Nerves and hormones

Nervous coordination in mammals

The ability to respond to stimuli is a fundamental characteristic of living organisms. Organisms with a central nervous system (CNS) are well adapted to cope with changes in the external environment and within the body. The nervous system has three distinct functions:

- collection of information about changes in its environment, both internal and external
- processing this information and often relating it to previous experiences
- acting on this information by coordinating the response of the organism

One remarkable feature is the speed of the response which is virtually instantaneous.

The central nervous system is composed of specialised cells called **nerve cells** or **neurones**. These cells are bound together by connective tissue to form nerve fibres. These neurones are stimulated by changes in their environment to transmit information to and from the central nervous system. This is done by a series of electrical impulses passing along the length of a neurone.

There are three types of neurones. Their main functions are:

- transmitting electrical impulses
- stimulating other cells

The specific function of each type of neurone are summarised below:

Name of neurone	Stimulated by	Transmits impulse to
Motor neurone	Another neurone, relay or sensory neurone	To an organ e.g. heart or a gland
Relay neurone	Another relay neurone or sensory neurone	Another relay neurone or motor neurone
Sensory neurone	A **receptor** e.g. neurones in the skin or rods and cones in the eye	A relay neurone or a motor neuron

The electrical **impulses** can only travel in one direction in a neurone. Motor neurones are sometimes called **effector neurones** since they produce a physical response to stimulation.

The general structure of nerve cells

The neurone in general contains a **cell body** with a nucleus that controls the activity of the cell. The cytoplasm within the cell is extended to produce **dendrons**. Each dendron has a number of long fine structures called **dendrites**. These dendrites are stimulated by electrical **impulses** from other neurones. The information is then passed to the cell body.

The **axon** is the long thin section of the neurone, which can be up to a metre long. This is formed by a single extension of the cell body cytoplasm. The axon always transmits impulses away from the cell body.

Axons end in a series of **synaptic knobs**. These structures stimulate other nerves or a target organ, in which case a physical response happens (e.g. an arm to move or to close the eye lid). Another important feature is **Schwann cells**. These cells are found along the length of the axon. Schwann cells wrap around the axon with small gaps between each cell. Neurones with Schwann cells are called **myelinated neurones**. These cells act as an electrical insulator and speed up transmission of

impulses. There are neurones that are **unmyelinated**; they transmit impulses more slowly than myelinated neurones.

Nerves and their impulses

All living cells maintain an (electrical) potential difference across the cell membrane, i.e. maintain a difference in the electrical field inside and outside the cell membrane. This is called the **membrane potential**. Neurones have the ability to change their membrane potential.

Under normal conditions (no stimulation) the membrane of a neurone has a negative charge (-ve), compared to its surroundings. This is known as the **resting potential**.

How is the resting potential created?

The resting potential depends on the concentration of four ions within the cell:

- potassium, K^+
- sodium, Na^+
- chloride, Cl^-
- carboxylate, $RCOO^-$ (from proteins)

The concentrations of potassium and carboxylate ions are high inside the cell while the concentration of sodium and chloride ions is higher outside the cell. In the resting phase, the axon membrane allows K^+ ions to pass through it more freely than the other ions.

The K^+ ion diffuse out rapidly this makes the environment inside the cell slightly negative since there are fewer positive ions.

Eventually a balance between the number of K^+ ions entering and leaving the cell is achieved. This movement of K^+ ions creates the **resting potential**. When a membrane is in this condition it is said to be **polarised**.

When a neurone is stimulated the electrical potential of its cell membrane is altered, it is **depolarised**. Depolarisation changes the permeability of the membrane towards sodium ions at the site of the stimulation causing a sudden influx of sodium ions into the axon. Now the overall charge inside the cell is more positive. This is known as the **action potential**.

An animation showing the propagation of the action potential can be viewed on:
http://www3.uah.es/farmamol/Public/Animaciones/actionp.html

When enough sodium ions have entered, creating a positive charge inside the axon, the membrane permeability towards sodium ions decreases significantly in favour of the potassium ions again.

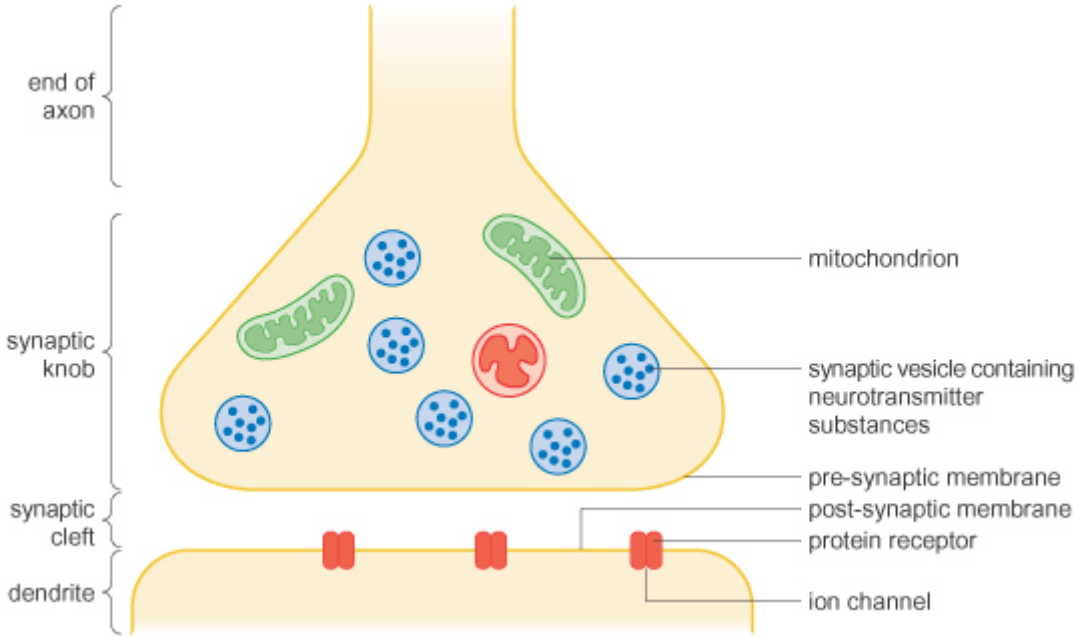
This flow of potassium ions continues until the **resting potential** is achieved, that is the concentration of the ions, is restored in this region of the axon and the membrane is **re-polarised**.

As the concentration is restored in the first section, the polarisation of an adjacent section of the membrane is depolarised. The ion transfer reaction is repeated.

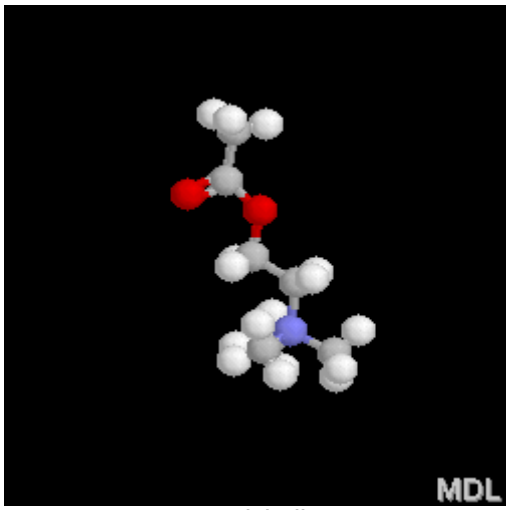
These reactions are **localised**, they start at the first stimulation point on the axon. The first reaction starts a wave of **localised ion transfer reactions**. These reactions propagate a series of action potentials followed by resting potentials repeated at regular intervals along. In this way electrical or nerve impulses are transported along the whole length of the axon by the movement of ions between the axon and its external environment.

The Synapse

Once the nerve impulse has passed to the end of the axon, the dendrites, it needs to be transferred to another neurone or tissue. At the end of each dendrite is a bulbous structure called a **synaptic knob**. The synaptic knob contains many structures common to living cells. In addition they have **synaptic vesicles**. These vesicles contain a chemical that assists the transfer of the impulse, a **neurotransmitter** called **acetylcholine**. The **pre-synaptic membrane** binds to the end of the adjacent neurone. Large protein molecules called **receptor molecules** are found on the surface of the postsynaptic membrane. There is a gap between the two structures about 20 nm wide known as the **synaptic cleft**.



The nerve impulse is transported across the synaptic cleft by a similar method used to transport the impulse along the length of the axon that is by the propagation of action potentials. Calcium ions, Ca^{2+} and Sodium ions, Na^{+} together with acetylcholine play vital roles in this process.



Acetylcholine

When the nerve impulse reaches the **pre-synaptic membrane** it depolarises the membrane. This causes changes in the electrical potential of the immediate environment, i.e. a localised ion transfer reaction is started. This action alters its permeability in favour of calcium ions, Ca^{2+}. The influx of Ca^{2+} ions causes the synaptic vesicles to fuse to the inner surface of the membrane and acetylcholine

is released into the gap. The empty vesicles return to the cytoplasm. The acetylcholine diffuses across the synaptic cleft and fuses with the receptor molecules at the surface of the post-synaptic membrane.

The attachment of the neurotransmitter depolarises the membrane altering its permeability in favour of sodium ions, Na^+. This flow of Na^+ ions into the post-synaptic neurone creates a new localised ion transfer reaction - a new action potential.

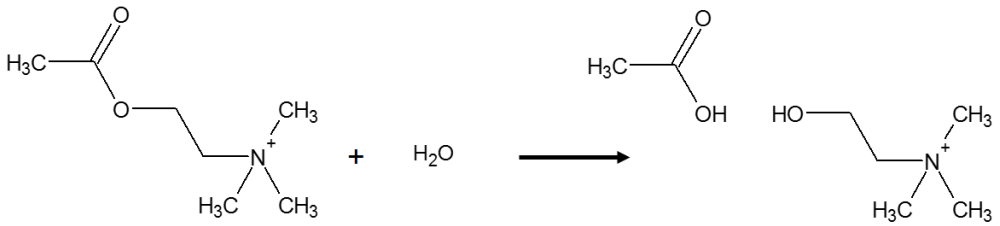
As soon as acetylcholine depolarises the **post-synaptic membrane**, it must be removed from its surface to allow for the transmission of another impulse. This is achieved with assistance of water and a suitable biological enzyme. The acetylcholine molecule is **hydrolysed** by water.

This reaction breaks the acetylcholine to make two products. An ethanoate ion CH_3COO^-, combines chemically with the H^+ from the water to produce ethanoic acid, CH_3COOH.

The hydroxyl ion OH^- portion from the water, combines chemically to the remaining portion of the molecule producing choline, $HOCH_2CH_2N^+(CH_3)_3$.

Choline from acetylcholine

Acetylcholine is hydrolysed (i.e. reacts with water) to form ethanoic acid and choline



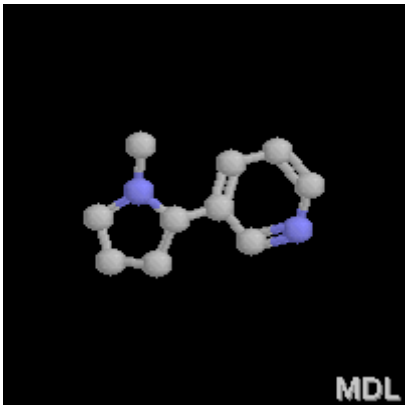
acetylcholine choline

These products are released by the **receptor molecules**. They diffuse across the cleft and back into the pre-synaptic neurone where they recombine to form acetylcholine. These molecules are stored in the synaptic vesicles for future use. A lot of energy is required for the recombination process that is provided by the many mitochondria present.

Successive nerve impulse transmissions build up on the post-synaptic membrane until enough depolarisation has taken place and an action potential is generated. The impulse is then transported by the propagation of action potentials along the length of this neurone to another neurone or to a target organ.

The effect of drugs on synaptic transmissions

Discovering the chemical structure of neurotransmitters has given chemists an understanding of the action of drugs and poisons on the nervous system. There are many drugs that are known to influence the functioning of synaptic transmissions. An example is nicotine found in tobacco products. Nicotine is only one of 3500 different compounds found in tobacco smoke.



Nicotine

Nicotine is part of a group of nitrogen-containing chemicals called **alkaloids**. Alkaloids have hydrocarbon-based skeletons, i.e. they contain mainly carbon and hydrogen atoms and are found in plants. Examples of other alkaloids are caffeine, morphine and cocaine.

Nicotine mimics the action of neurotransmitter chemicals like acetylcholine. Both molecules are based on hydrocarbon skeletons but the important fact about these structures is that they contain a nitrogen atom with a positive charge. This makes the structures very reactive in the part of the molecule that has the charge. Acetylcholine receptors on post-synaptic membranes will accept nicotine because it has a similar arrangement of is atoms and similar charge on the nitrogen atom.

When tobacco is burned, small droplets of tar containing nicotine are inhaled and find their way to the lungs and eventually to the alveoli or air sacs. Nicotine is a weak base (pH 8.5); its pH is adjusted when it enters the airway to match the pH of body fluids (pH 7.4).

It is rapidly absorbed through the fine membrane of the air sac and the mouth into the bloodstream. From this point nicotine is distributed very quickly throughout the body, taking about eight seconds to reach the brain. In the brain it creates a burst of activity amongst the acetylcholine receptors to give a feeling of pleasure.

The initial concentration of nicotine is high after one inhalation. It takes about 45 minutes for this concentration to be reduced by half. At low concentrations it acts as a stimulant at higher levels it acts as an inhibitor, i.e. it will prevent neurone stimulation.

When nicotine is bound to the postsynaptic receptor, it depolarises the membrane triggering the influx of sodium ions from surrounding tissues. This initiates a wave of action potentials as before.

However nicotine is not removed by hydrolysis so the stimulation is maintained, i.e. the flow of ions is maintained and other nerve transmissions cannot get through. However eventually nicotine is broken down mainly in the liver by **oxidation**, in a number of stages with the assistance of enzymes.

This over-stimulation happens at all axons exposed to nicotine and it has an effect on all organs and functions. One adverse effect of the over-stimulation of nerve fibres is the constriction of blood vessels, at the same time stimulating the heart making it beat faster and increasing the blood pressure.

As the level of nicotine falls the affected neurones have a chance to recover. However it is likely that long-term use of nicotine is likely to result will result in chronic illness or death as there will always be permanent tissue as well as nerve damage.

Hormonal coordination

Hormones do not belong to one particular chemical group. Some are **amines**, nitrogen-containing molecules, others are **protein** and **polypeptide** in origin. A few are **steroids** that are derived from fats and lipids.

These chemicals messengers are passed in very small amounts, directly into the bloodstream by glands that collectively form the **endocrine system**. Once in the bloodstream the hormones are carried to all parts of the body. They bring about specific effects in the behaviour and development of animals.

The basic similarities between the nervous and the endocrine systems are that they provide the body with methods to communicate with its internal and external environments in order to coordinate responses. They both employ chemicals to transmit messages and respond to stimulus caused by changes in their environments.

However there are differences in:

- response times
- how they work

The responses of the nervous system, are usually instantaneous. Hormones are transported all over the body via the blood, so response times will vary. Puberty is the stage in human development when children become adults. This transition takes years to complete and is controlled mainly by the hormones oestrogen, progesterone and testosterone that are **steroids** in origin.

Hormones are like 'impulses' from the glands. In order to stimulate a particular response, more than one hormone may need to be released.

The pituitary gland, found at the base of the brain, influences the activity of the other endocrine glands. It is controlled by the information it receives from the brain. This gland produces a large number of hormones that influence the activity of other glands. Hormones target specific cells. These target cells have molecular receptors on their surface membranes, (like on post-synaptic membranes). The shape and size of these receptors ensures that only certain hormones can be attached, they fit like two pieces of the same puzzle.

The way hormones work depends on the type of hormone.

- The attachment of the hormone to the receptor triggers the production of a second chemical inside the cell that completes the function. This is the action of **proteins** and **polypeptides**.
- **Steroids** like oestrogen bond with the receptor forming a new compound that has the ability to pass through the cell wall. In this way it is able to effect changes directly.
- Sometimes the action of bonding with the receptor alters the permeability of the cell membrane allowing other molecules to enter the cell. Insulin, a **polypeptide**, acts in this way. The cell membrane is depolarised allowing glucose molecules to enter for cell respiration.

The endocrine and nervous systems work independently to carry out unique functions by different methods with some similar elements. However, they do work together to control and co-ordinate the internal environment of the animal.

Test your knowledge

Take quiz on *Nerves*