

# Chapter 6

## The peripheral nervous system

# Unit 3B

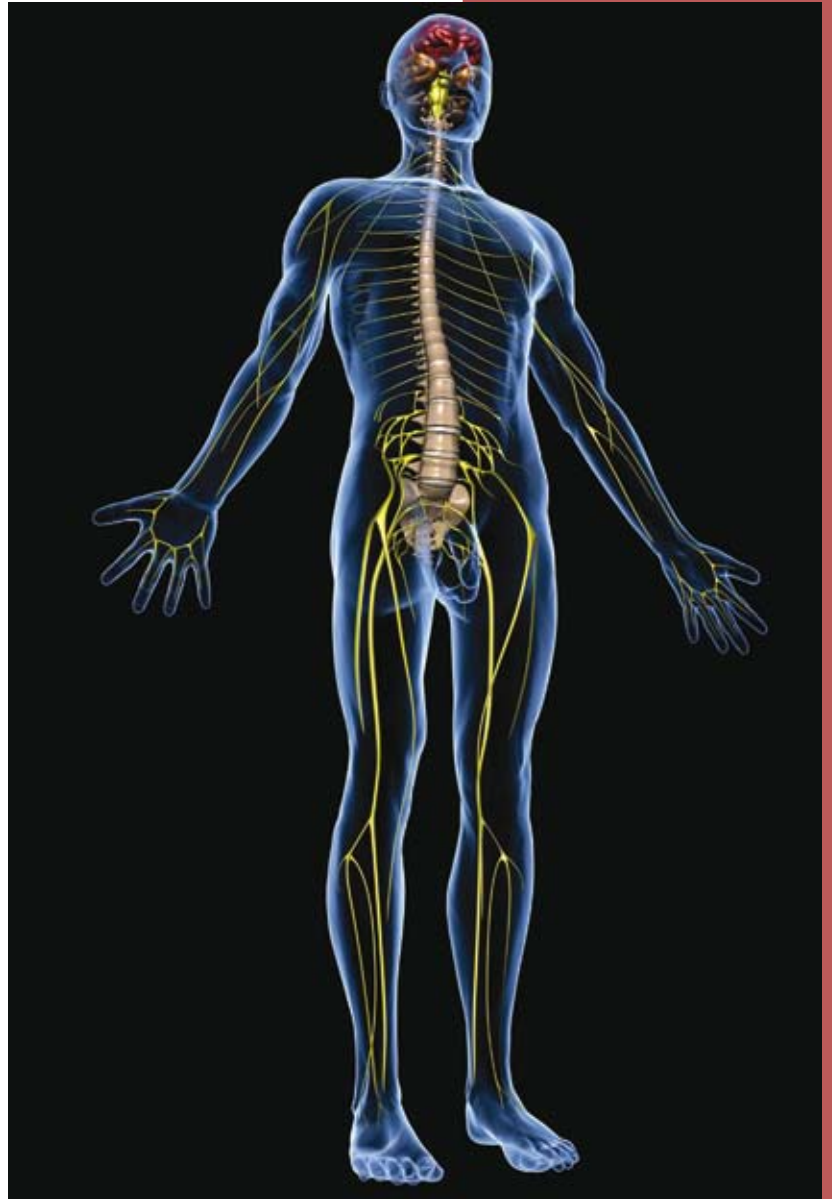
### Unit content

#### Body systems

The nervous system and the musculo-skeletal system interact to provide coordinated actions of the body.

Central and peripheral nervous system:

- afferent and efferent systems
- structure of motor, sensory and interneurons
- the reflex arc including components and their functions in the transmission of messages
- transmission of nerve impulses.



**Figure 6.1** The peripheral nervous system consists of nerves that extend to all parts of the body

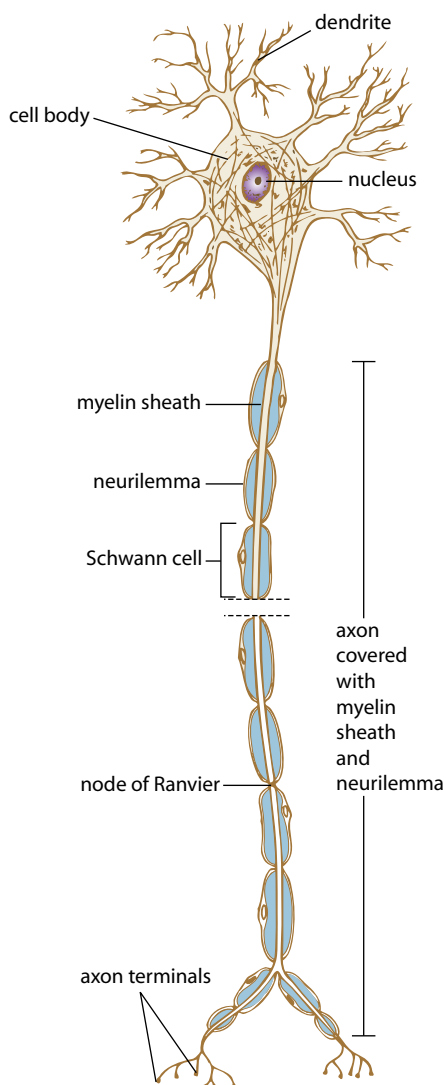
The brain and spinal cord make up the *central nervous system* (CNS), the place where incoming messages are processed and where outgoing messages are initiated. Nerves carry the messages in and out of the CNS. These nerves make up the peripheral nervous system that is the subject of this chapter.

## Nervous tissue

As we saw in Chapter 5, nerve cells, or **neurons**, are composed of a cell body with long extensions that carry messages to or from the cell body. Dendrites carry messages towards the cell body while the axon usually carries nerve impulses away from the cell body. Axons may be myelinated, covered with a myelin sheath of fatty material, or they may be unmyelinated.

Outside the brain and spinal cord the myelin sheath is formed by special cells called **Schwann cells**, which wrap around the axon. At intervals along the axon there are gaps in the myelin sheath called **nodes of Ranvier**. The sheath has three important functions: it acts as an insulator; it protects the axon from damage; and it speeds up the movement of nerve impulses along the axon. Around the myelin sheath the outermost coil of the Schwann cell forms a structure called the **neurilemma**, which helps in the repair of injured fibres (see Figs 6.2 and 6.3).

**Figure 6.2** Structure of a typical neuron with a myelinated axon



## Types of neurons

### Functional types

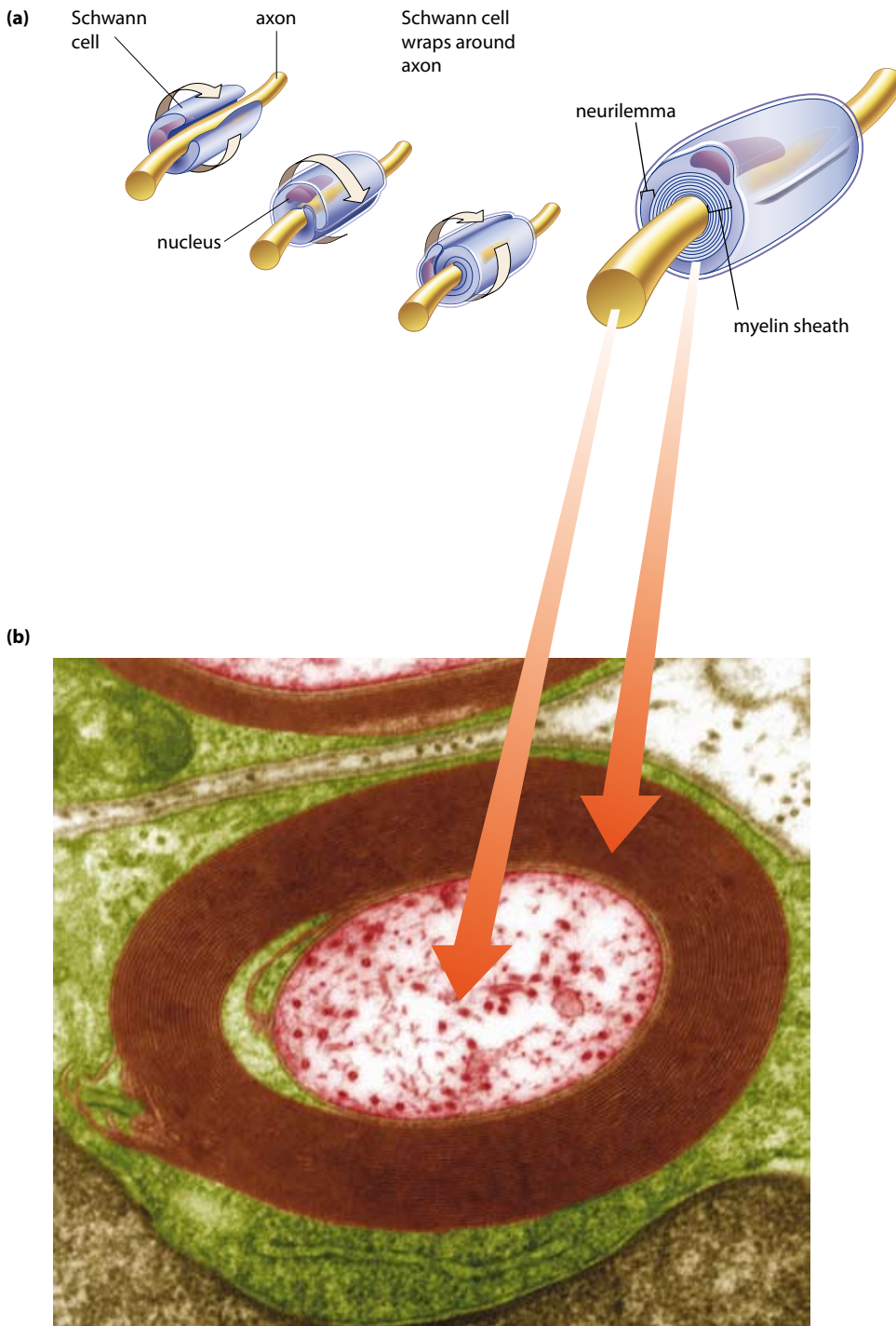
Neurons may be classified into three types depending on the *function* each performs.

- **Sensory** (or receptor) neurons carry messages from receptors in the sense organs, or in the skin, to the central nervous system (brain and spinal cord).
- **Motor** (or effector) neurons carry messages from the central nervous system to the muscles and glands—the effectors. A typical motor neuron is shown in Figure 6.2.
- **Interneurons** are located in the central nervous system and are the link between the sensory and motor neurons. Interneurons may also be called **association neurons**, **connector neurons** or **relay neurons**. Typical examples can be seen in Figure 5.3 on page 64.

### Structural types

Another way of classifying neurons is by their *structure*. It is based on the number of extensions from the cell body (see Fig. 6.4).

- **Multipolar neurons** have one axon and multiple dendrites extending from the cell body. This type of neuron is the most common and they include most of the interneurons in the brain and spinal cord and also the motor neurons that carry messages to the skeletal muscles.
- **Bipolar neurons** have one axon and one dendrite. Both axon and dendrite may have many branches at their ends. Bipolar

**Figure 6.3**

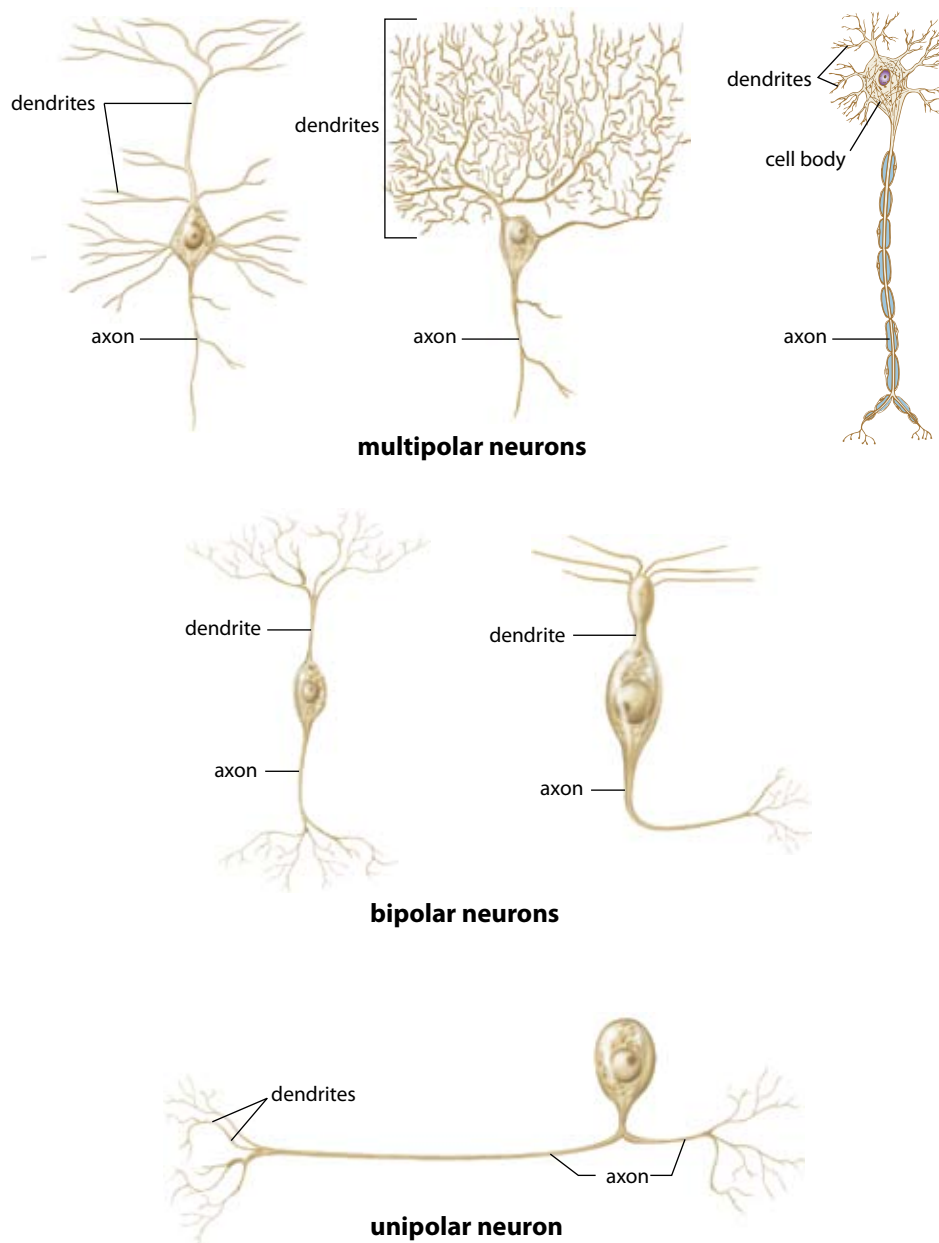
**(a)** Schwann cells form the sheath of a myelinated axon by wrapping around the axon. **(b)** Coloured transmission electron micrograph of a transverse section of a myelinated axon. The myelin sheath (brown) is formed when Schwann cells wrap around the axon and deposit layers of myelin between each coil. The outermost layer (green) is the cytoplasm of the Schwann cell—the neurilemma.

neurons occur in the eye, ear and nose where they take impulses from the receptor cells to other neurons.

- **Unipolar neurons** have just one extension, an axon. The cell body is to one side of the axon. Most sensory neurons that carry messages to the spinal cord are of this type.

The axons and dendrites of nerve cells are known collectively as **nerve fibres**. Outside the central nervous system nerve fibres are arranged into bundles called **nerves**. In a nerve the fibres are held together by sheaths of connective tissue.

**Figure 6.4** The structure of different types of neurons



**Table 6.1** The difference between neurons, nerve fibres and nerves

|             |   |
|-------------|---|
| Neuron      | A nerve cell  |
| Nerve fibre | Any long extension of cytoplasm of a nerve cell body, although the term usually refers to an axon |
| Nerve       | A bundle of nerve fibres held together by connective tissue                                       |

## Synapses

Nerve impulses have to be passed from neuron to neuron. The junction between the branches of adjacent neurons is called the **synapse**. At the synapse the neurons do not actually join—there is a very small gap between them. Most synapses occur between the end branches of an axon of one neuron and a dendrite or the cell body of another neuron (Fig. 6.5). Messages have to be carried across the synapse.

A similar synapse exists where an axon meets a skeletal muscle cell. This tiny gap is called the **neuromuscular junction**.

## Divisions of the nervous system

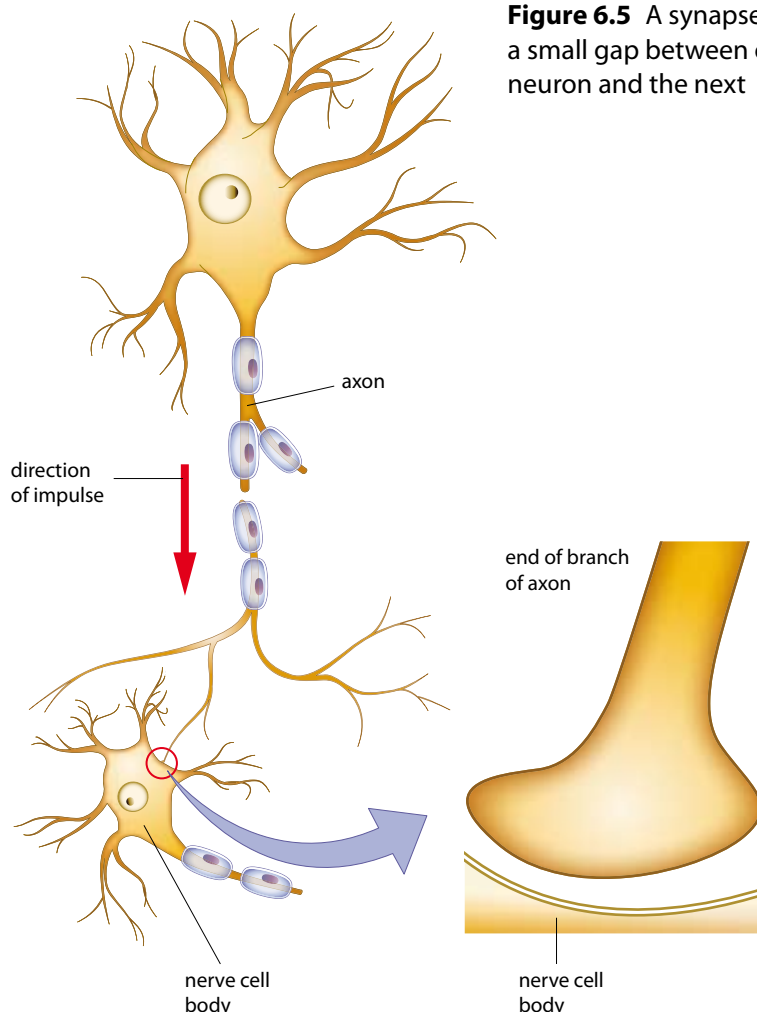
The body's nervous system consists of the brain and spinal cord and all the nerves. To make things confusing, some of the parts of this nervous system are also called nervous systems. The two main parts of the nervous system are the central nervous system (discussed in Chapter 5) and the peripheral nervous system. The central nervous system, the control centre, consists of the brain and spinal cord, while the nerves that connect the central nervous system with the receptors, muscles and glands make up the **peripheral nervous system**.

The peripheral nervous system consists of nerve fibres that carry information to and from the central nervous system and groups of nerve cell bodies, **ganglia**, which lie outside the brain and spinal cord. The nerve fibres are arranged into nerves that arise from the brain and the spinal cord. Twelve pairs of nerves arise from the brain. These are the **cranial nerves**. The names of some cranial nerves, such as the optic nerve and the auditory nerve, are probably familiar to you. Most cranial nerves are mixed nerves; that is, they contain both motor and sensory fibres, but a few cranial nerves carry only sensory impulses or only motor impulses.

Thirty-one pairs of **spinal nerves** arise from the spinal cord. They are all mixed nerves and each 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** (Fig. 6.6).

The 12 pairs of cranial and 31 pairs of spinal nerves that make up the peripheral nervous system contain fibres carrying nervous impulses to and from all parts of the body. To make it easier to study the various functions of the peripheral nervous system, it has been divided and subdivided into parts, each with a particular function.

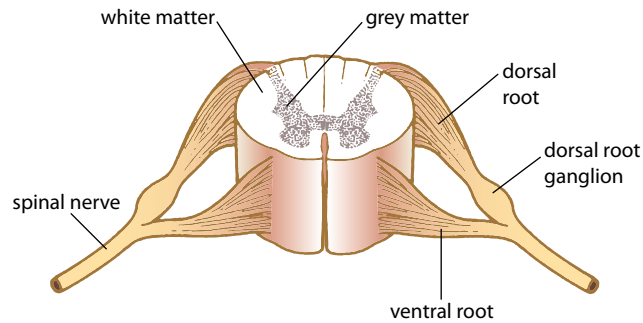
1. The **afferent** (or **sensory**) **division** of the peripheral nervous system has fibres that carry impulses *into* the central nervous system. These impulses are carried into the central nervous system by sensory nerve cells from receptors in the skin and around the muscles and joints. These nerve cells from the body are called **somatic** sensory neurons. The afferent division of the peripheral nervous system also has sensory nerve cells that take impulses from the internal organs into the central nervous system. These are called **visceral** sensory neurons (Fig. 6.7).



**Figure 6.5** A synapse is a small gap between one neuron and the next

For names and descriptions of individual nerves, go to <http://www.innerbody.com/image/nervov.html>

**Figure 6.6** Part of the spinal cord showing a pair of spinal nerves with roots



2. The **efferent** (or **motor**) **division** has fibres that carry impulses *away* from the central nervous system. It is subdivided into:
  - (a) the **somatic division** (sometimes called the somatic nervous system), which takes impulses from the central nervous system to the skeletal muscles
  - (b) the **autonomic division** (autonomic nervous system), which carries impulses from the central nervous system to heart muscle, involuntary muscle and glands. (The role of the autonomic nervous system will be discussed in Chapter 7.) The autonomic division is further subdivided into:
    - (i) the **sympathetic division** (sympathetic nervous system)
    - (ii) the **parasympathetic division** (parasympathetic nervous system).

These parts of the nervous system are summarised in Figure 6.7.

## Transmission of nerve impulses

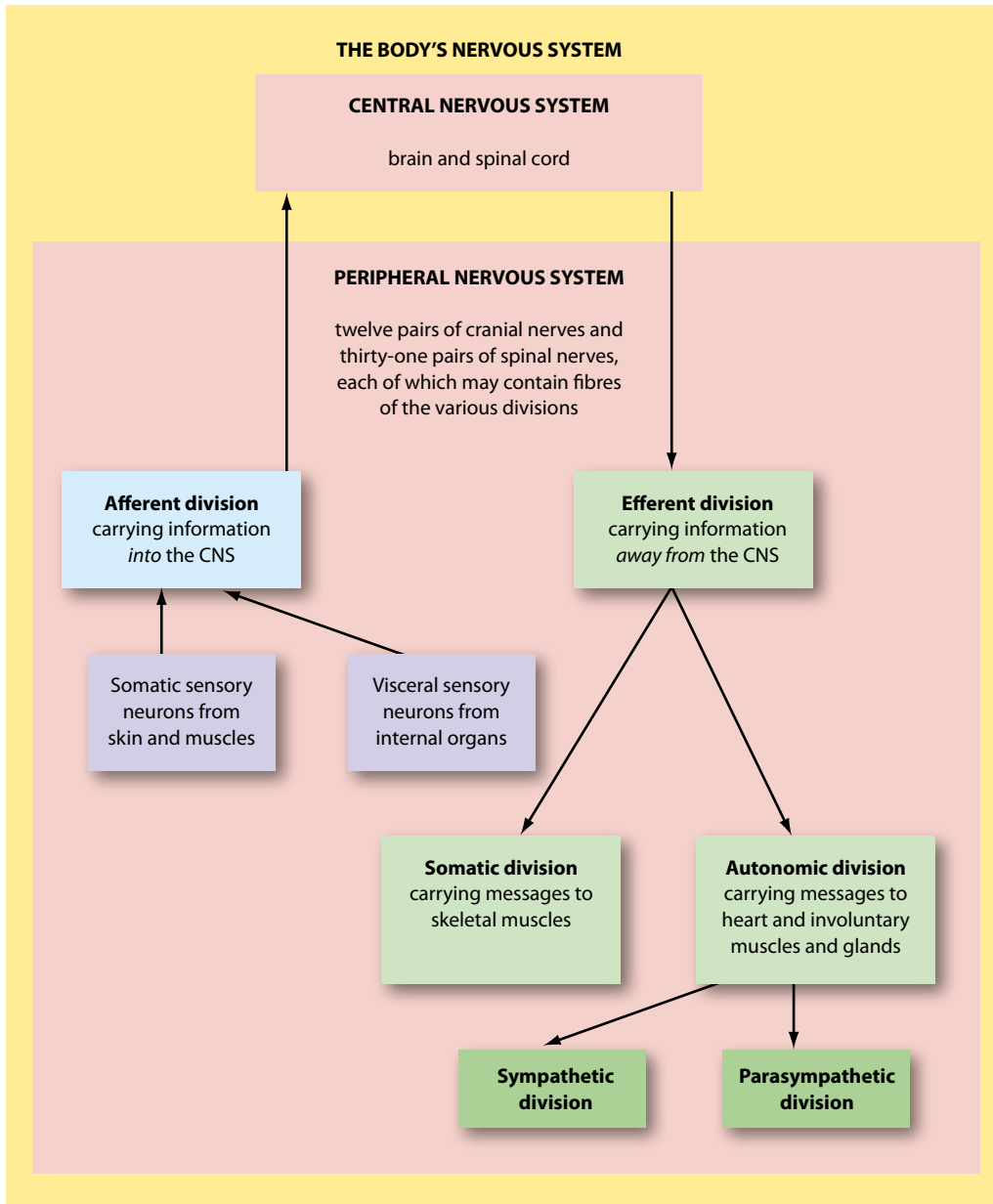
The message that travels along a nerve fibre is called a **nerve impulse**. Nerve impulses are transmitted very quickly so that the body is able to respond rapidly to any change in the internal or external environment.

A nerve impulse is an **electrochemical change** that travels along a nerve fibre. It is described as electrochemical because it involves a change in electrical voltage that is brought about by changes in the concentration of ions inside and outside the cell membrane of the neuron. Electrical voltage and the nature of the nerve impulse will be described in more detail in Chapter 7.

Although all nerve impulses travel quickly there is a lot of variation in speed of transmission. The speed at which an impulse travels depends on whether the nerve fibre is myelinated or unmyelinated and also on the diameter of the fibre. In unmyelinated fibres the impulse travels steadily along the fibre. The maximum speed of this type of transmission is 2 metres per second, which is equivalent to about 7 km/hour.

In myelinated fibres the myelin sheath is not continuous. It is punctuated by gaps, called the nodes of Ranvier. The nerve impulses jump from one node to the next. This jumping conduction, known as **saltatory conduction**, allows the nerve impulse to travel much faster. Depending on the diameter of the fibre, impulses can travel at speeds of 18 m/sec (65 km/hour) up to 140 m/sec (500 km/hour).

The strength of a nerve impulse does not diminish as it travels along a nerve fibre. If you stub your toe, nerve impulses will be generated that travel along an axon all the way up to your spinal cord. The voltage of the impulses arriving at the spinal cord will be the same as the voltage of those generated at the toe. This situation has been likened to a burning fuse. When the fuse is lit, the heat generated ignites the next part of the fuse which then produces enough heat to light the next part, and so on. The



**Figure 6.7** The functional organisation of the body's nervous system

end of the fuse burns with the same amount of heat as the beginning. Like a burning fuse, a nerve impulse does not become weaker with distance.

## Reflexes

A **reflex** is a rapid, automatic response to a change in the external or internal environment. Reflexes are one of the ways in which the body achieves homeostasis. All reflexes have four important properties:

- A **stimulus** is required to trigger off a reflex—it is not spontaneous.
- A reflex is **involuntary**—it occurs without any conscious thought.
- A reflex response is **rapid**—only a small number of neurons are involved.
- A reflex response is **stereotyped**—it occurs in the same way each time it happens.

For more information and images relating to the peripheral nervous system, go to <http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookNERV.html>

Some reflexes involve the unconscious parts of the brain but most are coordinated by the spinal cord. When a nerve impulse comes into the spinal cord from a receptor, the message is not necessarily carried up to the brain. The impulse may be passed to motor neurons at the same level in the cord, or may travel a few segments up or down the cord before travelling out through a motor neuron. In these cases the reflex is carried out by the spinal cord alone and is known as a **spinal reflex**. The pathway a nerve impulse follows in travelling from a receptor to an effector is known as a **reflex arc** or, in the case of a spinal reflex, a **spinal reflex arc**.

Since a spinal reflex does not involve the brain, it is involuntary, even though contraction of skeletal muscles may occur. Impulses may be sent to the brain so that we become aware of what is happening, but this awareness does not occur until after the response has been initiated. For example, if you step on something sharp with bare feet, the reflex response is to withdraw the foot from the painful stimulus. By the time the brain becomes consciously aware of the painful stimulus the foot has already been withdrawn.

A reflex arc has the following basic components:

1. A **receptor** is either the ending of a sensory neuron or a specialised cell associated with the end of a sensory neuron. The receptor reacts to a change in the internal or external environment by initiating a nerve impulse in the sensory neuron.
2. A **sensory neuron** carries impulses from the receptor to the central nervous system.
3. There is at least one **synapse**. The nerve impulse may be passed directly to a motor neuron or there may be one or more interneurons, which direct the impulse to the correct motor neuron.
4. A **motor neuron** carries the nerve impulse to an effector.
5. An **effector** receives the nerve impulse and carries out the appropriate response. Effectors are muscle cells or secretory cells.

Figure 6.8 shows the components in a simple spinal reflex involving three neurons. The response would occur in a fraction of a second and while it was occurring impulses would travel up the spinal cord to the brain. Only after the response had been made would the person become consciously aware of the situation. Many reflexes, such as the one shown in Figure 6.8, protect the body from injury. Blinking when something touches the cornea of the eye, sneezing or coughing when something irritates the nose or trachea, and constriction of the pupil in response to intense light are other protective reflexes.

Other reflexes include secretion of saliva in response to the sight, smell or taste of food, the ejaculation of semen during sexual intercourse and the responses brought about by the autonomic nervous system (see Chapter 7).

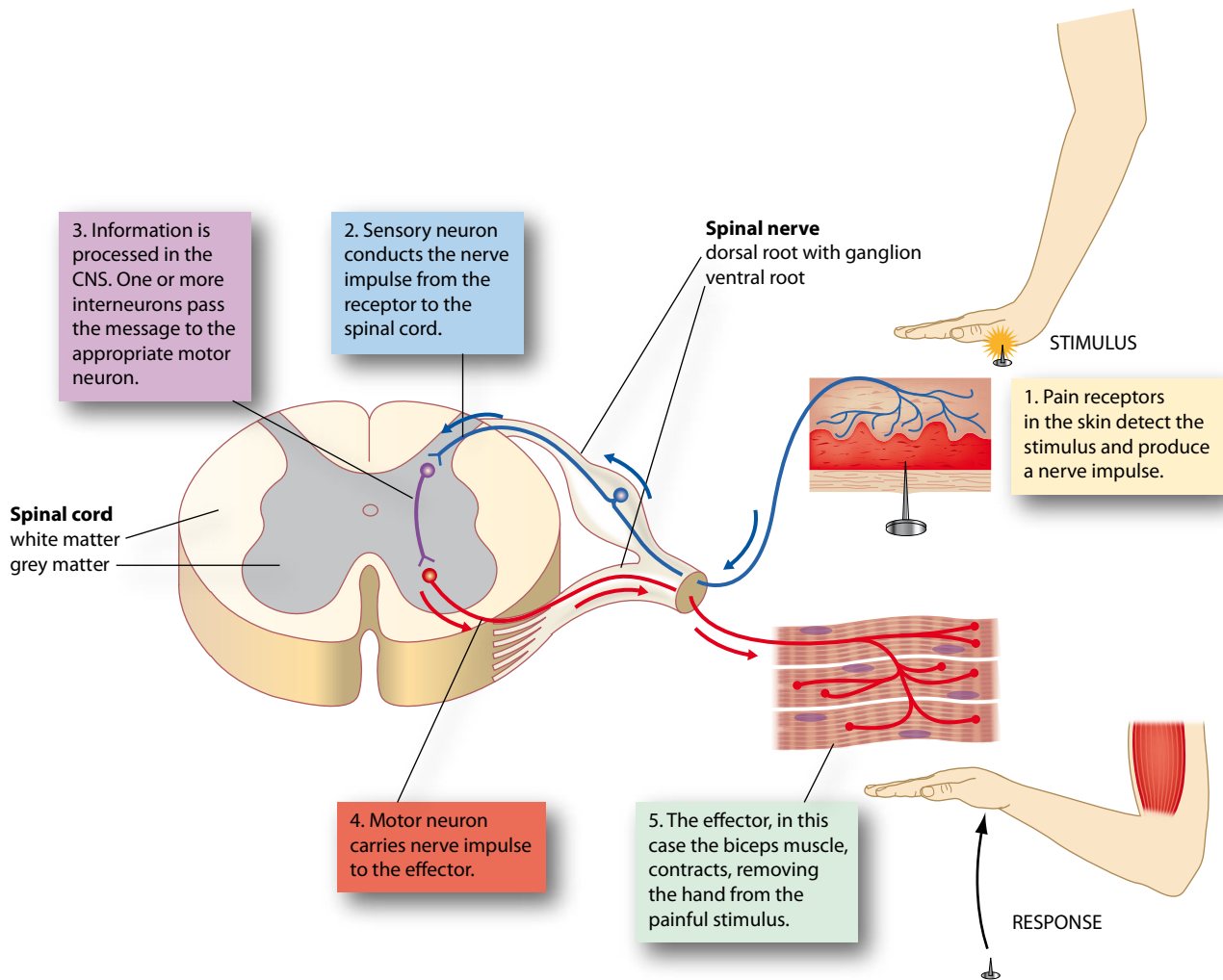
## Learned reflexes

The protective reflexes mentioned above are present from birth. More complex motor patterns appear during a baby's development—including reflexes such as suckling, chewing or following movements with the eyes. These innate reflexes are determined genetically.

Some complex motor patterns are learned and are called **acquired reflexes**. Muscular adjustments required to maintain balance while riding a bike, jamming on the brakes of a car to avoid a dangerous situation or catching a ball are all acquired reflexes. They are learned through constant repetition.

You can see animations of a reflex arc at [http://www.bbc.co.uk/schools/gcsebitesize/science/ocr\\_gateway/ourselves/3\\_keeping\\_in\\_touch6.shtml](http://www.bbc.co.uk/schools/gcsebitesize/science/ocr_gateway/ourselves/3_keeping_in_touch6.shtml), or [http://msjensen.cehd.umn.edu/1135/Links/Animations/Flash/0016-swf\\_reflex\\_arc.swf](http://msjensen.cehd.umn.edu/1135/Links/Animations/Flash/0016-swf_reflex_arc.swf)





## Extension

Doctors may use reflexes to find out whether a patient has an impairment of the nervous system. Absence or exaggeration of a particular reflex may indicate damage to nerves or to the spinal cord either through injury or disease.

Find out about the following reflexes and what absence or exaggeration of the reflex could indicate:

- patellar reflex (knee jerk)
- Achilles reflex (ankle jerk)
- abdominal reflex
- plantar reflex and Babinski sign.

**Figure 6.8** The neurons involved and the pathway followed by the nerve impulses in a spinal reflex. In this example the impulses enter and leave the spinal cord by the same spinal nerve. This is not always the case



## Working scientifically

### Activity 6.1 Reflexes

In this activity you will examine some simple reflex responses.

#### You will need (for each pair)

Rule; glass rod; antiseptic solution; beaker; stethoscope

#### What to do

For each of the following tests one member of the pair should act as the subject, the other, the investigator.

#### I The knee reflex

The subject should sit on a stool or a bench-top with one leg crossed over the other. Using a rule the investigator should lightly strike the subject's crossed leg just below the knee cap.

1. Describe the response that occurs.

The stimulus for the response is the stretching of the patellar tendon just below the knee cap.

2. Describe the location of the muscle or muscles that produce the response.
3. Describe, in words, the reflex arc that is involved in the response.

Try to get a response with the knee straight and bent at different angles.

4. Does the response seem to be stronger at any particular angle of flexion? If so, can you suggest an explanation?

#### II The heel reflex

Stand the subject beside a stool or chair with one leg kneeling on the seat of the chair. Use a rule to strike the back of the subject's ankle.

5. Describe the response.
6. What is the stimulus in this case?
7. In what ways is the heel reflex similar to the knee reflex?
8. Doctors often test reflexes such as the knee and heel reflex. What do you think testing such reflexes would tell a doctor?

#### III The eye reflex

With the subject seated directly in front, the investigator should suddenly clap her hands in front of the subject's face.

9. Describe any response observed.
10. Is the response a natural or a learned response?
11. Does the response have a purpose? Explain.

#### IV The swallowing reflex

The uvula is a piece of tissue that hangs down at the back of the throat. When the mouth is wide open it can be seen as an inverted V shape.

With the subject's mouth open as widely as possible, the investigator should lightly touch the uvula with a glass rod that has been dipped in antiseptic solution.

12. Describe the response that occurs.
13. How does this reflex aid swallowing?
14. Draw and label a diagram showing the reflex arc that is involved in the swallowing reflex.

## V Cardiac sphincter reflex

Where the oesophagus enters the stomach there is a circular band of muscle, the cardiac sphincter. This muscle controls the entry of food and liquids to the stomach.

Place a stethoscope against the left side of your partner's abdominal wall and listen while some water is swallowed.

15. Describe the sound you hear a few seconds after the water is swallowed.

The sound is caused by water entering the stomach after the relaxation of the sphincter muscle.

16. What stimulus causes the cardiac sphincter to relax?

### Conclusions

17. Do all of the reflexes that you have investigated have the four important properties that were described in this chapter?
18. Write a brief statement summarising the importance of reflexes to the normal functioning of the human body.

## Activity 6.2 Reaction time

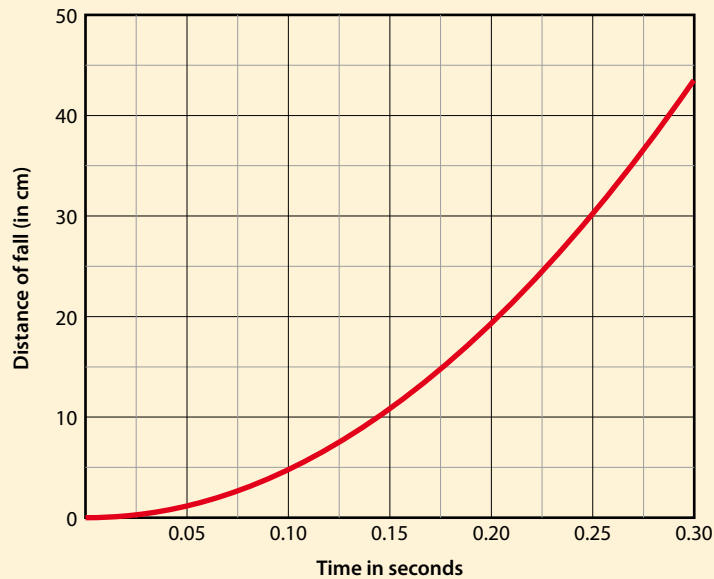
Responses do not occur instantaneously; even reflex responses require time for perception of the stimulus, conduction of impulses to and from the brain or spinal cord and for the effector to carry out the response. Reaction time, the time it takes to respond to a stimulus, depends on many factors including the type of stimulus, the intensity of the stimulus and whether conscious thought is involved in the response.

Design and carry out an investigation into reaction time. Some ideas are presented below but you may decide to do something quite different. (Reaction timers are available on the internet. Use a search engine to search for 'reaction timer'. Some sites time reactions directly, some allow you to download freeware and some give directions for making reaction timers. Sites that time reactions will not be suitable for many of the suggestions below.)

1. If you have access to an electronic timing device that will measure time in fractions of a second you could try:
  - (a) a visual stimulus such as a light coming on or going off and a single finger movement response such as depressing a switch
  - (b) a visual stimulus with a response involving many muscles such as moving the whole hand or arm to depress a switch
  - (c) an auditory stimulus with either a single finger or a multiple movement response
  - (d) a stimulus with a response by the foot
  - (e) comparing response time by the left and right hand/foot
  - (f) changes in response time with practice
  - (g) the effect of distracting the subject while waiting for the stimulus.

Record your results in a suitable way.

- If no electronic timer is available it is possible to estimate reaction time using a falling object. The investigator holds a metre or half-metre rule by one end so that it hangs vertically. The subject places the thumb and forefinger on opposite sides of, but not touching, the bottom end of the rule. When the investigator releases the rule the subject grasps it between thumb and forefinger as soon as it falls. From the scale on the rule the distance of fall can be measured. Use Figure 6.9 to determine the reaction time.



**Figure 6.9** Graph showing time taken for an object to fall a given vertical distance

Discuss with other students the sources of error in these investigations and try to minimise them as far as possible.

#### Further investigations

There are many other factors that may, or may not, influence reaction time. For example, you could investigate whether any of the following have an effect on reaction time:

- gender
- age
- caffeine consumption (in the form of tea or coffee)
- physical fatigue
- consumption of a meal
- use of the dominant hand compared with the non-preferred hand.

### Activity 6.3 More reaction times

Reaction time is the time that elapses between a stimulus and the response to the stimulus. You can test your reaction time at:

<http://faculty.washington.edu/chudler/java/reacttime.html>, or

<http://faculty.washington.edu/chudler/java/dottime.html>

- Describe the pathway taken by the nerve impulses involved in detecting the stimulus and making the response.

2. Is the response an innate or an acquired response?
3. Draw a column graph showing your reaction time for five trials.
4. Does your reaction time decrease with practice? If so, suggest why.
5. Do five trials with your left hand and then five trials with your right. Describe and explain any difference in the two sets of trials.

## REVIEW QUESTIONS



1. (a) Explain the difference between a myelinated and an unmyelinated fibre.  
(b) Describe how the sheath of a myelinated fibre is formed.
2. Depending on their functions there are three different types of neuron. Name the three types and describe the function of each.
3. Explain the difference between multipolar, bipolar and unipolar neurons. In what part of the nervous system is each type of neuron found?
4. Explain the difference between a neuron, a nerve and a nerve fibre.
5. (a) What is a synapse?  
(b) What is the difference between a synapse and a neuromuscular junction?
6. How many pairs of nerves arise from each of the brain and spinal cord?
7. On what sort of nerve would you find a ventral and dorsal root? Explain where these roots are located.
8. (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?
9. Why is a nerve impulse described as an electrochemical change?
10. What is saltatory conduction? What effect does it have on the speed of transmission of impulses?
11. What is a motor unit?
12. Explain how muscles are able to remain contracted for long periods of time without excessive fatigue.
13. What are the characteristics of a reflex?
14. Draw a diagram showing the components of a reflex arc. Fully label your diagram.
15. Explain the difference between an innate and an acquired reflex.

## APPLY YOUR KNOWLEDGE



1. A driver approaching traffic lights saw the lights change from green to amber. She transferred her foot from the accelerator to the brake in order to stop. Describe the pathways of the nerve impulses that would be involved in this response.
2. The speed of transmission of nerve impulses can vary from 2 m/sec to 140 m/sec. Explain how there can be such a wide range of speeds of transmission of impulses.
3. If the ventral root of a spinal nerve were damaged, would it affect the sensory functions or the motor functions of that nerve? Explain.
4. Poliomyelitis (polio) is caused by a virus. In the most severe form of the disease paralysis of certain muscles occurs when the virus destroys the cell bodies of

motor neurons in the spinal cord. Explain why the muscles would be paralysed as a result of a polio infection.

5. A person stepped on a broken bottle and by a reflex response withdrew the foot from the painful stimulus. Assume that the distance from the person's foot to the spinal cord was 1.2 metres. Using the figures for speed of transmission of nerve impulses quoted in this chapter, what is the shortest time (in milliseconds) that could have elapsed between the stimulus and the response (1000 milliseconds = 1 second).
6. When you withdraw your hand from a painful stimulus, the response occurs before you become consciously aware that you have hurt yourself. Explain how this is possible.
7. Multiple sclerosis is caused by destruction of the myelin sheath. Use references to find out how damage to the sheath results in the jerky body and limb movements, double vision, slurred speech and paralysis that may occur as a result of the disease.

For more information about multiple sclerosis, go to <http://www.msaustralia.org.au>