WJEC (England) Biology GCSE

Topic 4: Coordination and Control

Notes

('Higher Tier only' in **bold**)

4.1 Nervous coordination and control in humans

Sense organs

Sense organs are groups of receptor cells which respond to a specific stimulus. For example, the eye is a sense organ which responds to light. Other sense organs may respond to temperature, touch, sound and chemicals. Once the sense organ detects the stimulus, it relays this information to the central nervous system.

The nervous system

Both controlled movement and autonomic reflexes are carried out by the body's nervous system. The nervous system controls movement by sending electrical signals known as nerve impulses along a network of specialised nerve cells called neurones. This allows coordinated movement and a constant internal environment to be maintained (homeostasis).
The nervous system consists of two main sections: the central nervous system (CNS) and the peripheral nervous system. The CNS is made up of the brain and spinal cord, whereas the peripheral nervous system contains motor and sensory neurones, which carry impulses to and from the CNS.

There are three types of neurone, each with a different function:

- Sensory neurone - carries impulses from a receptor to the spinal cord and brain
- Relay neurone - carries impulses between different parts of the central nervous system
- Motor neurone- carries nervous impulses from the central nervous system to the effector, e.g. a muscle or a gland.

Where two neurones meet is called a synapse. When an impulse arrives at the presynaptic neurone, a neurotransmitter is released into the synaptic cleft. The neurotransmitter diffuses across the synapse, binding to receptors on the postsynaptic neurone. This triggers a nervous impulse in the postsynaptic neurone, thus the impulse can be propagated.

Nerve cell adaptations

The function of a nerve cell is to pick up an impulse from one neurone and pass this to the next neurone. As nervous impulses must occur almost instantaneously, nerve cells must be adapted to carry electrical impulses quickly and efficiently:

- The axon has a myelin sheath, made of Schwann cells, surrounding it. This provides electrical insulation when the nerve impulse passes down the axon which speeds up the impulse.
- The axon is long to carry the impulse over large distances quickly. Passing an impulse between two neurones across a synapse slows the impulse down.
- Nerve cells contain neurotransmitter substances which they secrete at synapses to allow the impulse to continue in the next neurone.
- The nerve cell has dendrites which pick up electrical impulses from other neurones.

The reflex arc

Some movement is involuntary; organisms have adapted to carry out automatic reflexes when in danger in order to quickly remove themselves from a hazard such as fire or sharp objects. As these reactions must occur almost instantly to protect the organism, the nervous impulse does not travel to the brain, unlike voluntary impulses which are controlled by the brain. Examples of automatic reflexes include the withdrawal reflex, blinking and the change of pupil size.

Reflex arc:

1. A stimulus, such as heat from a flame, is detected by receptors.
2. The receptor sends an impulse down the sensory neurone to the spinal cord.
3. The relay neurone in the CNS passes the impulse to the motor neurone.
4. The impulse travels along the motor neurone to an effector (e.g. a muscle), which reacts to remove the organism from the danger.

The structure of the eye

- Cornea - A clear layer which coats the iris. The cornea refracts light into the eye.
- Iris - The coloured section of the eye. This controls the amount of light that enters the eye by contracting and dilating the pupil.
- Pupil - Allows light into the eye
- Lens - Positioned behind the iris. The lens changes shape in order to focus the image on the retina.
- Sclera - The white part of the eye, it provides structure and protects the outer part of the eye.
- Choroid - A thin layer between the sclera and retina. It allows oxygen into the cells of the retina.
- Blind spot - A small portion of each eye does not contain light receptor cells, meaning that there is a blind spot in the visual field. It cannot be seen with both eyes open, as the two visual fields overlap. It can be found with one eye closed, however it is not usually noticeable as the brain fills in the blind spot.
- Retina - Contains rod and cone cells (photoreceptors) which are sensitive to light. There are also many blood vessels which supply nutrients to these cells.
- Fovea - a section in the middle of the retina which contains a large amount of cone cells; this section provides the clearest image.
- Optic nerve - Each photoreceptor cell is attached to a neurone. These neurones group together to form the optic nerve, which carries the impulse to the brain.

Common eye defects

- Short-sightedness - Short sightedness is caused by the lens being too thick and curved, or by the eyeball being elongated, thus the picture is focused in front of the retina. This means that objects far away are blurry.
- Long-sightedness - Long sightedness is caused by the eyeball being too short or by the lens becoming less elastic, which is often related to age. This causes the image to focus behind the retina, so objects close by are blurry. Both long-sightedness and short-sightedness can be corrected by wearing glasses or contact lenses.

- Cataracts - Cataracts develop slowly and cause the lens to become cloudy due to a build-up of protein, which restricts vision. They are commonly age-related but can also be a result of diabetes or appear after an injury to the eye. Cataracts can be removed using laser eye surgery, or invasive surgery to replace the lens.

The structure of the brain

- Cerebral hemispheres - the brain is made up of two halves called hemispheres. The cerebral hemispheres form the outer layer of the cerebrum and make up the cerebral cortex, which is responsible for a range of functions including processing of nervous signals, thought, problem solving and language.
- Cerebellum - located at the back of the brain behind the brain stem, the cerebellum is responsible for coordinated movement.
- Medulla oblongata - located in the brain stem, the medulla oblongata is responsible for a range of autonomic functions such as controlling breathing rate, heart rate and blood pressure.

Research into the structure and functions of the brain could have a huge impact on the ability to cure diseases in the ageing population, such as Alzheimer's and Parkinson's disease. In many of these diseases, nerve cells in the cerebral cortex begin to die, which results in a decrease in functionality. Knowledge of which areas of the brain control which functions would allow the direct cause of these diseases to be known, and thus a cure to be developed.

Studying the brain is extremely difficult, however. This is because there are billions of neurones, and in order to learn the function of many of these the brain must still be working, meaning that the patient must be alive. There are also ethical issues with studying the brain of patients with brain damage, as they may not be able to give informed consent. In addition, it may be difficult to theorise the cause of a certain problem as studies will only be carried out after the damage has occurred, so it cannot be compared to their healthy brain. Brain damage also rarely causes a singular problem; thus, it may be difficult to match which problem is caused by which damaged neurones.

Some functions can be mapped using non-invasive methods, such as functional magnetic resonance imaging (fMRI), PET scans and electrical stimulation. This means that the brains of healthy patients can be compared to those with various diseases to see the differences and thus theorise the cause. These methods are limited, however, as they are expensive, have poor temporal and spatial resolution, and some scanning methods may cause tissue damage.

4.2 Hormonal coordination and control in humans

Hormones

Hormones are chemical messengers that travel in the blood and are used for signalling in the body. They are produced in glands such as the pituitary and adrenal glands, before being excreted into the blood, where they travel to target organs. When they reach a target organ, they bind to receptors on the cell surfaces, which stimulates a response from within the cell.

Example glands and functions:

Gland	Hormone	Function
Adrenal gland (located at the top of the kidneys)	Adrenaline	Secreted during the 'fight or flight' response, and when stressed or excited. It leads to an increase in pulse rate and widened pupils. It also causes glycogen to be converted to glucose in cells so that it can be used in respiration for energy. Heart rate increases to provide more oxygen for this.
Pancreas	Insulin	Maintains blood-glucose concentration.
Testes	Testosterone	Maintains muscle and bone strength and plays a role in reproduction.
Ovaries	Oestrogen	Regulates the female reproductive system.
Thyroid (located in the neck)	Thyroxine	Regulates a variety of functions, including metabolic rate, growth and development, and digestion.
Pituitary gland (located at the hypothalamus in the brain)	Produces a range of hormones, including FSH, LH and ADH	The pituitary gland regulates other hormonal glands throughout the body, stimulating the release of hormones from them. It controls a number of processes related to homeostasis in this way, including blood pressure and temperature. It also produces hormones which control the menstrual cycle.

Feedback mechanisms

Most hormones are regulated by negative feedback systems. This is where a response is only carried out if a certain variable (e.g. temperature or blood glucose level) moves outside of an optimum range; corrective mechanisms then work to correct the change to move the variable back to the optimum.

- **Thyroxine is a hormone secreted by the thyroid. It travels in the blood to target organs, such as the liver and kidney, where it is used as a catalyst to regulate a variety of functions, including metabolic rate, growth and development, and digestion.**

The release of this hormone is controlled by a negative feedback loop: if the levels of thyroxine in the blood become too low, the hypothalamus releases a hormone called TRH (Thyrotropin Releasing Hormone). This is detected by receptors which trigger another hormone, TSH (Thyroid stimulating Hormone), to be released by the pituitary

gland. TSH travels to the thyroid and stimulates the release of thyroxine. Once the level of thyroxine in the blood has returned to normal, the release of TRH from the hypothalamus, and subsequently the release of TSH, is inhibited by normal thyroxine levels in the blood.

- **The hormone adrenaline is released from the adrenal glands, located at the top of the kidneys. When the body is under stress, adrenaline is released which causes a variety of physiological effects, including: increased blood supply to the muscles (dilation of blood vessels supplying them), increased pulse rate and breathing depth. This is an example of positive feedback - it's levels decrease when it is converted to another compound by the liver.**

Reproductive hormones and the menstrual cycle

A variety of interacting hormones are used to regulate the menstrual cycle and ovulation in women. The menstrual cycle happens approximately every 28 days. During each cycle, an egg cell is released from the ovaries. The uterus wall thickens by filling with blood capillaries in preparation for a pregnancy, which would occur if the egg is fertilised. If it is not fertilised, the egg dies and menstruation occurs, where the dead egg cell and old uterus lining is expelled from the body in a period.

The menstrual cycle is regulated by four interacting hormones:

- **FSH - Follicle stimulating hormone triggers the development of an egg cell in the ovary, and also stimulates oestrogen production by the follicle.**
- **LH - Luteinising hormone triggers an egg to be released in ovulation, the empty follicle becomes a corpus letup which releases progesterone.**
- **Oestrogen - Helps to repair and thicken the uterus lining after menstruation. Oestrogen inhibits FSH. When oestrogen levels increase, LH is released which causes ovulation.**
- **Progesterone - Progesterone is responsible for maintaining the thick uterus lining in the cycle and during pregnancy. When progesterone levels drop, the uterus lining breaks down and menstruation occurs. Progesterone inhibits both FSH and LH. Progesterone is also produced by the placenta (to inhibit FSH and LH) if a woman becomes pregnant.**
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Contraceptive hormones

The menstrual cycle can be controlled artificially by taking hormones. This can be used to prevent pregnancy by inhibiting ovulation so that no egg is released. These hormones are usually taken as an oral pill containing oestrogen and progesterone. Although these pills act to prevent a pregnancy, they do not prevent the spread of sexual diseases. Some people therefore prefer to use non-hormonal methods of contraception, such as condoms and spermicide, as they rarely have side effects and do protect against sexual diseases.

Infertility treatments

Hormones can also be used to promote pregnancy in some women who are infertile. There are a variety of different hormonal medications which can be taken to treat different causes of infertility. For example, FSH and LH encourage eggs to mature and be released from the ovary (ovulation). These treatments are usually taken as a pill or injected. Not all causes of infertility can be treated using hormones.

4.3 Homeostasis in humans

Homeostasis is the maintenance of a constant internal environment in organisms, despite external changes. This allows the environment to be at an optimum for cells to function. Internal conditions must be maintained between set limits and if these limits are exceeded, negative feedback mechanisms work to correct the change and restore the internal environment to the optimum. These mechanisms include hormones, nerves, receptors and effectors.

Regulating blood-glucose concentration

The level of glucose in the blood must be maintained as part of homeostasis. If the level of glucose in the blood is too high, water moves out of cells into the blood by osmosis. This leads to cells shrinking and eventually dying. If the level is too low, water moves from the blood into the cells, causing them to burst. Maintaining a constant blood-glucose level therefore prevents unwanted osmosis and cell death. In addition, it means that there is a reliable source of energy for cells. There are two hormones that are used to regulate blood-sugar levels: glucagon and insulin. Both of these are synthesised in cells in the pancreas and are released into the blood when the levels of blood-glucose are too high or too low:

- Insulin is released when blood-glucose concentration is too high. This is detected in the pancreas. Insulin causes glucose to be converted to glycogen in the liver. This lowers the concentration of glucose in the cells, thus glucose diffuses into cells from the blood, lowering the amount of glucose in the blood.

- **Glucagon is released when blood-glucose concentration is too low. Glucagon inhibits glucose being converted to glycogen in the liver and activates an enzyme that converts glycogen to glucose, making more glucose available to cells. It also decreases the respiratory rate in cells so that less glucose is used in respiration.**

Diabetes

In some people, blood sugar level is not regulated sufficiently. This disease is known as diabetes. There are two types of diabetes, type 1 and type 2:

- Type one diabetes is caused by an inability to produce insulin. This is because the cells that produce insulin in the pancreas are destroyed by antibodies in an autoimmune response. This results in high blood glucose levels. Type one diabetes can be managed by injecting insulin and restricting the amount of carbohydrate in the diet.

- Type two diabetes is usually caused by the body losing its responsiveness to insulin. This means that not enough glucose is taken up by cells, leading to high blood sugar levels. It can also be caused by insufficient insulin production in the pancreas. Type two diabetes is usually less severe than type one and is developed most commonly in older or obese people. It can be managed by changing the diet to restrict carbohydrate intake and increasing exercise.

Regulating temperature

It is important to maintain a constant temperature of 37°C in humans as this is the optimum temperature for enzyme reactions. If the temperature was lower, the rate of reaction would decrease so reactions would take too long to occur. If it was too high, the enzymes may denature and prevent reactions from occurring. The temperature is regulated by the hypothalamus in the brain, which contains thermoreceptors. If the temperature moves away from the optimum, a response is triggered to return the temperature to the optimum.

Reactions to a low internal temperature:

- Shivering - muscles contract to produce heat.
- Vasoconstriction - blood vessels constrict to reduce surface area and move away from the surface of the skin to reduce heat loss.
- Erection of hairs - hairs stand on end to trap warm air between them.

Reactions to a high internal temperature:

- Sweating- sweat evaporates from the skin, reducing the surface temperature.
- Vasodilation - blood vessels dilate, causing more heat loss to the environment.

The kidney

The kidney's role is to filter waste and excess substances from the blood so that they can be excreted from the body as urine. It is important for these waste substances to be filtered out of the blood as a build-up of toxins could cause harm to the organism.

Through this process, the kidney also maintains the water balance in the body by controlling how much water is excreted. It is important to maintain water concentration in the blood to prevent unwanted osmosis. If there is too much water in the blood, water will move via osmosis into cells, causing them to burst. If there is too little, water will move out of cells, causing them to shrink. This will result in cell death and tissue damage, so it is important that water balance is maintained.

The volume of urine produced is dependent on the water intake, temperature and exercise: a large amount of dilute urine is formed when there is a large intake of water, a low temperature (water is not lost through sweating), and when a low amount of exercise is carried out.

The structure of the kidney:

- Cortex - the outer region of the kidney; the cortex contains nephrons.
- Nephron - the nephron is the functional unit of the kidney. It is where the blood is filtered and glucose, urea, water and salts are removed.
- Tubule - All glucose, most water and some salts are reabsorbed into the blood in the tubule. This prevents the loss of too much water. Urea is not reabsorbed, leading to a high concentration of urea in the urine.
- Medulla - the inner region of the kidney.

- Ureter - two tubes that transport urine from each kidney to the bladder, where it is stored before being excreted from the body.

Filtration and selective reabsorption

1. Blood enters the kidney through the renal artery and travels to the nephrons, where filtration takes place.
2. High pressure causes small molecules, such as glucose, urea, water and mineral salts, to pass out of the blood into the Bowman's capsule. Diseases of the kidney can lead to larger molecules and blood cells passing out of the blood vessels during this stage. Consequently, kidney diseases can be diagnosed by testing urine for blood or proteins.
3. Selective reabsorption occurs in the tubule: molecules can move back into the blood if there is not enough. This allows water balance to be maintained, as well as blood-glucose concentration. Urea is a waste product and is therefore not reabsorbed.
4. Excess and waste substances which are not reabsorbed move to the collecting duct and then exit the kidney and travel to the bladder through the ureter. They can then be excreted from the body. Filtered blood exits the kidney through the renal vein.

The amount of water reabsorbed is controlled by a hormone called ADH. Osmoreceptors in the hypothalamus detect changes in the amount of water in the blood. If there is too little water in the blood, a nervous impulse is sent to the pituitary gland in the brain, which triggers the release of ADH into the blood. ADH travels to the kidney where it controls the permeability of cells to water, meaning that it controls how much water is reabsorbed from the kidney tubules. A high amount of ADH will make the cells more permeable so more water is reabsorbed into the blood. When the blood returns to its optimum concentration, ADH stops being released and the cells become less permeable again. This is another example of negative feedback, as ADH is only released when the concentration deviates from the optimum range.

4.4 Plant hormones

Plants are able to respond to their environment due to hormones, which facilitate plant growth and development and increase their chances of survival. Hormones also allow tropisms, which are growth movements of a part of a plant in a specific direction. If the plant moves towards a stimulus, it is referred to as a positive tropism, whereas if the plant moves away from it, it is a negative tropism. The main plant tropisms are phototropism and gravitropism:

- Phototropism is a response to light. Plant shoots are positively phototropic, meaning that they will bend towards a light source.
- Gravitropism (sometimes known as geotropism) is a response to gravity. Plant roots are positively gravitropic as they will grow downwards.

These tropisms are carried out by auxins, which are a type of plant hormone. Auxins are produced in the plant shoot and root tips and are transported through the plant via diffusion and active transport, or via the phloem over longer distances. Auxins control these responses by stimulating cells to elongate. For example, to make the plant shoot bend towards a light source, auxins move to the shady side of the plant and cause the cells there to elongate, which forces the shoot to bend towards the light.

Gibberellins

Gibberellins are another type of plant hormone. They react as a response to water:

- **Gibberellins are present in seeds. When water is present, they cause the seed to germinate, hence breaking seed dormancy. Dormant seeds are metabolically inactive; when water is absorbed into the cell, gibberellin causes a chain reaction to occur to begin respiration and hence produce energy for growth.**
- **In adult plants, they cause bolting. This is a response to a lack of water or cold temperatures and involves the plant flowering and producing seeds in an attempt to reproduce before death.**

Plant hormones in agriculture

Plant hormones can be used in farming to increase the yield or growth efficiency of a crop:

- **Ethene, a hormone which controls fruit ripening, can be used to slow the ripening of fruit (e.g. for transport or storage) or speed it up.**
- **Plant hormones can be used in selective weedkillers by making certain plants grow too quickly, causing plant death. This reduces competition for the desired plant and increases the crop yield.**
- **Gibberellins can be used to produce flowers to sell. They also impact the rate of fruit growth and can be used to increase the size of fruit.**
- **Auxins can be used in rooting powders to promote quick root growth in plant cuttings.**