Lesson Twelve

The Nervous System

Aims

By the end of this lesson you should be able to:

- recall the plan of the *nervous system* and understand its functions
- recall the structure of sensory, motor and relay *neurones*, and understand the transmission of nerve impulses along and between neurones
- recall the structure of the *spinal cord* and describe the operation of spinal reflexes
- recall the main areas of the *brain* and their functions
- recall that there are *receptors* that respond to heat, chemical, mechanical and light energy, and
    - recall the structure of the *eye*, explain the principles of stereoscopic vision, and explain how the eye reacts to changes in light intensity and the need to focus near and distant objects
    - recall the structure of the *ear*, and describe its functions in balance and hearing

Context

This lesson covers elements (a) to (h), (l) and (m) of Section 5 (Coordination) of the Edexcel specification. It is quite long, but includes clear sub-sections on the different parts of the nervous system.

Edexcel IGCSE Human Biology, chapter 5, pages 70-85.

Oxford Open Learning

Introduction

One of the key characteristics of organisms is that they respond to stimuli – if you prod them, they react! Biologists call this characteristic **sensitivity**. In human beings it is mainly produced by the **nervous system**.

To produce sensitivity, the nervous system needs several different parts:

- **receptors** that are sensitive to the stimulus (light, sound etc.)
- a **central nervous system (CNS)**, consisting of the **brain** and the **spinal cord**, which receives messages from the receptors, decides on the appropriate response, and coordinates it by sending messages to various effectors
- **effectors**, which produce the response. These are often muscles, producing movement. Sometimes they are glands, which release chemicals
- **nerves**, which link the receptors, CNS and effectors together, and carry messages between them in the form of **electrical impulses**

In this lesson we will first study how the electrical impulses are carried along nerves, then the structure and mode of operation of the CNS, and finally the eye and ear as two important receptors.

Twig

Log on to Twig and look at the film titled: **Intro to the Brain**

www.ool.co.uk/915mu

What does the brain look like and what does it actually do? What specific functions do the brain stem, cerebellum and cerebrum control?

Activity 1

Suggest the response to each of these stimuli. In each case, what is the effector?

(a) You step out into the road, and then hear a car horn blaring.

(b) You are hungry. You smell the aroma coming from a fish and chip shop.

(c) An insect flies rapidly towards your eye.

Log on to Twig and look at the film titled: **The Nervous System**

www.ool.co.uk/1567jf

Our bodies contain an intricate network of nerves and pathways which make up the Central Nervous System. How are they linked? And how do they connect different parts of our body to control bodily functions?

Nerves and Neurones

Look at figure 5.2 on page 71 of *Edexcel IGCSE Human Biology*. The brain and spinal cord are outlined in red, while some of the nerves are shown in yellow. Those running out from the spinal cord are called **spinal nerves**, and those from the brain are called **cranial nerves**.

Each nerve is thick enough to be visible to the naked eye, but it is made up of a huge number of individual cells called **neurones** running along its length. Every nerve contains two sorts of neurone:

- **sensory neurones** which carry electrical impulses from the receptors to the CNS

- **motor neurones** which carry electrical impulses from the CNS to the effectors

Any nerve will have lots of different impulses travelling along it, in both directions, each in a separate neurone. There is also a third sort of neurone, **relay neurones**, which carry impulses between the sensory and motor neurones inside the CNS.

Log on to Twig and look at the film titled: **Neurons as Cells**

www.ool.co.uk/916yg

Everything our brain does, from controlling movement to conscious thought, is achieved by the firing of electrical signals called neurons.

Also look at the film titled: **Neurons as Networks**

www.ool.co.uk/966tc

Neurons, the brain's electrical signals, control how our bodies work. Discover how they do this and why they are implicit in learning new skills.

Neurone structure

Look at the diagram of a motor neurone in figure 5.3 on page 72 of the textbook. This neurone is a single cell, and has the following parts:

- a **cell body**, which contains a nucleus, mitochondria, and the other usual organelles of an animal cell. It is located in the CNS.
- the cell membrane is drawn out into projections called **dendrons** which end in hair-like **dendrites,** like twigs on a tree. These make contact with other neurones in the CNS at junctions called **synapses**, so electrical impulses may be passed to it.

- one dendron is drawn out into a very long **axon**, which runs the entire distance down a nerve to an effector (here a muscle). The axon is surrounded by a **myelin sheath**, with regular gaps in it. The myelin sheath is made largely of lipid, and is an electrical insulator.
- The far end of the axon is drawn out into several **nerve endings**, rather like the dendrites at the near end. These make contact with muscle fibres at special synapses called **neuromuscular junctions**, and pass the electrical impulses to them.

Figure 5.3 also gives a diagram of a sensory neurone. It has essentially the same parts, but notice that:

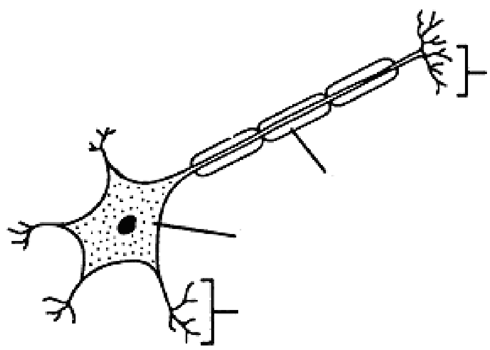
- the *motor neurone* has the cell body right at one end, with dendrites on it, whereas
- the *sensory neurone* has the cell body on a side stalk a bit away from one end, with no dendrites on it.

Relay neurones vary in shape, but all have dendrites and <u>no</u> long axon.

Get it right! The whole neurone (except for the myelin sheath) is a single cell. The axon runs right along a nerve and may be a metre or more long! Neurones are by far the longest cells in the body.

Activity 2

(a) Label the following diagram, and then check your answers from figure 5.3 on page 72 of the textbook.



(b) What sort of neurone is this? Give two reasons for your answer.

(c) Name at least three structures visible in this cell which are shared by all animal cells (recap this from Lesson 1 if necessary)

Nervous impulses

When a receptor receives light, sound, or some other sort of energy, it turns that energy into the form of electrical energy, a process called **transduction**. The electrical energy is then shot along the axons of its sensory neurones in short bursts called **nervous impulses** or **electrical impulses**.

The myelin sheaths along the axons speed up the rate of transmission of these impulses, and they typically travel at about 100 metres per second (or ten times as fast as an Olympic sprinter!) This high speed enables you to respond quickly to stimuli, which is important for survival.

Activity 3	Estimate the time it would take for an electrical impulse to travel in a neurone from the brain to the toe of a tall man.

Synapses

The junction between two neurones is called a **synapse**. See fig 5.15 on page 81 of *Edexcel IGCSE Human Biology*.

There is a small gap between the two neurones at a synapse called the **synaptic cleft**. The electrical impulse is unable to cross this gap, but its arrival stimulates the release of a chemical called a **neurotransmitter** by the first neurone into the synaptic cleft. This diffuses across the cleft and attaches to dedicated sites on the cell membrane of the second neurone. Its attachment stimulates a new electrical impulse which sets off down the second neurone – the impulse has crossed the synapse.

Synapses are important in several ways:

- They slow up the process of transmission, increasing reaction times.

- Because neurotransmitter is only released by one of the cells, and the dedicated sites are only on the other cell, impulses can only travel in one direction across a synapse. This keeps impulses heading in the right direction along the neurones as well.

- Each motor neurone can receive impulses from several other neurones at synapses (see figure 5.16 on page 81 of the textbook). This makes free decision-making possible in our brains – we do not always just react to stimuli in an automatic fashion.

- Several drugs (including caffeine and alcohol) alter transmission at synapses, often by imitating or blocking neurotransmitter molecules. This is how they change our experience and/or performance.

Log on to Twig and look at the fact-pack titled: **Spinal Cord**

www.ool.co.uk/1084be

How the millions of nerves in the spinal cord help the brain and body communicate.

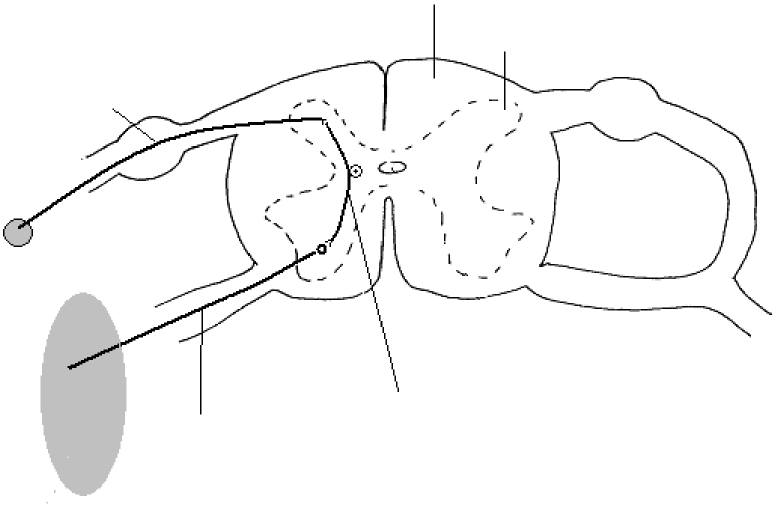
Reflexes and the Spinal Cord

The spinal cord is part of the central nervous system. It runs from the base of the brain down inside the backbone, which protects it from damage.

Structure of the spinal cord

The structure of the spinal cord, at the point where a spinal nerve enters and leaves it, is shown in figure 5.13 on page 79 of *Edexcel IGCSE Human Biology*. Note the following parts:

- an H-shaped central section called the **grey matter**. This is where the cell bodies of the motor and relay neurones are located;
- an outer section called the **white matter**. This consists mainly of neurone axons with their myelin sheaths;
- a "roundabout" system linking the spinal cord to the spinal nerve:
  - the top branch of the roundabout, called the dorsal root (towards your back), carries the sensory neurones into the spinal cord. It has a bulge called the dorsal root ganglion where the cell bodies of the sensory neurones are located;
  - the bottom branch, called the ventral root (towards your front) carries the motor neurones out of the spinal cord. It has no ganglion, because the cell bodies of the motor neurones are in the grey matter of the cord itself.

Activity 4	(a) Label this diagram of the spinal cord, and then check your answers from page 79 of the textbook. 
	(b) Is your back at the top or bottom of the diagram? How do you know?

Reflexes

Actions which are under the control of the will are called **voluntary actions**. For example, raising your arm when you decide to is a voluntary action. The impulses causing voluntary actions originate in the conscious part of the brain (see later).

Reflex actions are not voluntary, but automatic. For example: if something flies towards your eye, you blink (the "eye blink reflex"); if your hand touches something very hot you pull it away (the "withdrawal reflex"). These reactions "happen on their own" - you do not need to think about them.

Reflex actions have **survival value**. That is, they decrease the chance of damage to the body or death. They share the following features:

- they are rapid (useful for survival)
- they are involuntary (we do not decide to do them and, often, cannot stop them happening)
- they are innate (you do not need to learn them)

Reflexes, or reflex actions, have these properties because they are all based on an electrical impulse pathway called the **reflex arc**.

The reflex arc

Look at figures 5.12 and 5.13 on page 79 of *Edexcel IGCSE Human Biology*, which both show reflex arcs.

The stimulus generates an electrical impulse in a receptor. This electrical impulse travels to the CNS in a sensory neurone. At the CNS it transfers at a synapse to a relay neurone and at a second synapse to a motor neurone. The impulse travels down the motor neurone to a muscle (the effector) and causes it to contract, producing the response. Now:

- because only two synapses are involved, the response will be *rapid* (remember, it is synapses that slow down impulse transmission)
- because the conscious decision-making part of the brain it not involved, the response will be *involuntary*
- because the "wiring" of neurones is produced during development without the need for any experience, the response will be *innate*

The eye blink reflex mentioned above involves a cranial nerve and the lower, non-conscious part of the brain. But most reflexes, called spinal reflexes, involve spinal nerves and the spinal cord, not the brain at all. These include

- the **withdrawal reflex**, and
- the **knee jerk** reflex

Activity 5	Read about the knee-jerk reflex on page 80 of the textbook, and then try it out as directed there. Can you get it to work?

The Brain

The human **brain** is a large swelling at the top of the spinal cord, protected by the bony **cranium** or skull. The different regions of the brain are specialised to do a large number of different jobs - see figure 5.17 on page 82 of *Edexcel IGCSE Human Biology*:

- the **medulla** or brain stem, at the top of the spinal cord, controls unconscious processes like the heartbeat and breathing
- the **cerebellum**, a cauliflower-like structure at the lower back of the brain, coordinates balance
- the **hypothalamus**, which we met in Lesson 11, contains centres regulating body temperature and water content
- the **pituitary gland** releases a variety of hormones into the bloodstream, including ADH which we also met in Lesson 11

- however, by far the largest part of the human brain is the **cerebrum**.

The cerebrum

The cerebrum is the location of our sensory experience, thoughts and memory, and the place where our conscious decisions and actions originate. It is divided into two halves called the **cerebral hemispheres**. Its outer layer, called the **cerebral cortex**, is folded over to give it a larger surface area, which increases intelligence. It appears grey from the outside because the grey matter, containing the cell bodies, is on the outside rather than on the inside as in the spinal cord.

Different regions of the cerebrum are themselves specialized to do different jobs: see figure 5.19 on page 83 of the textbook.

- The **sensory areas** (green on the diagram) receive and interpret impulses from the receptors (sense organs). Each sense organ feeds its impulses into a different part of the sensory area. This is why their impulses are interpreted differently to give, for example, the different experiences of sight and hearing. Notice:
    - the vision area at the <u>back</u> of the brain
    - the "main sensory area" where the receptors scattered around the skin send their impulses, each bit of skin to a different location
- The motor areas (brown on the diagram) control the movements of the various parts of the body. Again each muscle has its own dedicated region of the motor area which controls it
- The association areas (yellow on the diagram) are where, among other things:
    - sensory experience is interpreted, "making sense" of what we see and hear
    - complicated actions like writing are coordinated
    - experience is compared with stored memories to produce "recognition"
    - reasoning takes place

The human cerebrum is more highly developed than that of any other animal, which accounts for our high intelligence, speech and technological capabilities.

Activity 6	Suggest what might happen if: (a) the auditory nerve, coming from the ear, was "rewired" to feed into the vision area at the back of the brain (do NOT try this at home!). (b) a person was given a mild electric shock in the part of the motor area which controls the left leg

Receptors and Sense Organs

A **receptor** is a cell, or a group of cells, which is sensitive to a stimulus. A **sense organ** is an organ dedicated to making one or more receptors work. For example, the eye is a sense organ which contains light-sensitive receptors (rod and cone cells) in its retina.

Any receptor is sensitive to only one sort of stimulus. Human beings have receptors sensitive to, among other things:

- heat (temperature receptors in the skin – see Lesson 12)
- light energy (rods and cones in the retina of the eye – see below)
- certain sorts of chemical (taste buds in the tongue; olfactory organs in the nose)

- mechanical forces (cells detecting sound and gravity in the inner ear – see below; pressure and pain receptors in the skin – see Lesson 12)

The human body does not contain receptors sensitive to all forms of energy. It has none sensitive to radio waves or X-rays for example. These forms of energy may still cause damage, however: X-rays can cause cancer even though we are unaware of their presence.

Get it right! Experience occurs in the brain, not in the sense organs. The brain interprets the incoming electrical impulses to produce our experience of heat, light, sound and so on. If, for example, the vision area of the brain is damaged, the victim will be blind even though their eyes are in perfect working order.

Log on to Twig and look at the film titled: **How we see 1: Eyes**

www.ool.co.uk/944wc

The process of seeing is a collaboration between the brain and the eye. How does the eye work to create sight, from the lens and iris to the pupil, retina and optic nerve?

The Eye

Study the diagram of the eye on page 73 of *Edexcel IGCSE Human Biology*, and notice the following parts:

- Light enters from the left through a thin, transparent skin called the **conjunctiva**. It is **refracted** (bent) by the curved, transparent **cornea** and the curved, transparent **lens**, and brought to a focus on the **retina** at the back of the eye, which contains the light-sensitive cells.

- The retina cells are supplied with nutrients and oxygen by blood vessels running through the **choroid**. The choroid is also black to absorb the light which passes through the retina. This would otherwise bounce around inside the eye causing multiple images. The hard, white

sclera outside this keeps the eyeball in shape. It is continuous with the transparent cornea at the front.

- The **fovea** lies on the axis of the eye. It is here that the light falls when you look straight at something. It has mainly light-sensitive cells called **cones** which give clear colour vision but only work in bright light. The rest of the retina has fewer cones and more rods. Rods work in dim light, but give less clear black & white vision.

- The **optic nerve** carries electrical impulses away from the retina to the brain in sensory neurones. At the point where it leaves the eye there are no rods or cones. This is the **blind spot** – any object whose light falls here is invisible.

- The **iris** is a coloured (usually brown or blue) barrier in front of the lens. Light passes through a hole in its middle called the **pupil** to reach the retina. From the outside the pupil looks like a black spot surrounded by a coloured circular iris.

	Get it right! The light is focused **both** by the cornea **and** by the lens. In fact the cornea bends the light more than the lens.

Activity 7	Try out the exercise to locate your blind spot described in the last few lines of page 75 of the textbook.

Accommodation by the lens

By refracting (bending) the light, the cornea and lens between them focus an **inverted** (upside down) image (picture) of objects on the retina at the back of the eye. See figure 5.5 on page 74 of the textbook to see how this is done. Notice that the light from the *top* of the key ends up at the *bottom* of the image and vice versa, making the image upside down.

To focus nearby objects the lens must be fatter than to focus distant objects, so the lens changes its shape to bring near or distant objects into focus. This change is called **accommodation**. (See figure 5.7 on page 76 of the textbook for this. Notice that the light from the nearby object is spreading out as it reaches the eye, so must be refracted more.) The change in lens shape is caused by the contraction and relaxation of the **ciliary muscles**, which forms a ring around the lens:

- To focus a *nearby* object, the ciliary muscles *contract* and form a smaller ring. This makes the **suspensory ligaments**, which join the ciliary muscles to the lens, go slack. The lens springs into its natural, rounded shape and bends the light more strongly. You can feel the ciliary muscles working if you look at a very close object and try to focus it – you soon get eye strain!

- To focus a *distant* object, the ciliary muscles *relax* and return to their natural larger ring. This pulls the suspensory ligaments taut, pulling the lens into a thinner shape which does not bend the light so much. As the ciliary muscles are doing no work, the eye is relaxed looking at distant objects – no eye strain!

Twig

Log on to Twig and look at the film titled: **How we see 2: Brain**

www.ool.co.uk/945gk

Only a small part of what the eye 'sees' is in focus. To turn the image on the retina into complete vision the eye needs help from the brain.

Activity 8	(a) Predict whether it should be possible to get both a near object and a distant object in focus at the same time. Then try it out to test your prediction. (b) Hold an object as near to one of your eyes as you can while keeping it still in focus. Hold it for a few seconds and feel the strain in the eye. Which muscles are getting tired? Now relax your eye. The strain will disappear, but the object will go out of focus.

Response to changes in light intensity by the iris

The eye attempts to keep the intensity (brightness) of the light reaching the eye as constant as possible. It achieves this by contracting and relaxing muscles in the iris to change the size of the pupil in its centre.

The iris contains two sets of muscles (see figure 5.6 on page 75 of the textbook). Its **circular muscles** make the pupil smaller when they contract. Its **radial muscles**, spreading out from the centre like the spokes of a wheel, pull the pupil wider open as they contract.

- When the light is *bright* the circular muscles contract and the radial muscles relax. This makes the pupil smaller, reducing the amount of light getting to the retina.

- When the light is *dim* the circular muscles relax and the radial muscles contract. This makes the pupil larger, increasing the amount of light getting to the retina.

Activity 9	Observe the front of your eyes using a mirror in dim and bright light. What happens to the pupil as you move from dim to bright light, and why?

Stereoscopic vision

Because we have two eyes, with slightly different viewpoints, the brain receives two slightly different pictures of any object it looks at. The closer the object, the more different these two pictures are.

The **visual association area** at the back of the brain uses this information to construct a three-dimensional picture of the world. Stereoscopic or binocular vision (vision with two eyes) permits depth perception – we can see how far away objects are.

This ability was developed during the period of our evolution which we spent up trees. During this period we traded in the ability to see behind us (achieved by having the eyes on the sides of the head) for the ability to see how far away was the branch we were about to leap for!

Activity 10	Try the exercise with the pencil described in the first paragraph of page 76 of the textbook.

The Ear

The human ear has two quite different functions:

- it is sensitive to *sound*, and
- it is an organ of *balance*

The structure of the ear is shown on page 77 of *Edexcel IGCSE Human Biology*. Note the following parts.

- The **outer ear**, filled with air (coloured blue in the diagram), leads down the **auditory canal** to the **tympanum** or ear drum. This vibrates backwards and forwards rapidly when sound waves hit it.

- The **middle ear**, also filled with air, transmits and magnifies these vibrations through a complicated arrangement of three **ossicles**, or ear bones: the **malleus** (hammer), **incus** (anvil) and **stapes** (stirrup). The middle ear connects to the back of the throat through an air-filled tube called the **Eustachian tube**, which opens when we swallow. This tube keeps the air pressure the same on both sides of the tympanum, so that it can vibrate freely.

- The **inner ear** is filled with liquid. It contains receptors responsible for hearing in a spiral structure called the **cochlea**, and receptors responsible for balance in the **semicircular canals**. The **auditory nerve** runs from both of these structures to the brain, carrying nervous impulses in sensory neurones.

Log on to Twig and look at the film titled: **How we hear**

www.ool.co.uk/949ru

How our ears hear different frequencies, and how they work with the brain to turn these into sounds which we understand.

Sound and Hearing

Figure 5.9 on page 78 of the textbook shows the cochlea uncoiled to make its function clearer.

The stapes transmits the magnified sound vibrations to the liquid in the cochlea through a tough membrane called the **oval window**. As this window moves rapidly back and forth with the vibrations, the fluid in the cochlea does the same. This repeatedly bends receptor cells in the **organ of Corti** attached to the centre of the cochlea. When bent they generate electrical impulses which travel to the brain.

Because liquid (unlike air) cannot be compressed, the cochlea also has a second membrane called the **round window**. This moves out as the oval window moves in, and vice versa to, stop the cochlea bursting.

Receptor cells at different positions along the organ of Corti vibrate strongly with different frequencies (pitches) of sound. This enables the brain to sense the pitch of a sound, as well as its loudness.

Balance

The inner ear also contains two different structures connected with different aspects of balance. One detects *movement* of the head, and the other the *orientation* of the head.

- The three **semicircular canals** each have a swelling called the **ampulla**, which contains a jelly-like **cupula** connected to the wall by sensitive **hair cells**. When you *move* your head the fluid in the canal moves. This moves the cupula which bends the hair cells, generating electrical impulses. Because the three canals are at right angles, any movement of the head will move the fluid in at least one of the canals, so the brain is made aware of the movement.

- If you spin around for a long time, the fluid in some of the canals carries on moving when you stop. As far as the brain is concerned your head is still spinning round, so you feel dizzy!

- The **utriculus** and **sacculus** (see figure 5.8, page 77) each contain a heavy **otolith** made of calcium carbonate (chalk) attached to the wall by hair cells. The weight of the otolith bends the hair cells, producing electrical impulses. These give the brain information about the *orientation* of the head: the impulses are different when you are lying down to when you are standing up.

Now is the time to read through chapter 5, pages 70 - 85 of *Edexcel IGCSE Human Biology*. They cover the same topics as this lesson, so will add to your understanding of the material.

Keywords

Sensitivity

Central nervous system (CNS)

Spinal cord

Neurone

Synapse

Transduction

Reflex arc

Refracted

Accommodation

Ossicle

Semicircular canal

Receptor

Effector

Impulse

Dendrite

Myelin sheath

Neurotransmitter

Cerebrum

Inverted

Tympanum

Organ of Corti

Cochlea

Summary

Lesson Twelve: The Nervous System

NERVOUS SYSTEM	------	stimulus – receptor – sensory neurone – CNS – motor neurone – effector – response
NEURONES	------	sensory, motor, relay
	------	electrical / nervous impulses
	------	synapses
SPINAL CORD	------	structure
	------	spinal reflexes
BRAIN	------	medulla, cerebellum, hypothalamus, pituitary gland
	------	cerebrum: sensory, motor and association areas
SENSE ORGANS	------	eye: structure, accommodation, control of light entering, stereoscopic vision
	------	ear: hearing, balance

What you need to know

- The structures of the different types of neurone
- The structure of the spinal cord and the route of a reflex arc
- The structure of the brain and the functions of its various parts
- The structure of the eye and how each part contributes to sight
- The structure of the ear and how each part contributes to either hearing or balance

What you might be asked to do

- Label diagrams of neurones, spinal cord, brain, eye and ear
- Explain impulse transmission along and between neurones
- Identify stimuli and responses
- Explain the occurrence and importance of reflex actions
- Explain how the eye copes with different light intensities and the need to focus near and distant objects
- Explain how the ear functions as an organ of hearing and balance

Suggested Answers to Activities

Activity 1

(a) Response: you jump backwards. Effector: your leg muscles.

(b) Response: your mouth waters. Effector: your salivary glands.

(c) Response: you blink. Effector: your eyelid muscles.

Activity 2

(b) It is a motor neurone, because the cell body is right at one end of the cell and has dendrites on it.

(c) Nucleus, cytoplasm and cell membrane.

Activity 3

Distance: about 2m.

Speed: about 100m/s (metres per second)

Time: about 2/100 = 0.02s

Activity 4

(b) At the top. The dorsal root ganglion is drawn towards the top, and "dorsal" means "back".

Activity 6

(a) If you played the person music, they would hear nothing, but would see flashing lights.

(b) Their left leg would twitch.

Activity 8

(a) No, it is not possible.

(b) The ciliary muscles are getting tired.

Activity 9

The pupil gets narrower in bright light, so that less light enters and reaches the retina. (If the retina receives too much light it can be damaged.)

Tutor-marked Assignment F

Question 1

A person was ill because their kidneys were not working properly. Certain substances contained in blood and urine differed in the amount present when the person was healthy as opposed to when they were unwell. The table below shows the percentages (%) of these substances.

Healthy person			Unwell person		
	% of substance in blood	% in urine		% of substance in blood	% in urine
Water	89.0	97.5	Water	90.0	98.5
Urea	0.03	2.0	Urea	1.0	1.0
Salts	0.35	0.5	Salts	0.4	0.4
Glucose	0.05	0.0	Glucose	0.05	0.1
Protein	7.0	0.0	Protein	7.0	0.0

Use the figures in the table to help you answer the following questions.

(a) In the healthy person, what was the percentage of urea in

(i) the blood?

(1 mark)

(ii) the urine?

1 mark)

(b) What process, going on in the kidney tubule, was responsible for the urea being more concentrated in the urine than in the blood?

(2 marks)

(c) What was different about the urea when the person was ill compared to when the person was healthy?

(2 marks)

(d) (i) Which substance was not found in the urine either when the person was healthy or when the person was ill?
(1 mark)

(ii) Explain why this substance was not found in the urine. (2 marks)

(e) (i) Which substance was not found in the urine of the healthy person, but was found in the urine when the person was ill?
(1 mark)

(ii) Explain how the kidney of a healthy person avoids losing this substance in the urine.
(3 marks)

(iii) Describe a chemical test you could carry out to show the presence of this substance in the urine. (3 marks)

Total marks for Q1 = 16

Question 2

If the tendon below the knee is tapped with a hammer, the lower leg jerks upwards. A student conducted an investigation to find out how the speed of the hammer affected the distance the lower leg moved.

Each trial was recorded on a video. A frame was taken every 33 milliseconds. The video was then played using single-frame advance. The number of frames for the hammer to move to the knee was found. The faster the speed, the smaller was the number of frames. The video was also used to find the distance moved by the toe.

The table below shows the results obtained:

Trial number	1	2	3	4	5	6	7	8	9	10
Distance hammer moved to knee (in cm)	20	20	20	20	20	20	20	20	20	20
Number of frames it took the hammer to move to the knee	15	16	12	10	9	8	7	6	2	2
Distance moved by toe in cm	0	0	5	5	10	10	10	10	15	15

(a) (i) What was the student's dependent variable? (1 mark)

(ii) State one potential variable that the student controlled. (1 mark)

(b) Explain the advantages of using the video camera for this investigation (2 marks)

(c) Give a conclusion based on the results of the investigation. (2 marks)

(d) Comment on the precision of the results for the distance moved by the toe. (2 marks)

(e) Describe the pathway in the nervous system which caused the toe to move when the tendon was struck. (6 marks)

Total marks for Q2 = 14

Question 3

A cataract is an eye problem involving the lens of the eye becoming cloudy. It can be treated by a simple operation which removes the lens. After the operation, the patient is able to see again, but will probably need to wear glasses.

(a) Explain why the eye can still form an image after the lens has been removed. (2 marks)

(b) After the operation, the patient will be unable to perform "accommodation".

Explain what is meant by accommodation, and why the patient will be unable to do it. (3 marks)

(c) Is the patient more likely to need glasses to see nearby or distant objects? Explain your answer. (3 marks)

(d) Will the operation affect the patient's ability to see in dim light? Explain your answer. (2 marks)

(total marks for Q3 = 10)

Question 4

While running in the Olympic marathon, a runner produces a lot of extra heat in their leg muscles and loses a lot of water by breathing and sweating. Outline some of the processes in the body which attempt to prevent the runner overheating and dehydrating. Give your answer in full sentences.

(10 marks)

Total marks for TMA = 50