WJEC Biology A Level

Topic 4C: Neurobiology and Behaviour

Notes

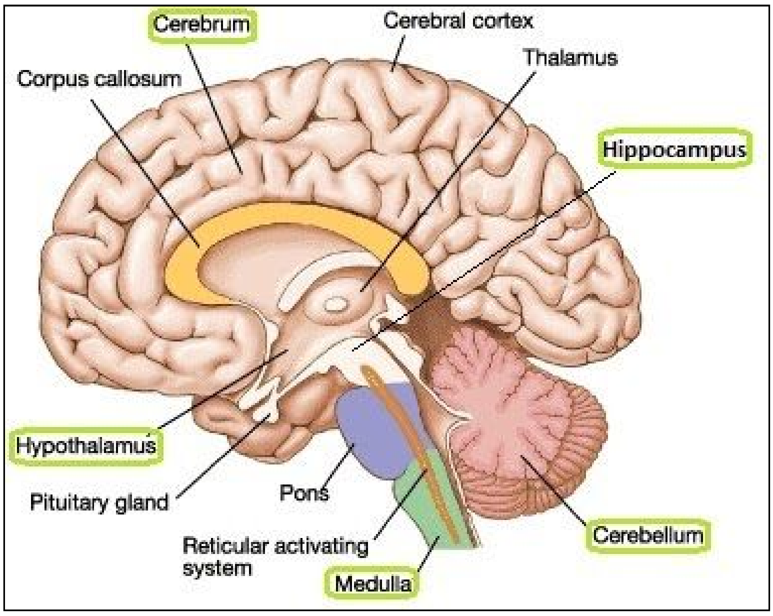
The Brain

The human brain is located within the skull and is covered by three membranes called the meninges.

Cerebrospinal fluid (CSF) that supplies brain neurones with oxygen and nutrients is produced in the ventricles, which are spaces of the brain filled with CSF.

The brain can be subdivided into three main areas:

- The forebrain → made up of the hypothalamus, thalamus and cerebrum.
- The midbrain → contains nerve fibres that link the forebrain to the hindbrain.
- The hindbrain → includes the cerebellum and the medulla oblongata.



[Brain Structure](#)

Each structure in the brain has a different function:

- **Cerebrum:**
  - ❖ Divided into two hemispheres connected by a bundle of nerves called the corpus callosum.
  - ❖ Each cerebral hemisphere has four structural regions:
    - ➢ Frontal lobe → reasoning, planning, part of speech and movement (the motor cortex), emotions and problem solving.
    - ➢ Parietal lobe → somatosensory functions and taste.
    - ➢ Temporal lobe → language, learning and memory.
    - ➢ Occipital lobe → vision.
  - ❖ The cortex is the outer layer, composed of grey matter (neurone cell bodies) and the inner area is white matter (myelinated axons).

- Integrates sensory functions and initiates voluntary motor functions.
- Also responsible for intellectual function in humans → learning, reasoning, personality and memory.

- **Hypothalamus:**
  - Controls general body functions → body temperature, blood solute concentration, hunger, thirst and sleep.
  - Main control region of the autonomic nervous system.
  - Links the brain to the endocrine system, through the pituitary gland.

- **Thalamus:**
  - Important relay centre → sends and receives information to and from the cerebral cortex.

- **Hippocampus:**
  - Interacts with other areas of the cortex → e.g. connection to hypothalamus and thalamus to form the limbic system, involved in emotion, learning and memory.
  - Involved in learning, reasoning and personality.
  - Consolidates memories into a permanent store.

- **Cerebellum:**
  - Coordinates precision and timing in voluntary muscular activity, posture and learning motor skills.

- **Medulla Oblongata:**
  - Connects the brain to the spinal cord.
  - Controls involuntary, autonomic functions → heart rate, ventilation and blood pressure.

The Autonomic Nervous System

The part of the peripheral nervous system that controls automatic functions of the body (includes heart rate, ventilation rate, blood pressure, digestion and parasympathetic nervous system) by the antagonist activity of the **sympathetic and parasympathetic nervous systems**.

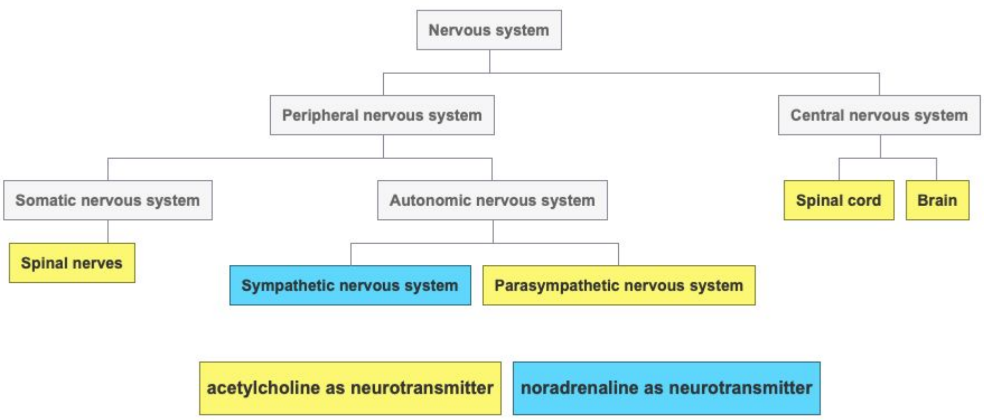
Sympathetic Nervous System

- Uses noradrenaline as its neurotransmitter to produce mainly stimulatory/excitatory effects e.g. increases blood pressure, ventilation rate and heart rate.
- Acts to prepare the body for activity i.e. the ‘fight or flight’ response.
- Originates in the thoracic and lumbar regions of the spinal cord (from level T1 to level L2/L3).
- Connects to many organs in the body including the eye, the salivary glands, the gut, the heart and the lungs.

Parasympathetic Nervous System

- Uses acetylcholine as its neurotransmitter to produce mainly inhibitory effects e.g. decreases blood pressure, ventilation rate and heart rate, relaxes sphincter muscles in the gastrointestinal tract (to aid digestion).
- Promotes restorative function of the body.
- More discrete in its actions that the sympathetic nervous system.
- Originates from two places in the body:
  - The brainstem as cranial nerves III (Oculomotor), VII (Facial), IX (Glossopharyngeal) and X (Vagus).
  - The sacral region of the spinal cord (levels S3 and S4).
- Connects to many organs including the eye, the salivary glands, the genitalia, the gut, the heart and the lungs.

Many organs are supplied by both sympathetic and parasympathetic nerves, which use opposing signals to adjust the activity of the organ appropriately to meet the needs of the body at a certain time.



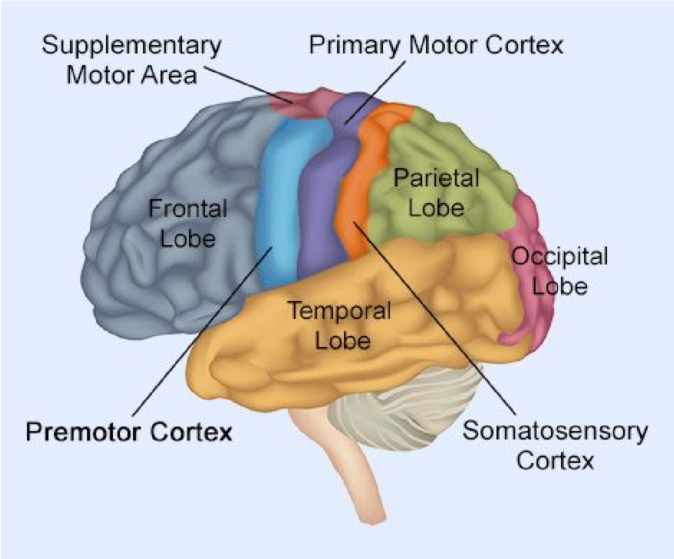
The Nervous System

The Cerebral Cortex

The outer layer of each cerebral hemisphere that is 2-3 mm deep with a highly folded surface to increase the cortical area available for processing information.

Can be divided into three functional areas:

- Sensory areas → receive nerve impulses from receptors in the body.
- Motor areas → send nerve impulses to appropriate effectors via motor neurones.
- Association areas → make up most of the cerebral cortex and receive impulses from sensory areas and associate this information with previously stored information (from memory) which allows the information to be interpreted and given meaning. Association areas also initiate appropriate responses which are passed to the relevant motor areas.



The Cerebral Cortex

The Motor Cortex

Consists of three important regions:

1. The primary motor cortex → located in the frontal lobe of each cerebral hemisphere, in front of the somatosensory cortex.
2. The premotor cortex → located in front of the primary motor cortex.
3. The secondary motor cortex → located in front of the premotor cortex.

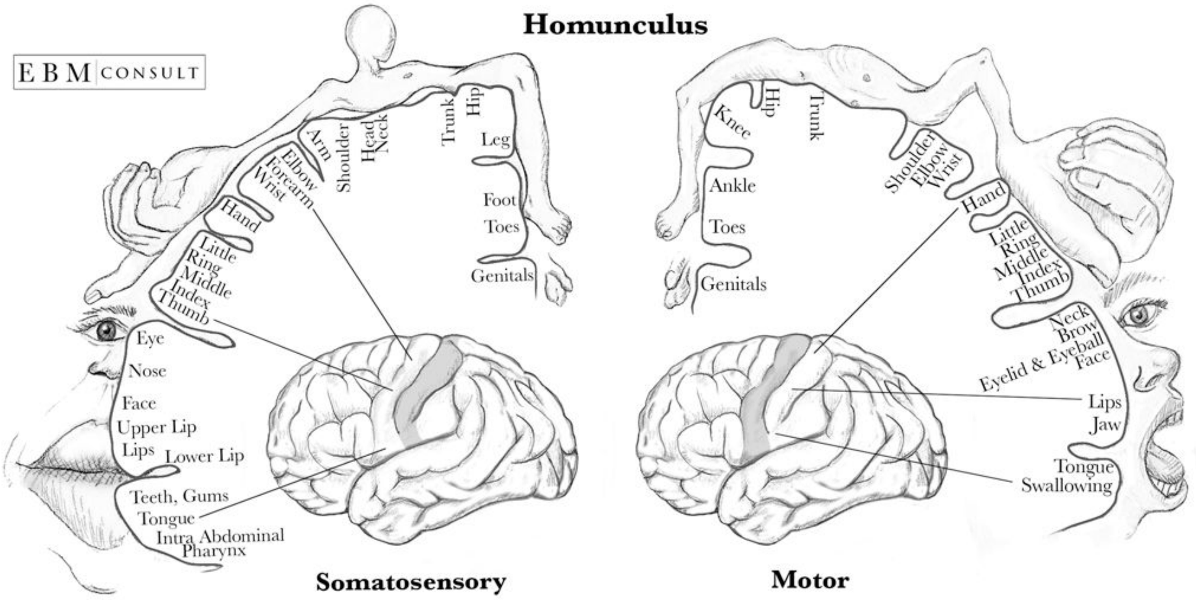
Motor neurones from the primary motor cortex of one cerebral hemisphere cross over in the medulla oblongata and innervate the effectors on the opposite side of the body, therefore controlling voluntary muscles on the opposite side of the body.

The Sensory Cortex

The somatosensory cortex is located in the parietal lobe of each cerebral hemisphere and integrates sensory functions from the opposite side of the body.

The areas of the body innervated by the primary motor cortex and somatosensory cortex are "mapped" onto these areas in particular arrangements, with body parts that display more refined and complex movements and sensations (the fingers, lips and tongue) taking up a greater area of the cortex than body parts that perform simpler movements and are involved in less detailed sensations.

These arrangements can be illustrated in diagrams known as the sensory homunculus and motor homunculus.



Motor and Sensory Homunculus

Language Comprehension and Speech

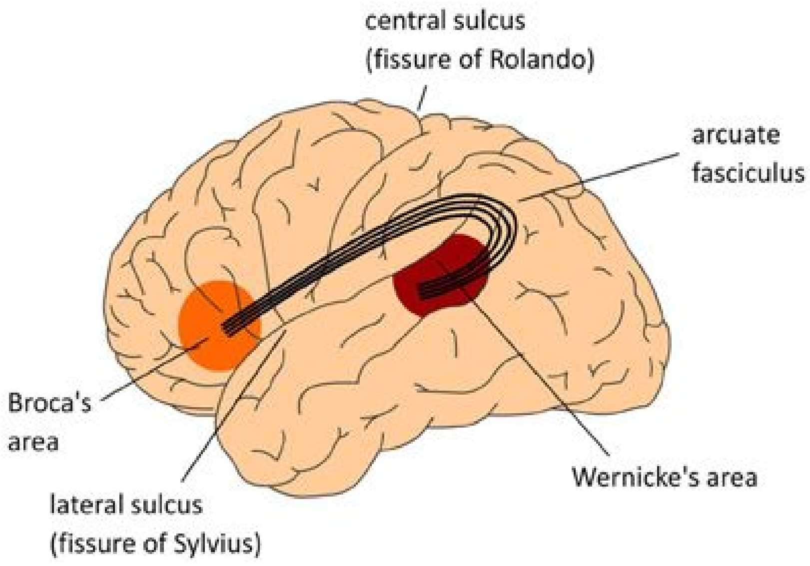
In most people, language comprehension and speech is controlled in the left hemisphere of the cerebral cortex. Broca's area and Wernicke's area are the two principal regions in left cerebral hemisphere responsible for language comprehension and speech.

Wernicke's area

- Located in the temporal lobe of the left hemisphere
- Responsible for the comprehension of written and spoken language

Broca's area

- Located in the frontal lobe of the left hemisphere, directly in front of the primary motor cortex
- Motor control over speech → motor neurones from this area innervate the muscles of the mouth, larynx and intercostal muscles to produce vocal sounds
- Deals with grammar



Speech areas in the Brain

Wernicke's area is connected to Broca's area by a set of nerve fibres called the **arcuate fasciculus**.

Neuroscience

Investigating the Brain

There are different non-invasive methods of investigating the brain through imaging and analysis of its activity. Each of these methods have their advantages and disadvantages, and are described in detail below.

Electroencephalography (EEG)

This detects voltage fluctuations in the brain's electrical activity over time through electrodes placed on the scalp. It is silent and does not use ionising radiation, but only displays activity in the cerebral cortex. It is used in the diagnosis of epilepsy.

Computerised Tomography (CT)

This method uses X-rays to show the internal structure of the brain in slices, from any angle. It provides high resolution of bone, soft tissue and blood vessels at the same time, but requires a high X-ray dose to do so. It is used to detect brain injuries and skull fractures.

Magnetic Resonance Imaging (MRI)

MRI involves a strong magnetic field and a radio wave pulse, which manipulate protons in water to give a 3D coloured map of the cerebral cortex. A detailed anatomical image is produced without using ionising radiation. MRIs take place in a small, enclosed area so can be difficult for people with claustrophobia. It is used to identify structures e.g. brain tumours, demyelinating nerve fibres and aneurysms.

Functional MRI Imaging (fMRI)

MRI fundamentals are used to show flow of oxygenated blood - allowing structure and functioning of the brain to be assessed from second to second. Again this method can be difficult to tolerate for people with claustrophobia, but if successful, allows brain function to be studied in real time.

Positron Emission Tomography (PET)

In PET scanning, FDG (radioactive isotope with a short half-life) metabolism shows areas of glucose use. It is able to detect biochemical changes in the brain but does so while exposing tissue to gamma radiation. It is mainly used to image tumours.

Brain Development and Neuroplasticity

The brain is formed early in embryonic development from the neural tube - derived from the ectoderm germ layer of the embryo. The neural tube expands at the anterior end to form the brain, and by week 5 of gestation, the cerebral hemispheres can be identified. Sulci and gyri that wrinkle the hemispheres' surfaces don't develop until the 8th month of gestation.

While the cerebral hemispheres are forming, the neural tube cells are rapidly dividing and do so until they differentiate into neurones and glial cells that make up the central nervous system. The rate of cell division becomes much slower before and during differentiation.

The neurones migrate to form the different structures of the brain. They branch off axons and dendrites to form synaptic communications with each other, resulting in neural circuits. Glial cells increase in number until adolescence, whereas neurones stop forming at birth.

Neural Circuits

A neural circuit is a group of interconnected neurones. Neural pathways are neural circuits on a larger scale - nerve fibres that connect different parts of the brain.

When people have new experiences or acquire new information, neural circuits in the brain change. These changes can take different forms:

- A synapse is formed or lost
- Change in the amount of neurotransmitter released at a synapse
- The post-synaptic neurone response to neurotransmitter is changed

Neural circuits are reinforced by constant exposure to the information or experience that created them, and regress when the information or experience is no longer encountered.

Neuroplasticity

This is the ability of the brain to re-organise itself throughout life by making new neural connections and breaking old ones. This process rapidly occurs in the first two years of life when extensive learning happens (critical period).

Neuroplasticity is essential for the brain to recover from injury as the new connections (intact axons growing new nerve endings to reconnect to damaged neurones) made allows vital functions to be regained e.g. relearning to speak after a stroke.

Developmental Plasticity

This is the process of change in neural connections during development as a result of environmental interactions and learning. Neurones in the immature brain rapidly form branches and new synapses.

It is most prominent in the first few years of life, named the critical period, when the nervous system is particularly sensitive to external stimuli. Exposure to sensory stimuli during this critical period allows new skills to form and development to progress. This is demonstrated in children born deaf who are not given an alternative method of expression (e.g. sign language) to vocalizing. These children have poorer language development.

Throughout life, neural connections are fine-tuned in response to interaction with the environment. Synapses that are not used are lost in a process called synaptic pruning. This happens mainly in the adolescent years and increases efficiency in the transmission of impulses in the brain.

Gene Expression

During an organism's growth, different parts of its genome are activated and deactivated at specific times and locations by chemical reactions. Different genes are expressed at different times and changes in the expression of genes is behind many brain functions. Epigenetics looks at the chemical reactions involved in gene activation and deactivation and explores the factors that influence them. Epigenetic changes are thought to be involved in the development of brain diseases such as addiction and mental illness.

Adults subject to abuse in childhood are at higher risk of mental illness such as serious depression, schizophrenia, eating disorders, personality disorders, bipolar disease and general anxiety. They find it harder to recover from mental illness and also more likely to abuse alcohol and drugs.

It is theorised that childhood experiences change certain physical aspects of the brain during the key developmental period, through a change in gene expression which predisposes adults to an increased risk of mental illness.

Adults who were abused or neglected as children also have higher levels of the hormone, cortisol. The cortisol production pathway is always active in these individuals and doesn't engage in the normal negative feedback mechanism that downregulates cortisol production when levels are high in the blood. This means these adults have higher background levels of stress.

Behaviour

Behaviour describes all the activities that an organism displays. Some behaviours are innate and some are learned:

- Innate behaviours are those that are ingrained → e.g. a baby's fear of loud noises
- Learned behaviours are those that develop secondary to experiences → e.g. a dog salivating at the sound of a bell after learning to associate this with food being on its way

Innate Behaviour

Woodlice activity can be used to demonstrate 3 types of innate behaviour:

- **Escape reflex** → a rapid automatic response that protects an animal from harm:
    - E.g. when prodded with a glass rod, the woodlice curl up in response
    - Humans are display reflexes such as sneezing after inhaling a foreign chemical and removing a hand away after feeling something hot
- **Kinesis** → a movement response with no specific orientation with respect to the stimulus:
    - E.g. in response to the temperature becoming warmer, woodlice move faster and change direction more often
- **Taxis** → a movement response in a particular direction with respect to the stimulus:
    - E.g. woodlice move from brighter to darker areas → known as a negative phototaxis as the action occurs in response to light and the woodlice are moving away from the stimulus

Learned Behaviour

Learning is a long lasting change in behaviour generated by experience. It allows animals to modify their behaviour:

- **Habituation** → animals learn to ignore a repeated stimulus if it is not accompanied by either a reward or a punishment:
    - E.g. tapping a tortoise on its shell for the first time will cause it to retract into the shell, but with repeated tapping the tortoise learns that this is not a threat and no longer retracts its body to within its shell
- **Imprinting** → a young animal follows the first large moving object it sees:
    - The moving object is most likely to be the animal's mother so this behaviour results in the animal receiving food, warmth and protection
- **Conditioning** → a type of associative behaviour in which a particular stimulus is linked to a particular response:

- **Classical →** An animal associates a natural stimulus with a particular response and then learns to recognise an artificial stimulus and gives the same response:
  - This is demonstrated in Pavlov's experiment with dogs:
    - He noticed that the dogs salivated at the sight and smell of food
    - If a bell was rung just before the food was brought, the dogs would salivate at the sound of the bell
    - Eventually, if the bell was rung but no food was brought, the dogs still salivated at the sound of the bell
    - The bell became the conditioned stimulus for the response of salivation
- **Operant →** an animal learns a behaviour following repeated reward or avoids the behaviour after repeated punishment:
  - BF Skinner experimented this theory with rats:
    - When the rats pressed a particular lever, they were given food
    - The rats learned which lever gave food → food was the reward and positive reinforcer for the learning
    - In another experiment, the rats were electrically shocked through the floor of their box
    - A light came on just before the shock and the rats learned that if they pressed a lever to switch off the light, the electric shock didn't happen → the shock was the punishment and negative reinforcer in their learning how to press a lever to switch off the light

- **Exploration** → an animal investigating its environment and learning about it:
  - E.g. a rat in a maze will explore and learn about this environment → there may be no immediate point to remembering the maze layout so this is a form of latent learning - the knowledge may be useful at some time in the future
- **Insight** → when something suddenly occurs to an animal and they have an "aha!" moment:
  - This was shown in a experiment conducted by Kohler in the 1920s involving chimpanzees:
    - Bananas were hung just out of the chimpanzees reach
    - The chimpanzees got angry and frustrated because they couldn't reach the bananas
    - They ignored the sticks and boxes lying around them
    - They then realised they could climb on top of the boxes and use the sticks to knock down the bananas and eat them
    - The chimpanzees acted as if they'd had a sudden insight into their situation

- **Imitation ➞** animals copy a behaviour that they see. This usually involves animals in the same species, allowing behaviour traits to spread between individuals and be passed from generation to generation:
    - Japanese quail birds can learn by imitation → in experiments, they imitate other Japanese quail in pecking a treedle to release food
    - Whales learn songs from other whales and dolphins learn sequences of whistles → this could be one way in which individuals in a social group recognise each other

Social Groups

Many species form structured groups, in which interactions between individuals of the social group are the basis of their social behaviour.

Social behaviour requires communication between animals and always start with one individual producing a signal (sign stimulus) that is detected by another individual. The sign stimulus may trigger an innate response in the detecting individual, by activating nerve pathways that cause coordinated movements without involving the brain. The innate responses are called stereotyped behaviours of fixed action patterns (FAPs).

An example of a stereotyped behaviour of fixed action pattern is the begging response in gull chicks in response to the sight of the red spot on its parents' beak. This is an advantageous response that allows the chick to identify and learn who its parent is and receive adequate food to live. This phenomenon was demonstrated in experiments conducted by Tinbergen.

These behaviours are complex and can be changed by experience. Motivational state also affects responses of individuals as demonstrated by a hungry, motivated cheetah stalking prey (sign stimulus) that it sees, compared with a cheetah that is not hungry and therefore won't pursue an animal that could be prey.

Insects

Social insects (bees, ants and termites) live in colonies, containing thousands of individuals from the same species. One colony is split into different groups called castes, which each perform different roles, to benefit the entire colony. The labour of the colony divided between the castes is what allows insect societies to be efficient and survive.

A honeybee colony consists of a fertile female queen bee, thousands of sterile female worker bees and a few hundred fertile male bees (drones). There is a caste of bees that find food for the colony, another caste that will care for young bees and another caste that will defend and protect the colony.

Bees within the colony communicate with each other through pheromones, physical touch and “dances” (visual orientation displays).

A “dance” is performed by a worker bee that wants to let other worker bees know the location (distance and direction) of a source of nectar. The “dance” is performed on a vertical plane inside the hive or on the floor at the entrance of the hive. If the dance is “round”, this is to show that the nectar source is less than 70m from the hive, but doesn’t indicate the direction of the source from the hive. A waggle “dance” indicates that the nectar source is greater than 70m from the hive and provides information on the distance of the source from the hive, as well as the direction of the source relative to the hive and the Sun’s position.

Vertebrates

Social groups are constructed according to a dominance hierarchy - a higher ranking individual is dominant over lower-ranking individuals.

Most of these dominance hierarchies are linear, meaning that no members are of equal rank. They only exist in populations where animals can recognise each other as individuals and are able to learn. Dominance hierarchies decrease aggression in social groups in reference to feeding, breeding-site selection and mate selection and also ensure resources are distributed out so the fittest individuals survive.

The hierarchies are relatively stable once set up and are maintained using aggression, although fighting is a last resort. Before fighting, there are ritualised actions with each reflex stimulated by the last action (the sign stimulus) of the other individual. These traits are demonstrated by dominance hierarchies of red deer.

Courtship and Sexual Selection

Courtship

This process is used to attract a mate. It allows species recognition, sex and sexually mature/receptive individuals, and stimulation and synchronisation of sexual behaviour.

Courtship practices are innate and therefore ensure intraspecific mating and increase likeliness of producing fertile offspring. This is demonstrated by sticklebacks.

Sexual dimorphism is when the males and females of a species look different and can be seen in many species e.g. peacocks and peahens.

Sexual Selection

This works against natural selection to highlight characteristics (as opposed to making characteristics less conspicuous). Two theories exist that explain the driving force of sexual selection:

- **Intra-sexual selection/male-male combat:**
  - In species (e.g. African lions, southern elephant seals) where males are much bigger than females, the males fight for sexual access to many females
  - Sexual selection has therefore favoured the evolution of larger, more aggressive males
- **Inter-sexual selection/female choice:**
  - Includes the physical attractiveness model and the male handicap model