemisphere into four lobes – the **frontal**, **temporal**, **occipital** and **parietal lobes**. Another part of the cerebrum, the **insula**, is deep inside the brain and is regarded as a fifth lobe.

The cerebral cortex is involved in mental activities such as thinking, reasoning, learning, memory, intelligence and sense of responsibility. It is also concerned with perception of the senses and the initiation and control of voluntary muscle contraction. Nearly all the impulses from our sense organs are carried to the cerebral cortex, which then has all the relevant information about the environment and can initiate responses accordingly.

The cortex can be roughly divided into three functional areas.

- **sensory areas**, which interpret impulses from receptors
- **motor areas**, which control muscular movements
- **association areas**, which are concerned with intellectual and emotional processes.

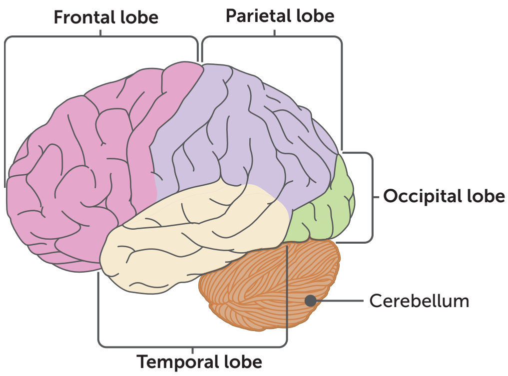


FIGURE 4.7 The lobes of the cerebrum. The fifth lobe, the insula, is not visible from the outside of the brain

One of the important functions of the cerebrum is memory. The association areas of the cerebral cortex are involved in memory. Memories are not stored in individual memory cells in the brain: they are pathways of nerve cells. When a memory is stored, new links are made between neurons or existing links are modified.

Although the two sides of the cerebrum appear to be very similar, close inspection shows that they are not identical. For example, in right-handed people the right frontal lobe is wider than the left and the left occipital and parietal lobes are wider than the right ones. Many specialised functions occur in only one hemisphere. Language ability, for example, is normally controlled by the left hemisphere; musical and artistic abilities are functions of the right hemisphere.

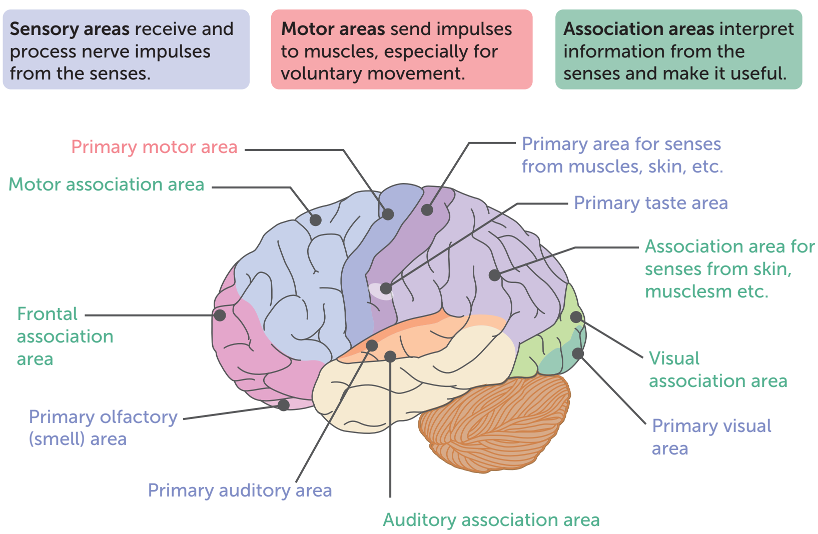


FIGURE 4.8 Some functional areas of the cerebral cortex

Cerebral hemispheres
This website provides further information on the different functions of the two cerebral hemispheres.

Between the cerebral cortex and the basal ganglia is white matter composed of bundles of nerve fibres that are surrounded by a sheath of white fatty material called **myelin**. Within the CNS, bundles of nerve fibres are called **tracts**; outside the CNS they are called nerves.

Three types of tracts occur in the white matter:

- tracts that connect various areas of the cortex within the same hemisphere
- tracts that carry impulses between the left and right hemispheres
- tracts that connect the cortex to other parts of the brain or to the spinal cord.

The basal ganglia consist of groups of nerve cell bodies associated with control of skeletal muscles. They play a role in initiating desired movements and inhibiting unwanted movement.

Key concept

The cerebrum is responsible for thinking, reasoning, learning, memory and sense of responsibility. Its folded structure increases the surface area for a large number of neurons.

Corpus callosum

The **corpus callosum** is a wide band of nerve fibres that lies underneath the cerebrum at the base of the longitudinal fissure. Nerve fibres in the corpus callosum cross from one cerebral hemisphere to the other and allow the two sides of the cerebrum to communicate with each other.

Cerebellum

The **cerebellum** lies under the rear part of the cerebrum. It is the second-largest part of the brain and its surface is folded into a series of parallel ridges. The outer folded part of the cerebellum is grey matter. Inside is white matter that branches to all parts of the cerebellum, rather like the branches of a tree.

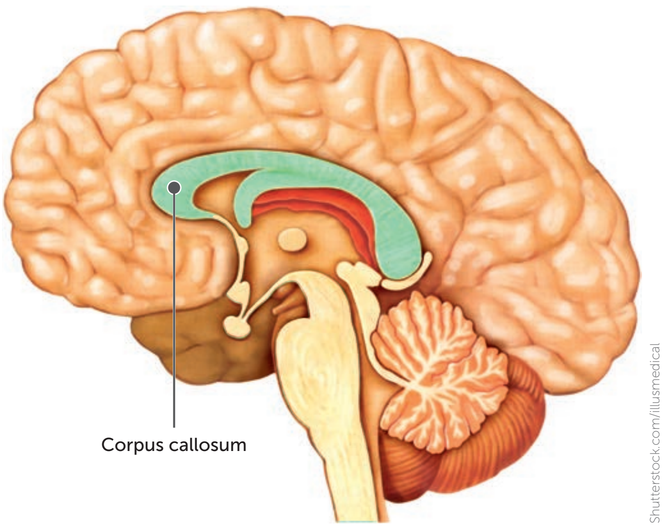


FIGURE 4.9 The corpus callosum joins the left and right hemispheres of the cerebrum

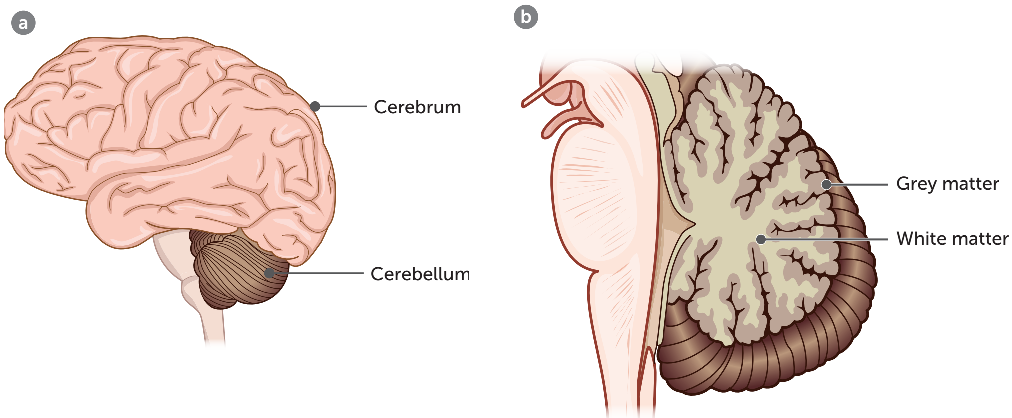


FIGURE 4.10 **a** Location of the cerebellum; **b** Cross-section of the cerebellum

The cerebellum exercises control over posture, balance and the fine coordination of voluntary muscle movement. To carry out these functions the cerebellum receives sensory information from:

- the inner ear for information about posture and balance
- stretch receptors in the skeletal muscles for information about the length of muscles.

All the functions of the cerebellum take place below the conscious level. Impulses do not originate in the cerebellum and so without it we could still move, but our movements would be spasmodic, jerky and uncontrolled. Smooth, coordinated movements, such as those required for writing, playing a musical instrument or using a computer, would be impossible.

Key concept

The cerebellum lies at the back of the brain and is responsible for posture, balance and the coordination of movement.

Hypothalamus

The **hypothalamus** lies in the middle of the brain and cannot be seen from the outside. Although small, the hypothalamus controls many bodily activities, but it is mostly concerned with maintaining a constant internal environment – homeostasis.

The functions of the hypothalamus include the regulation of:

- the autonomic nervous system, including the regulation of heart rate, blood pressure, the secretion of digestive juices, movements of the alimentary canal and the diameter of the pupil of the eye
- body temperature
- food and water intake
- patterns of waking and sleeping
- contraction of the urinary bladder
- emotional responses, such as fear, anger, aggression, pleasure and contentment
- the secretion of hormones and coordination of parts of the endocrine system; acting through the pituitary gland, the hypothalamus regulates metabolism, growth, reproduction and responses to stress.

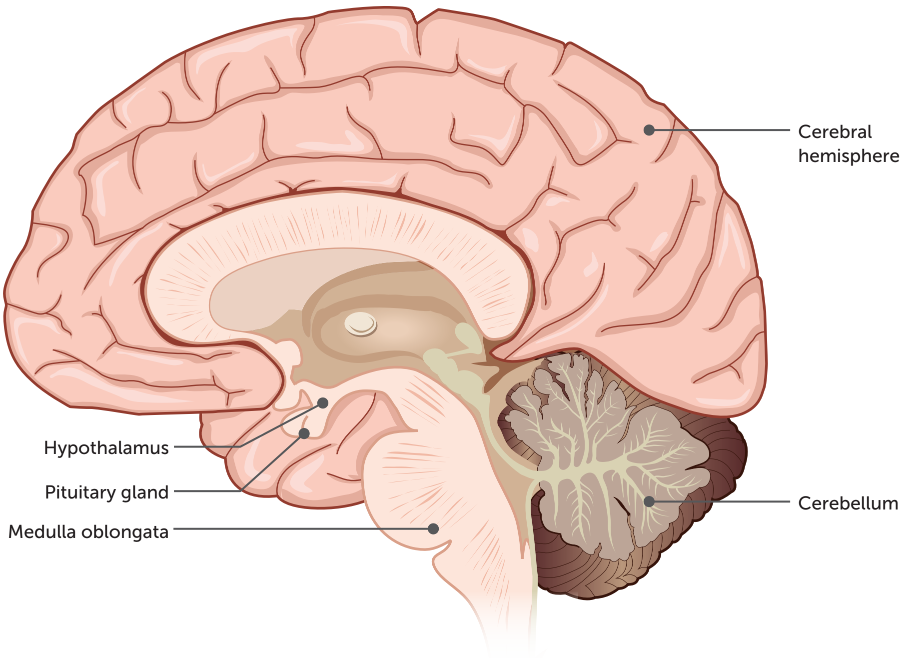


FIGURE 4.11 Location of the hypothalamus and medulla oblongata

Medulla oblongata

The **medulla oblongata** is a continuation of the spinal cord. It is about 3 cm long and extends from just above the point where the spinal cord enters the skull (see Figure 4.11). Many nerve fibres simply pass through the medulla going to or from the other parts of the brain, but the medulla does have an important role in automatically adjusting body functions.

The medulla oblongata contains:

- the **cardiac centre**, which regulates the rate and force of the heartbeat
- **respiratory centres**, which control rate and depth of breathing
- the **vasomotor centre**, which regulates the diameter of blood vessels.

In addition, other centres regulate the reflexes of swallowing, sneezing, coughing and vomiting. All the centres in the medulla oblongata are influenced and controlled by higher centres in the brain, particularly the hypothalamus.

Spinal cord

The **spinal cord** is a roughly cylindrical structure about 44 cm long in an adult. It extends from the foramen magnum, the large opening at the base of the skull, to the second lumbar vertebra, which is at about waist level.

As we have seen, the spinal cord, like the brain, is heavily protected. The cord is enclosed in the vertebral canal, and inside the ring of bone are the three meningeal layers. However, the outermost meningeal layer is not joined to the bone as it is in the skull. Instead, a space containing fat, connective tissue and blood vessels serves as padding around the spinal cord and allows the cord to bend when the spine is bent.

If a cross-section of the spinal cord is examined, it is seen to consist of areas of grey matter and areas of white matter. The composition of these two areas is the same as in the brain – the grey matter is composed of nerve cell bodies and unmyelinated nerve fibres, and the white matter is composed of myelinated fibres. Unlike the cerebrum and cerebellum of the brain, where the grey matter is at the surface, the grey matter of the spinal cord is at the centre, surrounded by the white matter.

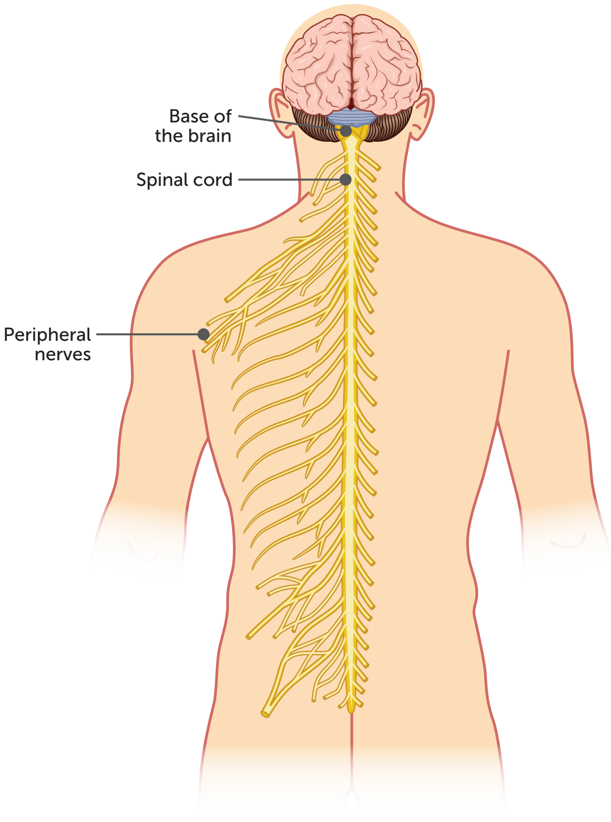


FIGURE 4.12 Position of the spinal cord

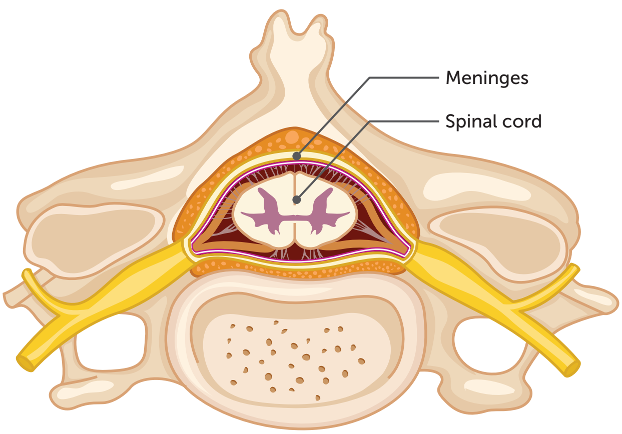


FIGURE 4.13 Cross-section of a vertebra showing the position of the spinal cord and meninges

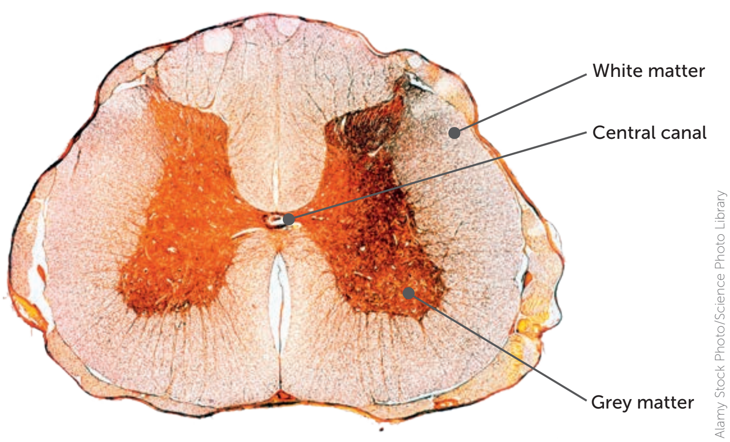


FIGURE 4.14 Cross-section of the spinal cord as seen under the low power of a microscope. The grey matter is coloured brown in this photo

The grey matter is roughly in the shape of a letter H. In the cross-bar of the H is a small space called the **central canal**, which runs the length of the spinal cord and contains cerebrospinal fluid.

The myelinated nerve fibres of the white matter are arranged in bundles known as ascending and descending tracts.

- **Ascending tracts** are sensory axons that carry impulses upwards, towards the brain.
- **Descending tracts** contain motor axons that conduct impulses downwards, away from the brain.

Thus, one of the functions of the spinal cord is to carry sensory impulses up to the brain and motor impulses down from the brain. The second function of the spinal cord is to integrate certain fast, automatic responses called reflexes. The mechanism involved in spinal reflexes was discussed in Chapter 3.

Key concept

The spinal cord takes messages between the brain and the peripheral nervous system.

Spinal cord
This website provides more information about the spinal cord.

Activity 4.1
Examining a dissected brain

Activity 4.2
Phineas Gage

TABLE 4.2 Structure and functions of the main areas of the CNS

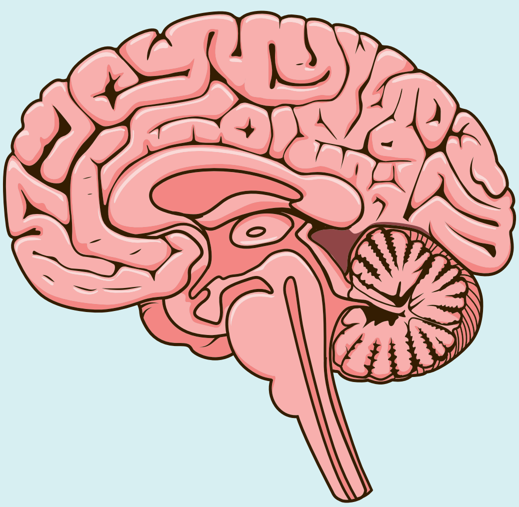
STRUCTURE	FUNCTION
Cerebral cortex	Higher-order functions such as thinking, reasoning, memory, learning, conscious awareness of surroundings
Corpus callosum	Communication between the two cerebral hemispheres
Cerebellum	Coordination of fine contractions of muscles resulting in smooth movements and the maintenance of posture and balance
Hypothalamus	Homeostasis; regulation of the heart, digestive system, appetite, thirst, metabolism, body temperature, response to fear or anger
Medulla oblongata	Under the influence of the hypothalamus, regulates the heart, breathing and diameter of blood vessels
Spinal cord	Provides a pathway for communication between muscles and glands and the brain; integration of automatic, protective reflexes

Questions 4.1

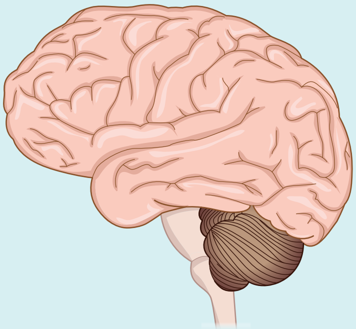
RECALL KNOWLEDGE

1 Label the following structures on the diagram below.

a Cerebellum
b Hypothalamus
c Pituitary gland
d Cerebrum
e Medulla oblongata
f Corpus callosum
g Spinal cord
h Convolution
i Sulci



2 Explain how the central nervous system is different from the peripheral nervous system.
3 List the structures that protect the central nervous system.
4 Explain how cerebrospinal fluid protects the brain.
5 a Label the parietal, frontal, occipital and temporal lobes of the cerebral cortex on the diagram below.



b Explain why it is not possible to label the insula in this diagram.

6 Describe the functional areas of the cerebrum.
7 Describe the appearance of a cross-section of the cerebellum.
8 Name and describe the centres that are located in the medulla oblongata.
9 Compare and contrast the structure of the brain and spinal cord.
10 Draw a labelled cross-section of the spinal cord to show the grey matter, white matter and central canal.

APPLY KNOWLEDGE

11 Explain why a broken back can result in the inability to move limbs.
12 Justify the naming of the grey matter and white matter.
13 Describe the movement of someone without a cerebellum. Justify your prediction using your knowledge of the functions of the cerebellum.
14 Suggest a reason for the hypothalamus being located towards the centre of the brain.

WS **4.1 Central nervous system**

4.2 PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system takes messages from receptors to the central nervous system and from the CNS to muscles and glands. It is composed of:

- nerve fibres that carry information to and from the CNS
- groups of nerve cell bodies, called **ganglia**, which lie outside the brain and spinal cord.

Types of nerves

The nerve fibres are arranged into nerves, which arise from the brain and the spinal cord.

Cranial nerves

Twelve pairs of nerves, such as the optic nerve and auditory nerve, arise from the brain. These are the **cranial nerves**. Most cranial nerves are mixed nerves; that is, they contain fibres that carry impulses into the brain, as well as fibres that carry impulses away from the brain. Fibres that carry impulses into the CNS are called **sensory fibres**; those that carry impulses away from the CNS are **motor fibres**. A few cranial nerves carry only sensory impulses or only motor impulses.

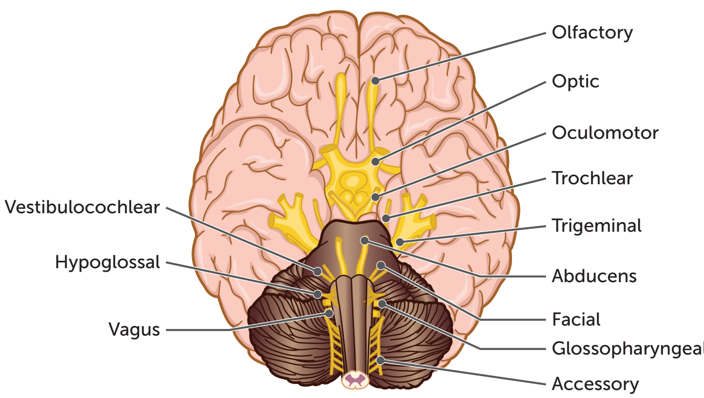


FIGURE 4.15 The 12 pairs of cranial nerves

Spinal nerves

Thirty-one pairs of **spinal nerves** arise from the spinal cord. They are all mixed nerves containing both sensory and motor fibres. Each nerve is joined to the spinal cord by two roots. The **ventral root** contains the axons of motor neurons that have their cell bodies in the grey matter of the spinal cord. The **dorsal root** contains the axons of sensory neurons that have their cell bodies in a small swelling on the dorsal root known as the **dorsal root ganglion**.

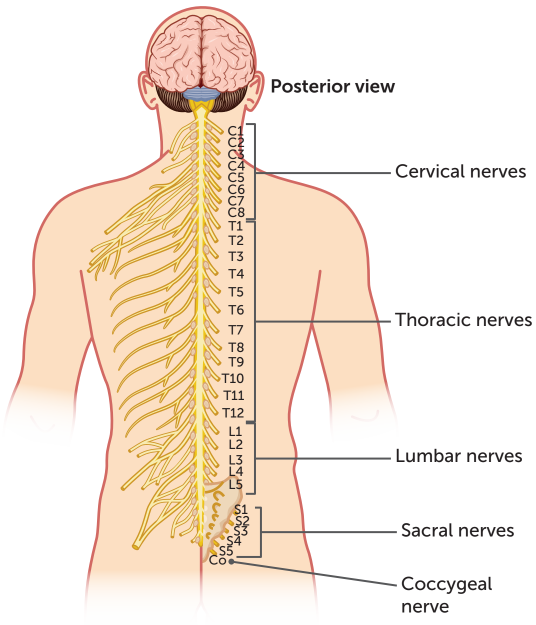


FIGURE 4.16 The 31 pairs of spinal nerves

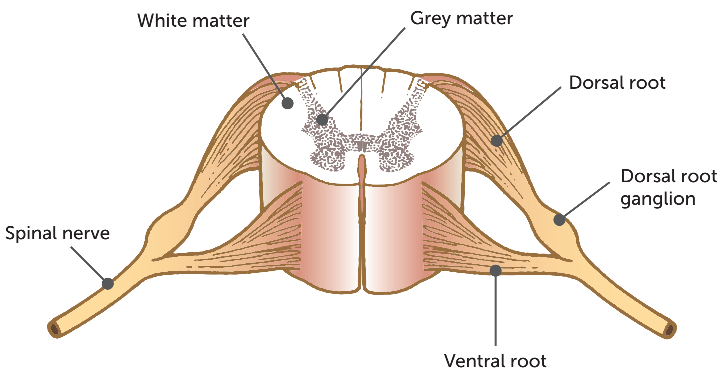


FIGURE 4.17 Cross-section of the spinal cord, showing a pair of spinal nerves with the dorsal and ventral roots

Key concept

The peripheral nervous system is made up of 12 pairs of cranial nerves and 31 pairs of spinal nerves that take messages between the central nervous system and receptors, muscles and glands.

Divisions of the peripheral nervous system

The nerves that make up the PNS contain fibres carrying nervous impulses to and from all parts of the body. To make it easier to study the various functions of the PNS, it has been divided and subdivided into parts, each with a particular function.

Afferent division

The **afferent** (or sensory) **division** of the PNS has fibres that carry impulses *into* the CNS by sensory neurons from receptors in the skin and around the muscles and joints. These neurons can be further divided into:

- **somatic sensory neurons**, which bring impulses from the skin and muscles
- **visceral sensory neurons**, which bring impulses from the internal organs.

Efferent division

The **efferent** (or motor) **division** has fibres that carry impulses *away* from the CNS. It is subdivided into:

- the **somatic division** (sometimes called the somatic nervous system), which takes impulses from the CNS to the skeletal muscles
- the **autonomic division** (autonomic nervous system), which carries impulses from the CNS to heart muscle, involuntary muscles and glands. The autonomic division is further subdivided into the:
  - **sympathetic division** (sympathetic nervous system)
  - **parasympathetic division** (parasympathetic nervous system).

These parts of the nervous system are summarised in Figure 4.18.

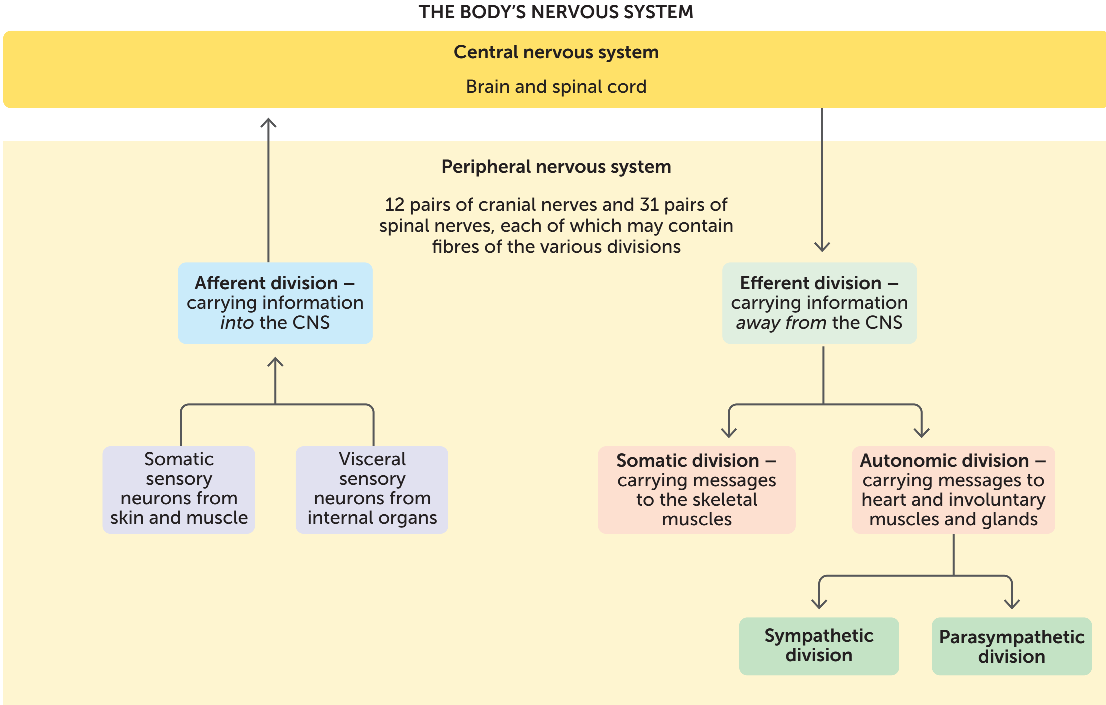


FIGURE 4.18 Functional organisation of the body's nervous system

Key concept

The peripheral nervous system is divided into divisions based on the type of nerve fibres, where the messages are travelling to or from, and the type of responses brought about.

Autonomic nervous system

The **autonomic nervous system (ANS)** controls the body's internal environment and is involved in many of the mechanisms that keep it constant. It usually operates without conscious control and is regulated by groups of nerve cells in the medulla oblongata, hypothalamus and cerebral cortex. Some of the body functions regulated by the autonomic division include:

- heart rate
- blood pressure
- body temperature
- digestion
- release of energy
- pupil diameter
- air flow to the lungs
- defecation
- urination.

The nerve fibres of the ANS make up part of the spinal nerves and part of some of the cranial nerves. They carry impulses to the heart muscle, other muscles of the internal organs and the glands. The impulse travels along two neurons from the CNS to an organ controlled by the ANS. The first neuron is myelinated and has its cell body in the CNS. The second neuron is unmyelinated and has its cell body in a ganglion (plural: ganglia); a group of nerve cell bodies outside the CNS.

The pathway from the CNS to heart muscle, involuntary muscle or glands is an important difference between the autonomic division and the somatic division. Where there are two motor neurons involved in the autonomic pathway, the somatic division has just one motor neuron carrying impulses from the CNS to the effector.

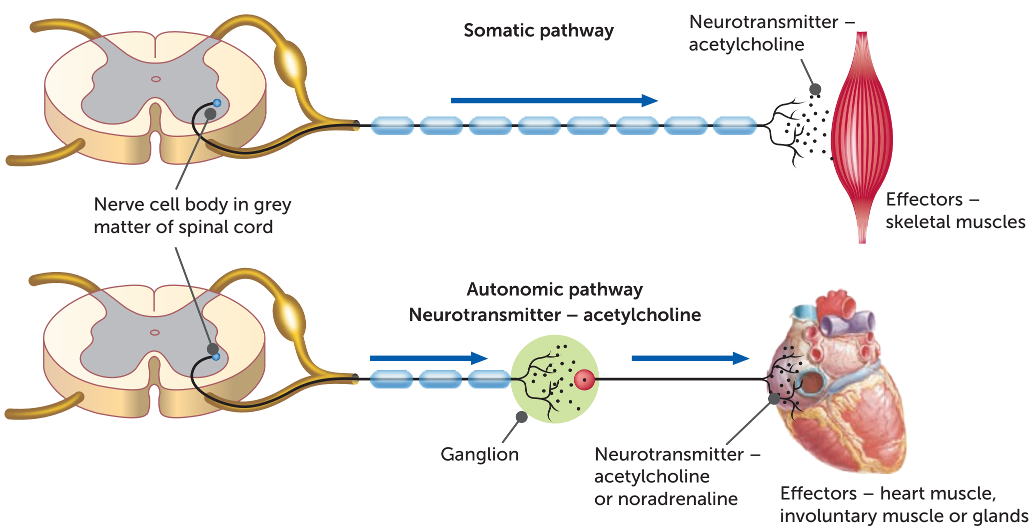


FIGURE 4.19 The difference in motor pathways between the autonomic and somatic divisions of the peripheral nervous system

There are two other important differences between the autonomic and somatic divisions. First, most organs under autonomic control receive two sets of nerve fibres – sympathetic fibres and parasympathetic fibres. Thus, the ANS is subdivided into sympathetic and parasympathetic divisions. Second, in the somatic nervous system, the neurotransmitter that carries the message from the neuron to the skeletal muscle is acetylcholine; in the ANS, either acetylcholine or noradrenaline carries the message to the effector. Table 4.3 summarises these and other differences between the autonomic and somatic divisions.

TABLE 4.3 Comparison of the autonomic and somatic divisions of the peripheral nervous system

CHARACTERISTIC	AUTONOMIC DIVISION	SOMATIC DIVISION
Effectors	Heart muscle, involuntary muscle, glands	Skeletal (voluntary) muscles
General function	Adjustment of the internal environment (homeostasis)	Response to the external environment
Efferent (outward) pathways	Two nerve fibres from the CNS to the effector with a synapse in a ganglion	One nerve fibre from the CNS to the effector; no synapse and no ganglion
Neurotransmitter at effector	Acetylcholine or noradrenaline	Acetylcholine
Control	Usually involuntary	Usually voluntary
Nerves to target organ	Two sets – sympathetic and parasympathetic	One set
Effect on target organ	Excitation or inhibition	Always excitation

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Impulses from the sympathetic and parasympathetic divisions have differing effects on organs or tissues. It is not possible to generalise and say that one set of fibres speeds up organ functioning and the other slows it down. However, it can be said that the parasympathetic division generally produces responses that maintain the body during relatively quiet conditions. On the other hand, the sympathetic division tends to produce responses that prepare the body for strenuous physical activity. These responses are often called fight-or-flight responses because they prepare the body for situations that may involve aggression or fleeing from a threat (see below).

The message from the autonomic nerves to the muscles and glands under their control is carried by a neurotransmitter at the nerve endings. Parasympathetic nerve endings release acetylcholine, and sympathetic nerve endings release noradrenaline.

Fight-or-flight response

Under normal circumstances, we are not aware of the activities of the ANS. This does not mean that it is in a resting state. When you are sitting quietly reading a human biology textbook, your sympathetic and parasympathetic nerves are sending out impulses to the internal organs to maintain the stability of the body's functions. For example, the heart has an inbuilt rate of contraction of about 100 beats per minute. While at rest, parasympathetic stimulation keeps this down to around 70 to 80 beats per minute.

FIGURE 4.20 a The sympathetic nervous system produces fight-or-flight responses; **b** The parasympathetic nervous system maintains the body during quiet times

In threatening situations, the balance between sympathetic and parasympathetic stimulation is upset and the sympathetic becomes dominant. Situations that involve fear, anger, stress, danger or competition provoke what is called a **fight-or-flight response** or **alarm reaction**. These responses prepare the body for increased activity (in other animals, to fight or to flee) and, therefore, rely on skeletal muscles producing movement and an increased level of alertness to think and act quickly. This state of preparedness needs a greater supply of oxygen and glucose and, hence, increased blood flow to relevant structures. Therefore, activation of the sympathetic division results in the following responses:

- The rate and force of contraction of the heart increase, with a consequent increase in blood pressure.
- Blood vessels dilate in organs involved in strenuous activity, such as the skeletal muscles, heart and liver.
- Blood vessels constrict in organs not involved in activity, such as the kidney, stomach, intestines and skin.
- Airways in the lungs dilate and the rate and depth of breathing increases.
- Blood glucose level rises, because the liver converts more glycogen into glucose.
- Secretion from sweat glands increases.
- The adrenal medullae release the hormones adrenaline and noradrenaline, which intensify and prolong the above responses.

Table 4.4 summarises the effects of the sympathetic and parasympathetic fibres of the ANS.

TABLE 4.4 Summary of the effects of the autonomic nervous system

STRUCTURE	EFFECT OF SYMPATHETIC STIMULATION	EFFECT OF PARASYMPATHETIC STIMULATION
Heart	Increases rate and strength of contraction	Decreases rate and strength of contraction
Lungs	Dilates bronchioles (fine air passages in the lungs)	Constricts bronchioles
Stomach, intestines	Decreases movement	Increases movement
Liver	Increases breakdown of glycogen and release of glucose	Increases uptake of glucose and synthesis of glycogen
Iris of the eye	Dilates pupil	Constricts pupil
Sweat glands	Increases sweat secretion	No effect
Salivary glands	Decreases secretion of saliva	Increases secretion of saliva
Blood vessels of: • skin • skeletal muscle • internal organs	 Constricts vessels Dilates vessels Constricts vessels (except in heart and lung)	 Little effect No effect Little effect
Urinary bladder	Relaxes muscles of wall	Constricts muscles of wall
Adrenal medulla	Stimulates hormone secretion	No effect

Note: This is only a summary of the most important effects of sympathetic and parasympathetic stimulation. There are many other effects of these divisions.

Key concept

The autonomic nervous system is responsible for maintaining the internal environment of the body. It contains sympathetic and parasympathetic divisions that work together to prepare the body for strenuous activity or rest, respectively.

Activity 4.3
Observing an autonomic reflex

Peripheral nervous system
This website provides more information about the peripheral nervous system.

Overview of the autonomic nervous system
This website provides more information on the autonomic nervous system and its disorders.

4.2 Nervous system overview

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Questions 4.2

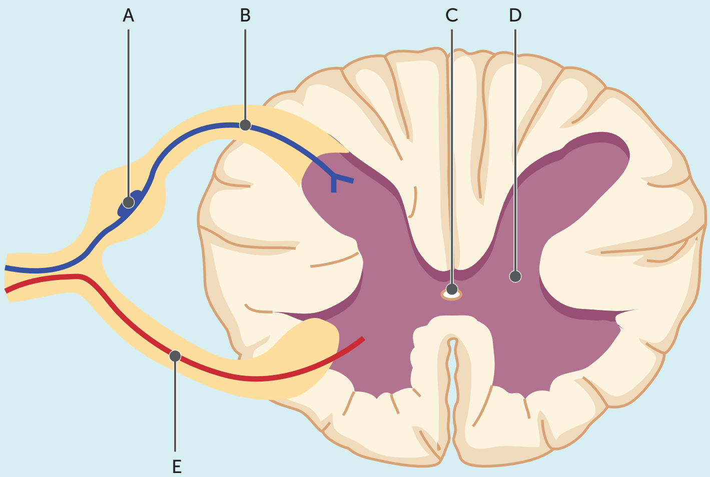
RECALL KNOWLEDGE

1 What structures make up the peripheral nervous system?

2 State the number of:
  a cranial nerves
  b spinal nerves.

3 'All of the nerves in the peripheral nervous system are mixed nerves, made up of both motor and sensory fibres.' Discuss this statement.

4 Label structures A–E on the diagram below.



5 Draw a tree diagram to show the divisions of the peripheral nervous system.

6 Which division of the PNS takes messages:
  a into the CNS from the internal organs?
  b from the CNS to the muscles and glands?
  c from the CNS to the involuntary muscles?
  d into the CNS from the skin and muscles?

7 Compare and contrast the sympathetic and parasympathetic nervous systems.

8 Explain how the sympathetic nervous system is able to prepare the body for a fight-or-flight response.

APPLY KNOWLEDGE

9 State one similarity and one difference between an ascending tract and a sensory nerve.

10 Suggest what would happen if the body could not produce acetylcholine.

CHAPTER 4 ACTIVITIES

ACTIVITY 4.1 Examining a dissected brain

A sheep's brain is similar to that of a human, so examining a sheep's brain can help you to understand what a human brain is like.

You will need

Sheep's brain; dissecting instruments; dissecting board or tray; gloves; safety glasses

What to do

1. Place the brain on the dissecting board.
2. Observe the brain from the top.
   a. Describe what the brain looks like.
   b. Identify the cerebrum (both left and right hemispheres) and the cerebellum.
   c. Take note of the convolutions, sulci and fissures.
   d. Take a photo of the brain from the top.
3. Using forceps, peel off some of the membrane that covers the surface of the cerebrum.
   a. This membrane is the inside layer of the meninges. Describe the appearance of the meninge.
   b. Take a photo of the meninge.
4. Turn the brain over and observe it from the bottom.
   a. Describe what the brain looks like.
   b. Identify the cerebellum, brain stem, medulla oblongata and, if possible, the pituitary gland.
   c. Take a photo of the brain from the bottom.
5. Carefully cut the brain in half by cutting between the left and right hemispheres.
   a. Describe what the brain looks like.
   b. Identify where the left and right hemispheres were joined together. This is called the corpus callosum.
   c. Take a photo of the brain.
6. Cut the cerebrum in half by cutting one hemisphere from left to right.
   a. Describe what the cerebrum looks like on the inside.
   b. Identify the white matter (myelinated fibres) and grey matter (cell bodies and unmyelinated fibres).
   c. Predict why the myelinated fibres make up the white matter.
   d. Take a photo of the inside of the cerebrum.
7. Cut the cerebellum in half.
   a. Describe what the cerebellum looks like on the inside.
   b. Take a photo of the inside of the cerebellum.
8. Cut the spinal cord in half.
   a. Describe what the spinal cord looks like on the inside.
   b. Describe how this is the same as or different from the inside of the cerebrum.
   c. Take a photo of the inside of the spinal cord.
9. Feel the texture of the different parts of the brain.
   a. Describe what the brain feels like.
   b. Suggest why it feels like this.

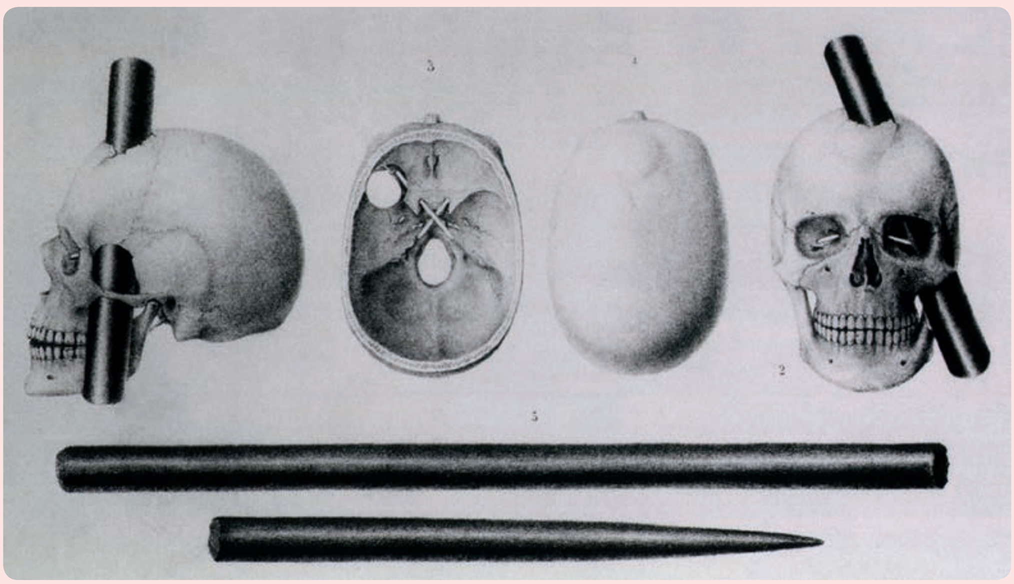
10 Packing up.
   a Wrap the brain in newspaper and put it in the bin.
   b Wash and wipe your chopping board and put it away.
   c Place the scalpel and probe in the containers provided. Make sure they are placed pointy end down.

Putting it together

1 Collate your photos on to one page.
   a Label each to show how it was taken (e.g. 'Top of brain').
   b Add labels to identify the parts of the brain that you can see in each photo.
   c Add labels to identify the lobes of the cerebrum.
2 A human brain has many more convolutions than a sheep's brain. Explain the significance of the greater number of convolutions in humans.
3 What is the function of the inner meningeal layer?
4 You would have noticed that the inside of the brain is moist.
   a What is the name of the fluid that fills spaces inside the brain?
   b Where does the fluid come from, and what is its function?

ACTIVITY 4.2 Phineas Gage

In 1848, Phineas Gage was foreman of a gang of workers building a railway in the American state of Vermont. His gang's job was to blast rock with explosives. On 13 September of that year, after placing gunpowder in a hole they had drilled in a rock, Gage began to compact the charge by pushing an iron rod into the hole. The rod was 3 cm in diameter and more than 1 m long. The charge exploded and drove the rod through Gage's skull. The image below shows how it entered the side of his face, passed behind his left eye and exited through the top of his cranium. Reports claimed that the iron rod landed 25 m away. Remarkably, Gage survived the horrendous injury to his brain. He was able to work again (but not with explosives!) and lived for 12 years following the accident.



Alamy Stock Photo/Everett Collection Inc

After the accident, changes were reported in Gage's behaviour, but his bodily functions such as heartbeat, breathing, digestion, metabolism and regulation of body temperature were unaffected.

Follow the weblink for help in answering the following questions.

1 How is it possible that Gage was able to function relatively normally with damage to such a large and vital part of his brain?
2 Changes in a person's functioning or behaviour as a result of injury to the brain were used by scientists to determine the functions of the affected parts of the brain. Were scientists able to learn anything about the brain from Gage's injury?
3 Did Gage's injury have any positive benefits for medical science?

Phineas Gage
This is a good place to begin your search for answers to these questions.

ACTIVITY 4.3 Observing an autonomic reflex

Work in pairs for this activity, with one person acting as the subject and the other as observer.

The subject should close his or her eyes for at least one minute. While facing a window, or other bright light, the subject then opens their eyes while the observer looks closely to see what happens.

Swap roles and repeat the activity.

1 What change was observed in the subject's pupils when the eyes were opened?
2 What change was observed in the subject's iris when the eyes were opened?
3 Why is the response that you observed described as a reflex?
4 Many reflexes are described as protective. Is the reflex that you observed a protective reflex? Explain.
5 Would it be possible to consciously prevent the response that you observed from occurring?
6 Which division of the autonomic nervous system caused the response that you observed?
7 Optometrists place drops of a drug in the eyes to dilate the pupils so that the eyes can be examined. The drug blocks receptors for acetylcholine. Suggest why such a drug placed in the eyes could cause the pupil to dilate.

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CHAPTER 4 SUMMARY

- The nervous system is made up of the brain and spinal cord (the central nervous system) and nerves (the peripheral nervous system).
- The central nervous system (CNS) processes incoming messages and initiates outgoing messages.
- The CNS is protected by bone (cranium and vertebrae), meninges and cerebrospinal fluid (CSF).
- The meninges are made up of three layers – the dura mater, arachnoid mater and pia mater – between the inside of the bone and the outside of the brain and spinal cord.
- CSF is found between the inner and middle layers of the meninges, as well as in cavities in the brain and the central canal of the spinal cord. It acts as a shock absorber, supports the brain, and transports nutrients and wastes.
- The brain is made up of different structures that carry out different functions.
- The cerebrum makes up the largest portion of the brain. Its outer layer, the cerebral cortex, is made up of grey matter that surrounds the white matter. There is also grey matter deep inside the cerebrum that is called the basal ganglia.
- Grey matter is made up of cell bodies, dendrites and unmyelinated axons, whereas the white matter is made up of myelinated axons. Tracts in the white matter connect different areas of the brain.
- The cerebral cortex is folded, forming convolutions (ridges), sulci (shallow downfolds) and fissures (deeper downfolds).
- The cerebrum can be divided into left and right hemispheres that are joined by the corpus callosum. It can also be divided into five lobes: parietal, frontal, occipital, temporal and insula.
- The cerebral cortex is involved in thinking, reasoning, learning, memory, intelligence, sense of responsibility, movement and senses. These functions allow the cortex to be divided into sensory areas, motor areas and association areas.
- The cerebellum, a folded structure at the base of the brain, is responsible for posture, balance and the coordination of movement.
- The hypothalamus helps maintain a constant internal environment by regulating heart rate, blood pressure, digestion, temperature, water intake and emotions.
- The medulla oblongata contains the cardiac, respiratory and vasomotor centres and plays a role in automatically adjusting body functions.
- The spinal cord runs down the back in the vertebral column. It contains myelinated fibres that take impulses towards the brain in the ascending tracts and away from the brain in the descending tracts.
- The peripheral nervous system (PNS) is made up of the nerves taking messages into and out of the CNS, and groups of nerve cell bodies called ganglia.
- Nerves can be classified as cranial or spinal, based on where they connect with the CNS.
- There are 12 pairs of cranial nerves. Most of these are mixed nerves, containing motor and sensory fibres.
- There are 31 spinal nerves. All of these are mixed nerves. The motor fibres exit the spinal cord via the ventral root, while the sensory fibres enter the spinal cord via the dorsal root. The cell bodies of the motor fibres are located in the dorsal root ganglion.
- The PNS can be divided into afferent and efferent divisions. The afferent division is made up of sensory neurons taking messages from the receptor into the CNS. The efferent division is made up of motor neurons taking messages

away from the CNS to the muscles and glands.
- The afferent division is further divided into somatic sensory neurons from the skin and muscle, and the visceral sensory neurons from the internal organs.
- The efferent division is further divided into the somatic division, which takes impulses to the skeletal muscles, and the autonomic division, which takes messages to the heart, involuntary muscles and glands.
- The autonomic nervous system operates without conscious control and helps to regulate body functions such as heart rate, blood pressure, body temperature, digestion, air flow and energy release. It is made up of the parasympathetic division, which maintains the body during rest, and the sympathetic division, which prepares the body for strenuous activity.

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CHAPTER 4 GLOSSARY

Afferent division Part of the peripheral nervous system containing nerve fibres that carry impulses into the brain and spinal cord; also called sensory division

Alarm reaction *see* fight-or-flight response

Arachnoid mater The middle meningeal layer

Ascending tract Any of the sensory nerve fibres in the central nervous system that carry impulses towards the brain

Association area A part of the cerebral cortex concerned with intellectual and emotional processes such as memory, reasoning, judgement and personality

Autonomic division The part of the efferent division of the peripheral nervous system that carries nerve impulses from the brain and spinal cord to internal organs, involuntary muscles and glands; also called the autonomic nervous system

Autonomic nervous system (ANS) The part of the nervous system that controls the body's internal environment

Basal ganglia The masses of grey matter inside each cerebral hemisphere

Cardiac centre The part of the brain that regulates heartbeat; located in the medulla oblongata

Central canal A hollow that runs through the centre of the spinal cord; filled with cerebrospinal fluid

Central nervous system (CNS) The part of the nervous system that consists of the brain and spinal cord

Cerebellum The part of the brain behind and below the cerebrum; concerned with coordination of movement

Cerebral cortex The outer layer of the cerebrum, made up of grey matter

Cerebral hemisphere One of the two halves of the cerebrum

Cerebrospinal fluid (CSF) Fluid produced in the cavities of the brain; fills the brain cavities and surrounds the brain and spinal cord

Cerebrum The largest part of the brain; made up of left and right hemispheres

Convolution An upward fold of the cerebral cortex of the brain; also called gyrus

Corpus callosum A bundle of nerve fibres that links the two cerebral hemispheres

Cranial nerve One of the 12 pairs of nerves that arise from the brain

Cranium The part of the skull that contains the brain

Descending tract Any of the motor nerve fibres in the central nervous system that carry impulses away from the brain

Dorsal root One of the two roots that link a spinal nerve to the spinal cord; located towards the back of the body and contains axons of sensory neurons

Dorsal root ganglion A group of nerve cell bodies located in the dorsal root of a spinal nerve

Dura mater The outer meningeal layer

Efferent division Part of the peripheral nervous system containing nerve fibres that carry impulses out of the brain and spinal cord; also called motor division

Fight-or-flight response A response preparing the body for increased activity; brought about by stimulation of the sympathetic division of the autonomic nervous system

Fissure A deep downfold in the cerebral cortex of the brain

Frontal lobe One of the five lobes of each cerebral hemisphere

Ganglia Groups of nerve cell bodies outside the brain or spinal cord; singular: ganglion

Grey matter The part of the brain and spinal cord made up of nerve cell bodies and unmyelinated fibres

Gyrus An alternative name for a convolution of the cerebrum; plural: gyri

Hypothalamus The part of the brain lying just below the thalamus; controls many homeostatic mechanisms, such as body temperature, water balance and heart rate

Insula A part of the cerebrum that is buried deep inside the brain; considered a fifth lobe of each cerebral hemisphere

Longitudinal fissure The longest fissure in the human brain; almost separates the cerebrum into two halves

Medulla oblongata The part of the brain that joins to the spinal cord

Meninges The membranes covering the brain and spinal cord

Motor area A part of the cerebral cortex that controls muscle movement

Motor fibre A fibre that carries impulses away from the central nervous system

Myelin White, fatty material that surrounds some nerve fibres

Nervous system The system involved with control and coordination of the body

Occipital lobe One of the five lobes of each cerebral hemisphere

Parasympathetic division One of the two divisions of the autonomic nervous system; opposes the function of the sympathetic division; also called parasympathetic nervous system

Parietal lobe One of the five lobes of each cerebral hemisphere

Peripheral nervous system (PNS) The part of the nervous system that connects the central nervous system with the receptors, muscles and glands

Pia mater The inner meningeal layer

Respiratory centre The part of the brain that regulates breathing rate; located in the medulla oblongata

Sensory area A part of the cerebral cortex that interprets impulses from receptors

Sensory fibre A fibre that carries impulses into the central nervous system

Somatic division The part of the efferent division of the peripheral nervous system that carries nerve impulses from the brain and spinal cord to skeletal muscles and skin; also called the somatic nervous system

Somatic sensory neuron A neuron in the afferent division of the peripheral nervous system that takes impulses from the skin and muscles to the central nervous system

Spinal cord The nerve cord that extends from the brain to about waist level; enclosed in the vertebrae

Spinal nerve One of the 31 pairs of nerves that arise from the spinal cord; joined to the spinal cord by dorsal and ventral roots

Sulci Shallow downfolds between convolutions of the cerebral cortex; singular: sulcus

Sympathetic division One of the two divisions of the autonomic nervous system; opposes the function of the parasympathetic division; also called sympathetic nervous system

Temperal lobe One of the five lobes of each cerebral hemisphere

Tract A bundle of nerve fibres in the central nervous system

Vasomotor centre The part of the brain that regulates the diameter of blood vessels; located in the medulla oblongata

Ventral root One of the two roots that link a spinal nerve to the spinal cord; located towards the front of the body; contains axons of motor neurons

Vertebral canal The opening in the vertebrae through which the spinal cord passes

Visceral sensory neuron A neuron in the afferent division of the peripheral nervous system that takes impulses from the internal organs to the central nervous system

White matter The part of the brain and spinal cord made up of myelinated fibres

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CHAPTER 4 REVIEW QUESTIONS

Recall

1 Describe the three structures that protect the central nervous system.

2 a What is cerebrospinal fluid?
  b Where does CSF come from?
  c Where does CSF go to?
  d What does CSF do?

3 a Describe the cerebral cortex.
  b List the advantages of the cerebral cortex being folded.
  c What is the difference between a sulcus and a fissure?

4 a Describe the functions of the cerebral cortex.
  b Name the three types of area in the cerebral cortex and identify the function of each type.

5 a Describe the location of the hypothalamus.
  b List some of the functions of the hypothalamus.

6 a Describe the location of the cerebellum.
  b What are the main functions of the cerebellum?

7 How many pairs of nerves arise from each of the brain and spinal cord?

8 On what sort of nerve would you find a ventral root and a dorsal root? Explain where these roots are located.

9 Does the autonomic nervous system require conscious control? Why is this important?

10 Describe four differences between the somatic and autonomic divisions of the peripheral nervous system.

11 What is a ganglion?

12 In general terms, what is the difference between responses brought about by the sympathetic and parasympathetic divisions of the autonomic nervous system?

Explain

13 Explain how the structure of the corpus callosum allows it to achieve its function.

14 Explain the medulla oblongata's role in adjusting normal body functions.

15 Explain what a mixed nerve is.

16 a What is the difference between the afferent and efferent divisions of the peripheral nervous system?
  b What is the difference between the somatic and autonomic divisions of the efferent division of the peripheral nervous system?

Apply

17 Compare and contrast the grey matter in the cerebrum, cerebellum and spinal cord.

18 After sustaining a head injury in a car accident, a person had difficulty chewing and swallowing. What part of the brain could have been damaged? Justify your answer.

19 Paraplegia (inability to move the legs) may be caused by an injury to the spinal cord. Explain why such an injury could result in paraplegia.

20 A person could survive complete destruction of one of the cerebral hemispheres, which make up nearly 40% of the volume of the brain. By contrast,

destruction of the hypothalamus, which is only about the size of an almond, would result in certain death. Explain the reasons for this difference.

21 If the ventral root of a spinal nerve were damaged, would it affect the sensory functions or the motor functions of that nerve? Explain.

22 a List four stimuli that could lead to a fight-or-flight response.
b List four responses that would prepare the body for fight or flight.

23 It is sometimes said that the sympathetic division of the autonomic nervous system produces fight-or-flight responses, while the parasympathetic division is concerned with 'rest and digest'. Do you think these are appropriate descriptions for the two divisions? Explain your answer.

24 Urinary retention (inability to empty the bladder or incomplete emptying of the bladder) and incontinence (uncontrollable, involuntary leaking of urine) are both possible symptoms of disease of the autonomic nervous system. Which part of the autonomic division would be affected in each case? Explain your answer.

25 If the dorsal root of a spinal nerve were damaged, would there be any impairment of the autonomic functions controlled by that nerve? Explain your answer.

26 Would a drug that stimulated acetylcholine receptors affect the autonomic division, the somatic division or both? Give reasons for your answer.

27 The drug atropine occupies acetylcholine receptors at the synapse. Ophthalmologists once used atropine when they needed to dilate a patient's pupils. Explain why atropine would have this effect.

Extend

28 In severe cases of epilepsy, as a last resort, the corpus callosum may be severed so that the two cerebral hemispheres can no longer communicate with each other. Patients who have had this procedure are commonly referred to as having a 'split brain'. As each of the two cerebral hemispheres has separate functions, a split brain has a significant impact on the performance of simple tasks. Use references to find out the effects that a split brain would have on a person's functioning.

29 We all need a certain amount of sleep to continue to function normally. Conduct research to find out:
a what happens to the brain during sleep
b the difference between deep sleep and rapid eye movement (REM) sleep
c the difference between sleep and a coma.

30 Lie detectors measure ANS activity. Their use is based on the idea that when a person lies, there are involuntary changes in their body functions.
Find out:
a what kinds of things lie detectors measure and how they are measured
b whether it is the activity of the sympathetic or parasympathetic divisions that produces the responses measured
c how reliable lie detectors are, and reasons for their reliability or unreliability.

31 As people get older, changes occur in the nervous system. Some changes are serious enough to be called a disease; an example is Alzheimer's disease. Other changes are just a natural part of ageing. Conduct research to find out:
a the changes to the nervous system that occur in everyone as they get older
b the reasons for those changes
c what can be done to reduce or delay the changes to the nervous system.

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