Index

The big picture

? Guiding question(s)

- What are the roles of nerves and hormones in integration of body systems?
- What are the roles of feedback mechanisms in regulation of body systems?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

It may surprise you, but we could draw an analogy comparing the functioning of human body systems to a city (**Figure 1**). The cardiovascular system comprises the heart, blood vessels and blood that transport materials in the body, very much like the transportation system of a city with its roads and vehicles to transport people and goods. In a similar way, the excretory system disposes of waste products like the sewage system of the city.

Figure 1. A hub of activity.

Credit: Asia-Pacific Images Studio, Getty Images

Overview
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The authorities that govern the city not only make decisions to ensure that things get done, but also oversee and make sure that all the systems work in synergy, in a coordinated manner. Feedback mechanisms, if in place, help safeguard the interests of the people. Technology provides instant information about traffic, safety alerts or general news!

Our nervous and endocrine systems work in a similar way – they ensure the integration of body systems. How do the nerves and hormones do this? What are the sources of instant information that safeguard the interests of trillions of cells? What are the feedback mechanisms in place?

Prior learning

Before you study this subtopic make sure that you understand the following:

- Cells and their functions (subtopics A2.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43253/) and B2.3 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43533/)).
- Neural signalling (subtopic C2.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43541/)).

Practical skills

Once you have completed this subtopic, you can gain application of skills by going to Practical 8: Using seedlings to investigate tropic responses in plants (/study/app/bio/sid-422-cid-755105/book/using-seedlings-to-investigate-id-46707/).

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Hierarchy of biological organisation and emergent properties

C3.1.1: System integration C3.1.2: Cells, tissues, organs and body systems as a hierarchy of subsystems

Learning outcomes

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

- Describe the importance of integration of body systems.
- Explain the hierarchy of biological organisation.

37.2 trillion! That is the number of cells that make up a human body. In a recent study, scientists analysed the number of cells in each organ keeping in mind the cell density and the cell volume. Totalling the numbers gave them a mind-boggling 37.2 trillion! The cell types and functions vary, yet the cells work in harmony. How do these cells manage to work in sync while carrying out their individual functions?

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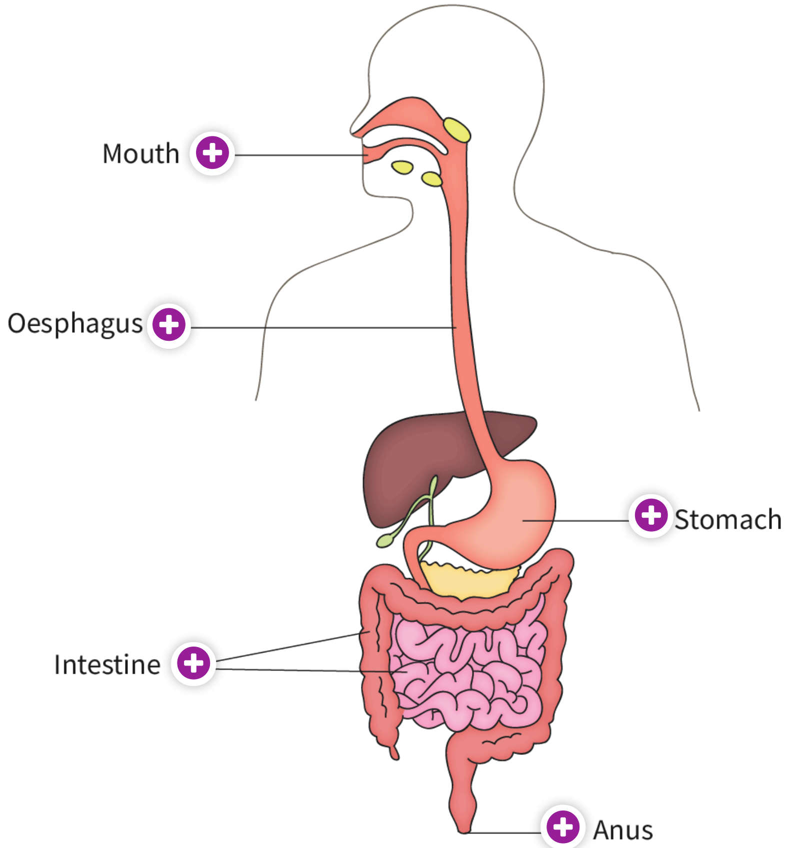
System integration

Nutrition, respiration, excretion, reproduction and coordination are some of the physiological processes that are seen in all living organisms. In humans and other complex multicellular organisms, these processes are carried out by specialised organ systems. For example, the various organs of the digestive system work in a coordinated manner to digest food (**Interactive 1**).



Interactive 1. The Parts of the Digestive System.

More information for interactive 1

An interactive illustration exhibits the various organs involved in the human digestive system. The labeled parts include the mouth, esophagus, stomach, intestine, and anus. The illustration also displays the liver and pancreas.

The illustration features five plus signs, representing interactive hotspots. Selecting a hotspot reveals a description of the corresponding part.

Hotspot on the mouth- Chews food and mixes it with saliva.

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Hotspot on the oesophagus- Moves the food to the stomach.

Hotspot on the stomach- Mixes and churns food with gastric juice.

Hotspot on the intestine- Digests food, absorbs nutrients and passes waste material.

Hotspot on the anus- Opens to allow waste to leave the body.

This interactive illustration displays the different parts involved in the digestive system and their functions.

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But, that is not all. While the digestive system digests the food that we eat, the circulatory system transports the nutrients and oxygen to cells. The oxygen is absorbed from the air that we inhale into our lungs, a function of the respiratory system. In cells, cellular respiration yields energy which is used for different functions like movement while waste material produced is transported by the cardiovascular system to the kidneys, a part of the excretory system. The nervous and endocrine systems coordinate all these activities.

Thus, the systems of the body do not work in isolation. The integrated activity of all the organ systems is needed for the survival and well-being of an organism.

Levels of biological organisation

Cells are the basic structural and functional units of life. Living organisms can be unicellular, made of one cell, or multicellular, made of many cells working together. In many complex multicellular organisms, the hierarchy of organisation from simple to complex is cells, tissues, organs, organ systems (or body systems), and then, the organism (**Figure 1**).

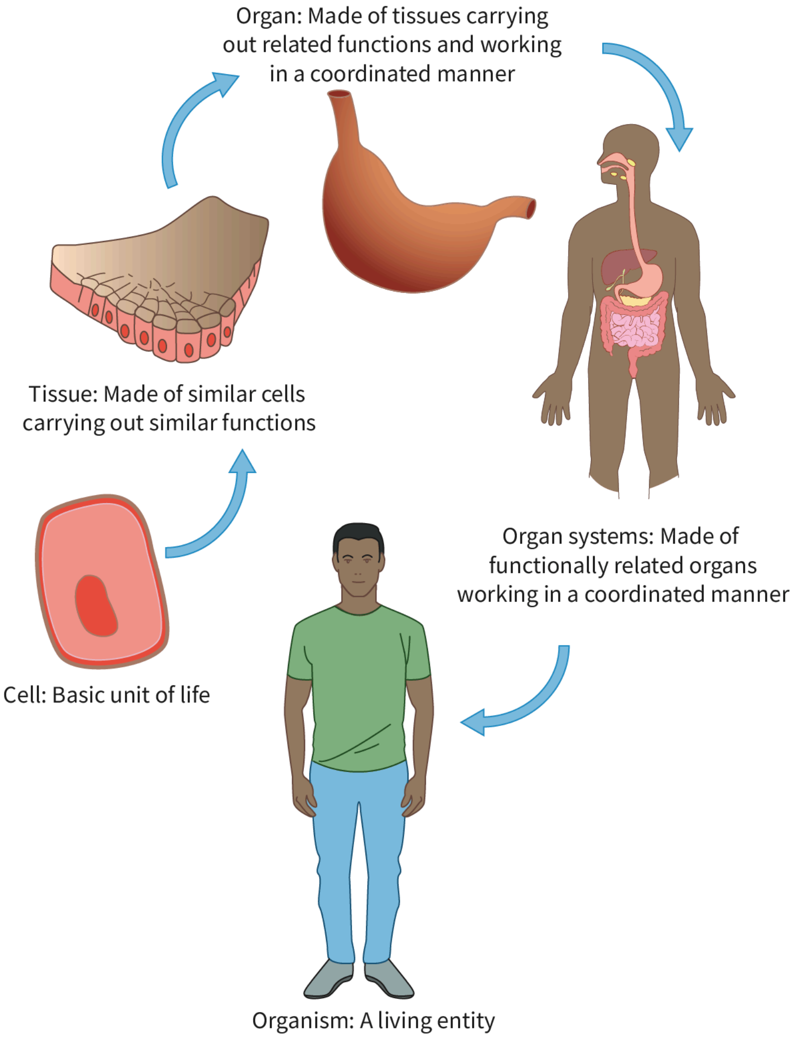

Figure 1. The hierarchy of biological organisation.

More information for figure 1

The diagram illustrates the hierarchy of biological organization. It begins with a cell, labeled as the "basic unit of life." Next, it shows tissue, described as "made of similar cells carrying out similar functions." Following this is an organ, which is shown as a stomach, labeled as "made of tissues carrying out related functions and working in a coordinated manner." The progression continues to organ systems, depicted as a human figure with internal organs

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visible, with the label "made of functionally related organs working in a coordinated manner." Finally, the hierarchy culminates in an organism, shown as a whole human figure, labeled as "a living entity." Arrows between each level indicate progression from simple to complex organization.

[Generated by AI]

Emergent properties

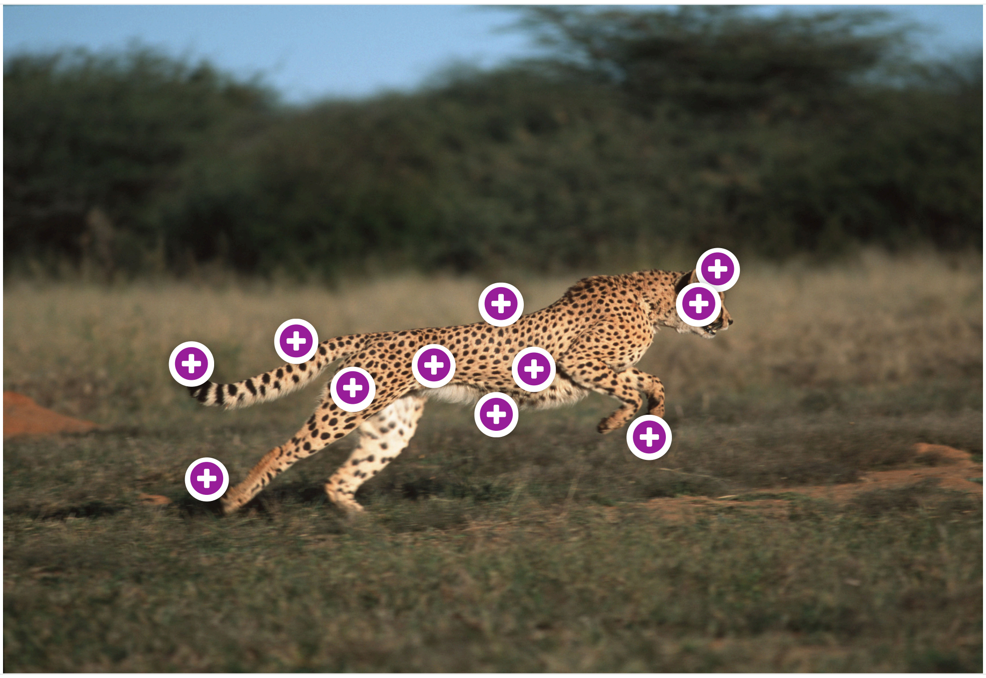
A unique outcome of the different levels of biological organisation is the origin of emergent properties. The phrase (attributed to Aristotle 385 BCE–322 BCE) 'the whole is greater than the sum of the parts', is often used to describe emergent properties. Let us consider, for example, a person like you or me. At any moment, our existence depends on the interaction of our cells, tissues, organs and organ systems. Yet, our identity is much more than the properties and interacting behaviours of our fundamental components.

Thus, emergent properties are properties that arise due to the integration of subsystems. These properties cannot usually be predicted based solely on the understanding of each individual component. For example, an old-fashioned watch is essentially a collection of parts including tiny springs and cogs. But, if you assemble the parts in the correct way, you get a watch that tells the time. It follows that, as the level of complexity in a system increases, new patterns will emerge. This holds true when the complexity increases from unicellular organisms to multicellular organisms as well as from a single organism to a population of organisms.

Cheetahs as predators: an example of an emergent property

The world's fastest land animals, cheetahs, are highly effective predators. **Interactive 2** shows some of the anatomical and physiological features of cheetahs. In addition, male cheetahs often live in groups of two or three individuals. This social organisation helps the cheetahs to 'hold' on to their territory, take down larger prey by hunting together, defend themselves better and share their duties.

Thus, the integration of the body systems and complex social interactions result in qualities that make cheetahs incredible predators and provide an example of an emergent property.



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Interactive 2. On the Prowl!

More information for interactive 2

An interactive photograph illustrates a cheetah running on grassy ground with trees in the background. The cheetah has a slim, muscular body, four long legs, and a tan coat with black spots all over its body. Its front legs are bent, and it features a long tail, a small head, and black tear marks running down its face.

The photograph has eleven plus signs, representing interactive hotspots. Selecting a hotspot reveals a description of the corresponding part.

Hotspot on the head- Small, aerodynamic head to reduce wind resistance.

Hotspot on black tear marks: Black tear marks protect from the glare and help them see long distances.

Hotspot on the front claws: Semi-retractable claws that provide traction while running.

Hotspot on the center of its body: Large heart and lungs.

Hotspot on spine: Flexible spine that acts as a spring while running and increases stride length.

Hotspot on the underside of the body: An undercoat with solid black spots helps in camouflage.

Hotspot on the body: Lean body with long legs.

Hotspot on the hind limbs: Longer and heavier hind limb bones enable longer strides.

Hotspot on the tail: A long muscular tail acts as a stabilizer while running at high speeds.

Hotspot on the tip of the tail: Black rings at the tip of the bushy tail help in camouflage.

Hotspot on the claws of the hind limbs: Grooves on claw pads help in traction.

This photograph helps users understand the special physical features of the cheetah.

Theory of Knowledge

Interactions between individuals lead to complex behaviours that cannot be predicted by an understanding of the individual alone. Would these emergent properties affect the way we gain knowledge? Do these emergent properties shape our attitudes, beliefs and our ability to make decisions?

Try the activity to learn more about emergent properties.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively

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- **Time required to complete activity:** 30—45 minutes
- **Activity type:** Individual activity

Emergent properties are a universal phenomenon. Research one of the topics related to emergent properties, following the instructions for using search engines given below. Collate the results and present as a PowerPoint presentation or poster in class.

Topics

- Flight in birds as an example of an emergent property.
- Emergent properties of cells to form tissues and tissues to form organs (one example).
- Emergent properties of microbial communities affect their hosts (the role of the gut microbiome in human health or biofilms).

Instructions

Search engines such as Google and Bing can provide you with a wide variety of primary and secondary literature about a particular topic. However, while reviewing research, in many cases, they can provide a vast breadth of information, all of which may not be accurate. On the other hand, there are search tools that are more precise, and help you find the information you are looking for faster. They usually consist of scholarly publications. Examples of such search tools include Google Scholar (for scholarly articles in several fields, from history to psychology to biology) and PubMed (for scholarly articles in the field of biomedical sciences). Both use Boolean operators, which help you narrow or broaden your search as required. To make use of these effectively, it is recommended that you use the 'advanced' option in your search. Here is a brief guide to using Boolean operators:

- AND: Usually limits search results and searches for articles that contain both (or all) the terms searched.
- OR: Usually broadens search results and searches for articles that contain either of the terms searched.
- NOT: Usually limits your search results by excluding a particular search term from your results.

In addition to these, if you want to search for a particular phrase you should enclose the phrase in quotation marks.

If you plan on using a general search engine, make sure that the websites you visit have accurate information. You can do this by checking whether they reference the original sources of information and the content source (an article published by a university will usually be accurate).

Before embarking on your research, prepare a list of key terms which you plan to use. You can modify this as you collect more information.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Integrating the functioning of the animal body

C3.1.3: Integration of organs in animal bodies C3.1.4: The brain as a central information integration organ

C3.1.5: The spinal cord as an integrating centre for unconscious processes

Learning outcomes

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

- Compare the roles of the nervous system and endocrine system in signalling.

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- Describe the roles of the brain and spinal cord in processing information.

It has been a long time since breakfast. You seem to be low on energy and your stomach is growling loudly. It is definitely time for a meal! How does your body know this? The walls of your stomach secrete ghrelin, the 'hunger hormone'. The blood carries the hormone to the hypothalamus of your brain sending out hunger pangs that lead you in search of food. This complex interaction between the endocrine and nervous systems works across systems and helps us function the way we do. How do the nervous system and endocrine system help in signalling? What are the roles played by the brain and spinal cord?

Hormonal and nervous signalling

Overview: nervous system

The human nervous system is one of the most complex systems of the body. Composed of the brain, spinal cord and nerves, the nervous system controls and coordinates the functioning of the other systems of the body. The nervous system collects, processes and responds to information by sending electrical action potentials or nerve impulses through specialised cells called neurons (see section C2.2.1–4 (/study/app/bio/sid-422-cid-755105/book/neurons-and-nerve-impulses-id-46646/)) to the target organs.

The nervous system comprises:

- The central nervous system (CNS), which consists of the brain and the spinal cord.
- The peripheral nervous system (PNS), which consists of the nerves that connect the brain and spinal cord to the organs of the body. The PNS in turn consists of:
  - The somatic nervous system that regulates voluntary movements.
  - The autonomic nervous system that regulates involuntary activities such as heartbeat or breathing rate.

Overview: endocrine system

The endocrine system also collects, processes and responds to information; however, it does this through specialised molecules called hormones. Hormones are secreted by endocrine glands and released into the bloodstream. These are carried to target organs where they control the actions of these organs.

Thus the nervous system uses electrical signals, whereas the endocrine system uses chemical signals. Due to this, the response of the nervous system is almost immediate although often short-lived, whereas the response of the endocrine system is slower yet longer-lasting.

Role of blood

Blood plays an important role in the transport of materials (see subtopic B3.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43215/)) through the body. As the blood flows through the network of blood vessels, it transports:

- oxygen from the alveoli (of the lungs) to cells
- carbon dioxide from cells to the lungs
- nutrients from the small intestine to cells of the body
- waste materials to organs such as the kidney or skin for removal
- hormones from the endocrine glands to target organs.

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As blood transports materials between the different parts of the body, it plays an important role in integrating organs and organ systems.

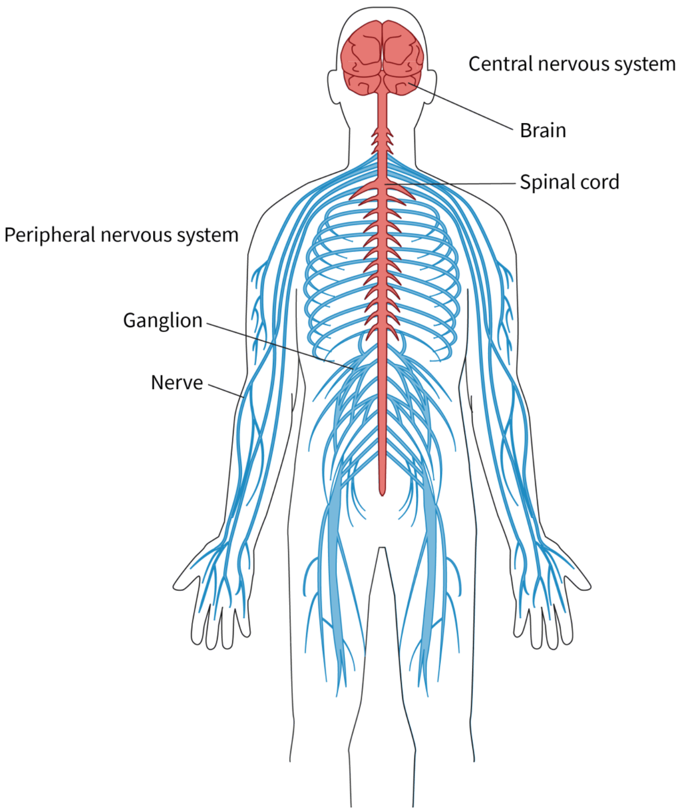
The structure of the brain

The brain is one of the organs of the body that still remains a mystery even to neurologists. We know that the brain regulates a number of functions that are essential for survival like breathing, digestion or excretion. In addition, the brain plays an important role in processing information combined from several inputs, as well as in memory and learning.

The brain is divided into three main regions: the cerebrum, cerebellum and the brain stem.

- The cerebrum is the largest part of the brain and controls multiple functions like vision, hearing, touch and other senses, speech, thinking and so on. It also initiates and coordinates movement. The cerebrum is divided into two halves, the cerebral hemispheres. Each of the cerebral hemispheres consists of four lobes: the frontal lobe, parietal lobe, occipital lobe and the temporal lobe. These lobes control specific functions.
- The cerebellum is located at the back of the head. The cerebellum plays an important role in voluntary muscular movements, balance and coordination. Like the cerebrum, the cerebellum is composed of two hemispheres.
- The brainstem consists of the midbrain, pons and medulla oblongata. The pons connect the midbrain to the medulla. The medulla regulates involuntary activities like heartbeat, breathing rate, blood flow as well as activities like vomiting, swallowing, sneezing and coughing. The medulla continues downward as the spinal cord.

Apart from this, some of the deeper structures seen in the brain are the hypothalamus, the pituitary gland, the amygdala, the hippocampus and the pineal gland (**Figure 1**).



(a)

More information

Student view

This diagram depicts the human nervous system with labeled parts. At the top, there is a head with a brain in red, labeled as 'Brain.' Below the brain, a red pathway runs down the back labeled 'Spinal cord,' representing the central nervous system, which is indicated with a label. The nerves extending from the spinal cord throughout the body are highlighted in blue, showing the peripheral nervous system. Labels identify the 'Ganglion' and 'Nerve' as components of this system. The diagram provides a clear view of the relationship and position of these elements within the human body.

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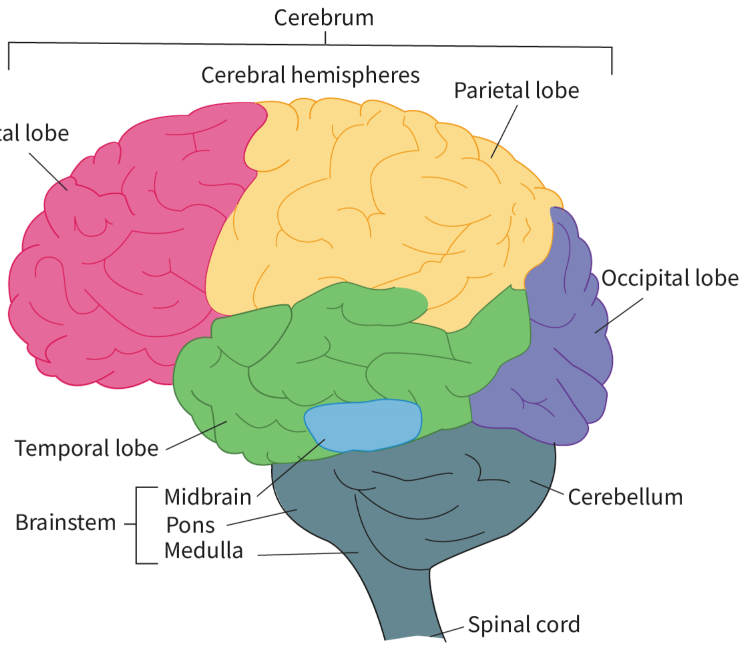

(b)

More information

This diagram illustrates the human brain, highlighting its various parts and their labels. At the top is the cerebrum, divided into two cerebral hemispheres. The frontal lobe is positioned at the front, labeled on the left side. Behind it, the parietal lobe is identified, sitting at the upper mid-region. The occipital lobe appears at the back labeled on the right. Located at the sides, the temporal lobe is shown beneath the frontal and parietal lobes. Below these regions, the cerebellum is labeled at the lower back section of the brain. Connected below is the spinal cord, leading from the brainstem, which consists of the midbrain, pons, and medulla. These parts are visibly marked and connected to their respective labels with lines, providing a clear representation of the brain's structure and positioning of different sections.

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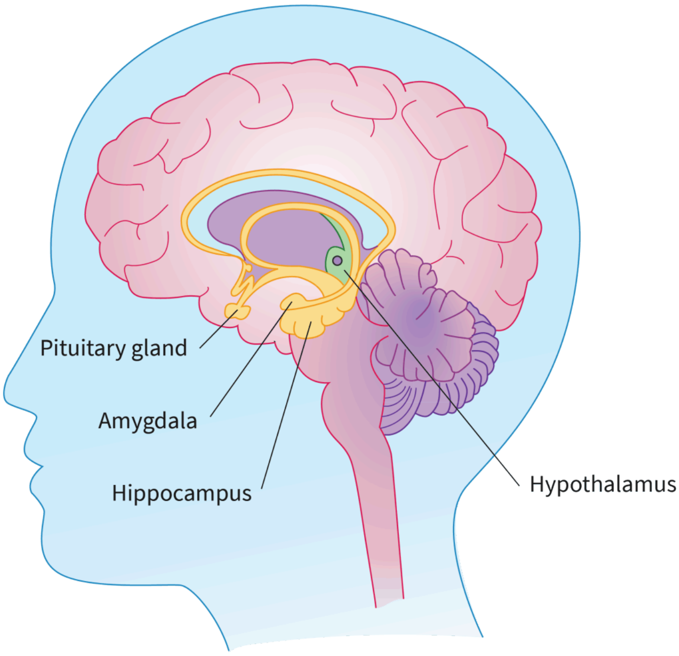

(c)

Figure 1. Brain structure: (a) the central and peripheral nervous systems; (b) main areas of the brain; (c) deeper structures of the brain.

More information for figure 1

The image is a labeled diagram of a side view of the human brain within a head silhouette. Major parts of the brain are marked, including the pituitary gland, amygdala, hippocampus, and hypothalamus. The pituitary gland is located toward the lower center, the amygdala is positioned near it, and the hippocampus is shown slightly higher. The hypothalamus is pointed out, indicating its position in relation to these components. The brain structure is illustrated with various colors to differentiate between the regions, demonstrating their positions and estimated sizes visually.

[Generated by AI]

Brain: a central information integration system

The brain processes information from multiple sources. Specialised receptors detect stimuli from various sources which are conveyed to the brain by nerves. In the brain, the information is processed and the response is sent by another set of nerves to the effectors, that is the muscles or glands.

While you read this section, your brain is actively processing the signals sent through your eyes. But that is not all – whether you are aware or not, your brain is also processing information coming in from other receptors like the sounds or smells in your environment as well as the position of your body or the movement of your fingers as you scroll down the page. Different regions of the brain separately decipher the information coming from different sources. Eventually the information is interpreted and translated to appropriate responses.

It is important to remember that the response to stimuli may vary from one person to another.

Brain: in learning and memory

For a long time, it was believed that brain development happened mostly in the first few years of life. However, studies now show that the brain can 'change' in response to inputs. This change happens due to changes in the neurons. These changes could be the formation of new synapses, strengthening of others and even removal of some as shown in **Video 1**. This is known as plasticity.

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Video 1. Plasticity of the brain.

More information for video 1

A video visualises neurons forming new connections during cognitive tasks. It explores the brain's remarkable capacity for learning, memory formation and structural adaptation through neuroplasticity.

It shows a time lapse of dendritic spine growth (neuroplasticity) or new neuron formation (neurogenesis). The text "Growth cone" appears, which shows dendrites extending toward other cells, illustrating wiring during thought. Dendrites are highlighted in other parts of the screen too.

Arrows trace the pathway of neural migration indicating the direction of electrical impulses.

We understand that the brain is not hardwired but a dynamic, self-rewiring system (e.g. strengthening pathways when learning a skill). Neurogenesis and plasticity underscore this lifelong adaptability.

Learning results in changes in the anatomy of neurons and is a form of plasticity. For example, when you learn to drive a car or play football, changes occur in the connections between neurons. When the same neural pathways are used again and again, as is often seen when you practise a task, these pathways strengthen.

Memory is the storage and recall of learning. Memories could be explicit like the knowledge of algebraic formulae or the capitals of countries or even of events in your life. Explicit memories are often referred to as declarative memories as we intentionally try to recall these things. On the other hand, implicit memories often are memories that help you to carry out day-to-day tasks like speaking to a friend or riding a bike without thinking about them. These memories arise due to past experiences.

Your memories are not stored in one part of the brain, rather they are stored over interconnected brain regions.

Theory of Knowledge

What is consciousness? Is consciousness a function of learning and memory? How do individual differences in consciousness affect acquisition of new knowledge? Does acquisition of tacit knowledge depend on consciousness?

Conscious and unconscious processes

Conscious processes are processes that we are aware of and can control, such as speaking or reading or hitting a ball. These also include explicit memories where we consciously recall information. Unconscious processes are processes that happen without our conscious control or awareness. These could include physiological activities such as digestion,

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breathing or coughing. These also include our implicit memory, which enables us to do routine tasks such as brushing our hair without being aware of it.

Spinal cord: an integrating centre for unconscious processes

The spinal cord, like the brain, plays an important role in integrating information. Unlike the brain which integrates information from conscious and unconscious processes, the spinal cord integrates information from unconscious processes only. For example, if a doctor taps just below your knee while you are sitting down with your leg crossed, your leg jumps. It is called the knee-jerk response or the patellar reflex. This spontaneous, involuntary response is a reflex generated by the spinal cord.

The spinal cord also acts as a relay system transferring information between the brain and the peripheral nervous system.

Try the activity to learn about fixed and growth mindsets.

Activity

- **IB learner profile attribute:** Balanced
- **Approaches to learning:** Self-management skills — Taking risks and regarding setbacks as opportunities for growth
- **Time required to complete activity:** 10—15 minutes
- **Activity type:** Individual activity

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The plasticity of the brain indicates that learning is lifelong. This is reflected in the growth mindset which challenges the assumption that intelligent people are born that way. But what is a mindset? A mindset refers to the beliefs that you use to make sense of the world. According to Carol Dweck, there are two types of mindsets: the growth mindset and the fixed mindset. Growth mindset says that the qualities or skills of a person can be cultivated with effort. People with this mindset accept failure and believe that with effort, their skills will improve. On the other hand, people with a fixed mindset believe that they are born in a certain way and cannot change. For example, a person with a fixed mindset, who scores low marks in a test may say ‘I can’t ever do this — I am not intelligent enough’, whereas a person with a growth mindset may say ‘I can’t do this YET!’ You can read more about mindsets here (https://www.mindtools.com/asbakxx/dwecks-fixed-and-growth-mindsets) or watch this video (https://www.youtube.com/watch?v=KUWn_TJTrnU).

It is normal to have a fixed mindset for some tasks and a growth mindset for others or even a mix of the two for the same task.

- Reflect on situations where you have exhibited a growth mindset and situations where you have exhibited a fixed mindset.
- Think of ways that you can adopt a growth mindset — this could be as simple as reaching out for help.
- Record your ideas in a table like **Table 1** below.

Table 1. Sample mindset results.

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Situations where I normally exhibit a growth mindset	Situations where I normally exhibit a fixed mindset	Ways I can challenge my fixed mindset

5 section questions

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Sensory and motor neurons

C3.1.6: Input to the spinal cord and cerebral hemispheres C3.1.7: Output from the cerebral hemispheres

C3.1.8: Nerves as bundles of nerve fibres of both sensory and motor neurons

Learning outcomes

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

- Compare the roles of sensory and motor neurons.
- Examine a transverse section of a myelinated nerve.

Touching sandpaper feels very different from petting a furry dog. Similarly, standing upside down evokes a different sensation from standing upright. How do we sense these differences?

Types of neurons

Neurons (see section B2.3.5–6 (/study/app/bio/sid-422-cid-755105/book/what-determines-cell-size-id-45384/)) are specialised cells that transmit electrical impulses (**Figure 1**). There are three main types of neurons:

- sensory neurons or afferent neurons
- interneurons
- motor neurons or efferent neurons.

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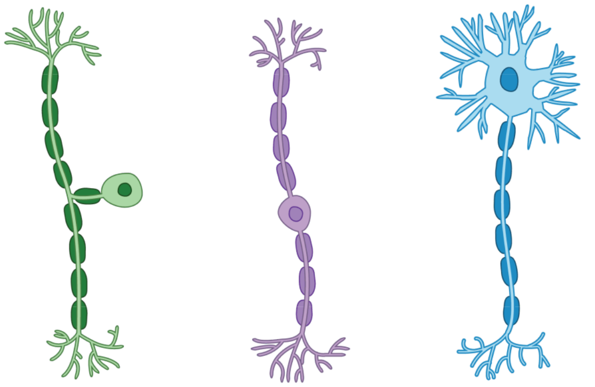

Figure 1. Neurons differ both structurally and functionally.

More information for figure 1

The image illustrates three different types of neurons, each labeled and depicted with distinct structures and functions.

1. **Sensory Neuron**: Located on the left, it is depicted in green. It conducts impulses from receptors to the central nervous system (CNS). The neuron has dendrites at the top, leading to a cell body with a nucleus, and an axon with myelin sheaths extending downward.
2. **Interneuron**: Positioned in the center and shown in purple, this neuron relays signals within the CNS. It features fewer dendrites at the top compared to the sensory neuron and also possesses a central cell body. The axon is similar in structure to the sensory neuron but connects CNS structures.
3. **Motor Neuron**: Shown on the right in blue, it transmits signals from the CNS to an effector, such as muscles. This neuron has elaborate dendrite structures originating from the cell body, which is centrally located. The axon extends downward with myelin sheaths similar to the other neurons.

All neurons have the same basic components laid out differently to serve their specific functions in signal transmission.

[Generated by AI]

Sensory neurons

When you touch a piece of ice, the sensory neurons located at the surface of your skin swing into action and convey the information to the central nervous system (CNS) and you sense the coldness. These neurons, which help us to 'feel' sensations, are called sensory neurons. They convey the sensory inputs from the surroundings to the CNS.

Receptors are specialised cells that pick up sensory stimuli and transmit it to the sensory neurons. Our body has different types of receptors for different stimuli. They could be in the form of free nerve endings like pain and temperature receptors or in the form of specialised cells like the photoreceptors (**Table 1**).

Table 1. Types of receptor in the body.

Mechanoreceptors	Stretch your hands above your head as high as you can. You can feel the stretch due to mechanoreceptors. Motion, pressure, stretch, touch and sound are detected by these receptors. A special type of mechanoreceptor, called baroreceptors, in our blood vessels warns the brain of changes in the blood pressure. Yet another type, proprioceptors are responsible for spatial awareness and coordination.
Chemoreceptors	Smell coffee? Your chemoreceptors are at play as they detect chemical compounds.

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Thermoreceptors	Jump into a pool of cold water and your thermoreceptors swing into action. Thermoreceptors detect both heat and cold.
Nociceptors or pain receptors	Nociceptors help to detect pain. These receptors are located both on the peripheral parts of the body like the skin as well as the internal organs.
Electromagnetic receptors	As the term implies, these receptors detect electromagnetic energy like light, electricity and magnetism. Photoreceptors present in your eyes detect light and help you to see.

The dendrites of a sensory neuron are longer and receive information from the environment (**Figure 2**). The impulse travels down the dendrites, to the cell body and then through a relatively short axon to the spinal cord (see subtopic C2.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43541/)). From the spinal cord the information is conveyed to the brain.

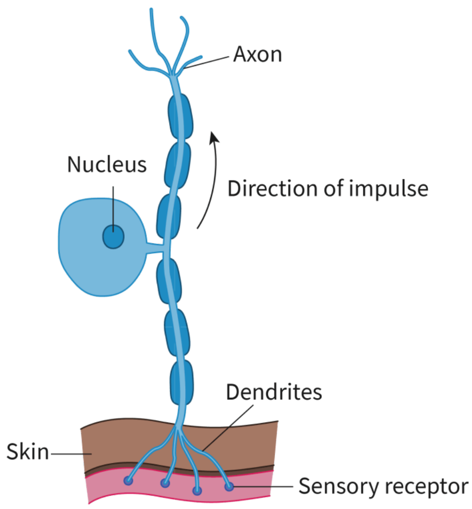

Figure 2. Movement of an impulse down a sensory neuron.

More information for figure 2

The diagram illustrates a sensory neuron, including its main components and the direction of impulse travel. At the top, dendrites extend to receive information from the environment. These dendrites attach to the cell body, which contains the nucleus. The nucleus is shown as a centralized circle within the cell body. From the cell body, the axon extends vertically downward, represented as a connected chain of oval shapes. An arrow labeled 'Direction of impulse' points upward along the axon, indicating the flow of information. At the lower end, the axon terminates, making contact with the skin, labeled at the bottom. The sensory receptor in the skin is connected to the dendrites, completing the pathway of the sensory neuron transmitting impulses from the skin to the spinal cord and brain.

[Generated by AI]

Motor neurons

The motor neurons (see section B3.3.2–4 (/study/app/bio/sid-422-cid-755105/book/muscle-contraction-hl-id-44815/)) are efferent as they transmit the nerve impulses generated in the brain or spinal cord to the muscles and organs of the body. These impulses cause the contraction of skeletal and smooth muscles, resulting in movement. In other words, the impulses transmitted by these neurons help us to jump, walk, speak, breathe and swallow.

There are two types of motor neurons:

Student view

- The upper motor neurons that carry the impulses from the brain to the spinal cord.
- The lower motor neurons that travel from the spinal cord to the muscles.

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Structurally too, motor neurons differ from sensory neurons – they have numerous dendrites and a single long axon.

Interneurons

Also called relay neurons, interneurons connect sensory neurons and spinal motor neurons (**Figure 3**).

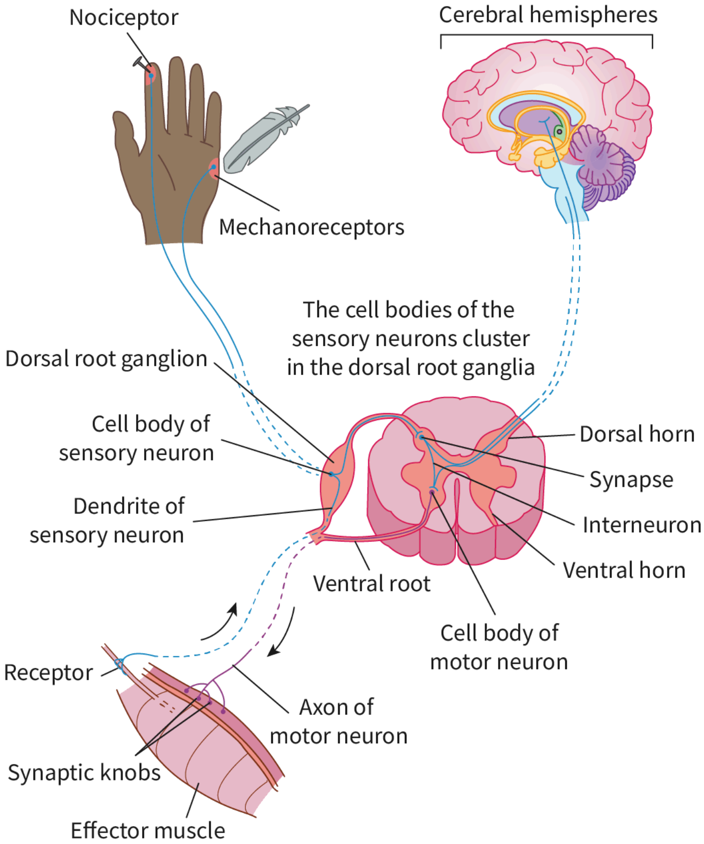

Figure 3. Transmission of nerve impulses.

More information for figure 3

This diagram illustrates the transmission of nerve impulses involving various components. At the top left, there's a close-up of a hand with a nociceptor and mechanoreceptors labeled, indicating sensory neurons' initiation point. The pathways extend to a brain section titled 'Cerebral hemispheres.' Below, the spinal cord shows labels like 'Dorsal root ganglion,' 'Cell body of sensory neuron,' and 'Dendrite of sensory neuron.' The diagram continues with 'Dorsal horn,' 'Synapse,' 'Interneuron,' and 'Ventral horn,' showing the flow through the spinal cord. Arrows indicate the path of nerve impulses connecting the brain to the 'Receptor' and 'Effector muscle' at the bottom, highlighting the role of 'Axon of motor neuron' and 'Synaptic knobs.' This depicts the relay of signals from sensory input to motor output.

[Generated by AI]

Look at the images in **Interactive 1**. Label the flashcards to identify the type of receptor involved in the action in each image.

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Name the receptors

1 / 4

Your answer Check

Your answer

Rights of use

Interactive 1. Types of Receptors in Action.

More information for interactive 1

An interactive carousel selector features four flashcards designed to help users identify the receptors involved in various actions. Each flashcard displays a photograph along with an empty space for users to enter their answers. A check button next to the input field allows users to verify their responses.

Navigation arrows at the bottom right and left allow them to switch between the flashcards.

Flashcard 1: A person smelling a perfume bottle.

Flashcard 2: People riding a roller coaster with smiles on their faces and hands raised.

Flashcard 3: Three persons sit around a wood fire. Two of them are holding coffee mugs.

Flashcard 4: A person lying on a bed, closing their eyes tightly and covering their ears. An alarm clock is nearby.

This interactivity helps users understand the receptors responsible for different actions.

Read below for the solution:

Flashcard 1: Chemoreceptors

Flashcard 2: Proprioceptors

Flashcard 3: Thermoreceptors

Flashcard 4: Mechanoreceptors

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Nerves

Nerves consist of bundles of axons of neurons. There are three types of nerves:

- sensory nerves composed of axons of sensory neurons.
- motor nerves composed of axons of motor neurons.
- mixed nerves composed of axons of both sensory and motor neurons.

Based on the presence or absence of a myelin sheath, nerves are categorised as myelinated or unmyelinated fibres (**Figure 4**).

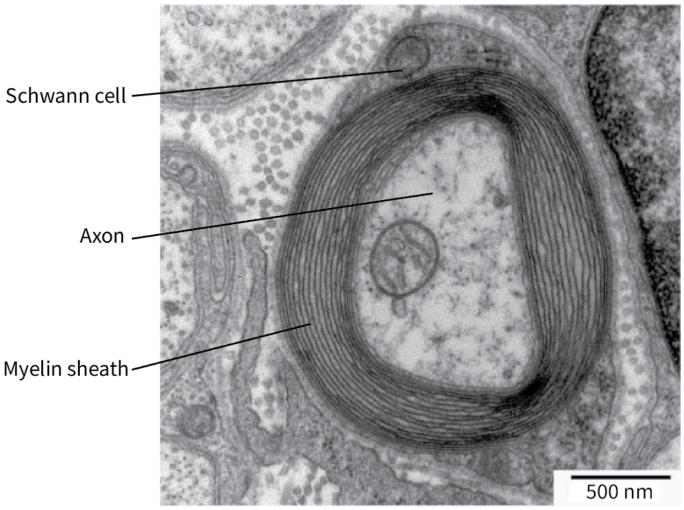
Myelinated nerve fibres

The individual axons in some nerve fibres are surrounded by a fatty sheath made of myelin. Myelin is a specialised membrane consisting of lipids and proteins. It is produced by the Schwann cells of the peripheral nervous system (PNS) and the oligodendrocytes of the CNS.

The myelin is spirally wrapped around the axon and acts as an insulating layer. However, the myelin sheath is not continuous along the entire length of the axon. It is interrupted at points called the nodes of Ranvier. Hence the electrical signals jump from one node of Ranvier to another.

Higher level (HL)

This is called saltatory conduction of the nerve impulses (see section C2.2.8–11 (/study/app/bio/sid-422-cid-755105/book/oscilloscope-and-saltatory-conduction-hl-id-46648/)) and increases the speed of transmission.



(a)

Source: Myelinated neuron (https://upload.wikimedia.org/wikipedia/commons/c/c1/Myelinated_neuron.jpg) by Roadnottaken is licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/)

More information

The image is a microscopic cross-section of a myelinated neuron. It is labeled with three main components: Schwann cell, axon, and myelin sheath. The Schwann cell is shown as part of the structure enveloping the neuron. The axon is centrally located within the structure and surrounded by the myelin sheath, which is depicted as multiple concentric layers encircling the axon. The scale bar at the bottom right indicates that the size of the structure is approximately 500 nanometers in diameter. This diagram helps to illustrate the arrangement and relationship between these cellular components crucial to nerve function.

Student
view

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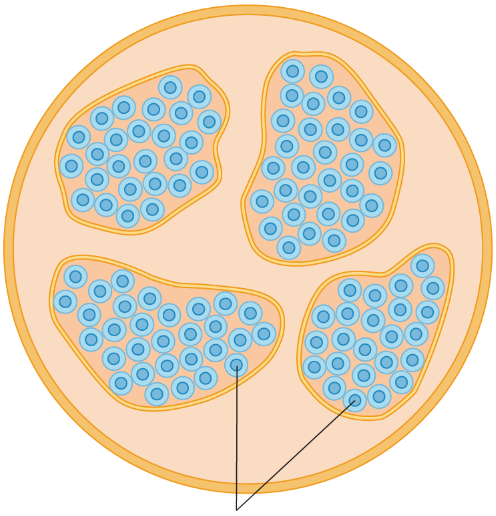
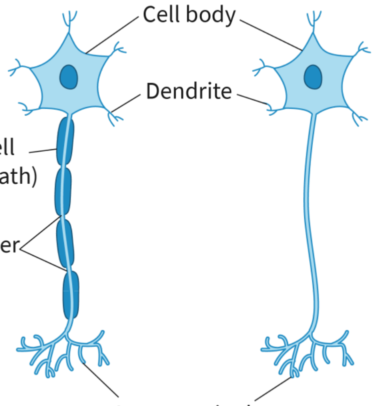


(b)

More information

The image is a diagram illustrating the cross-section of a nerve bundle. It shows a circular structure that includes multiple bundles of myelinated nerve fibers. Each bundle, depicted as separate enclosed areas within the circle, contains multiple blue circular shapes representing the fibers. These bundles are distributed across different regions within the circle. The text "Myelinated nerve fibres" points to the bundles, indicating what they represent. The entire diagram provides a simplified representation of the arrangement of myelinated nerve fibers within a nerve bundle.

[Generated by AI]



(c)

Figure 4. (a) Transverse section of a myelinated nerve fibre. (b, c) Illustrations of (b) a transverse section of a nerve and (c) the difference between a myelinated and an unmyelinated nerve fibre.

More information for figure 4

The diagram displays two types of nerve fibers: one on the left that is myelinated and one on the right that is unmyelinated. Both illustrations have labeled parts such as the cell body, dendrite, and axon terminals. The myelinated nerve fiber shows a series of Schwann cells forming the myelin sheath along the axon, interrupted by Nodes of Ranvier. The unmyelinated nerve fiber lacks these myelin sheaths. The primary components, such as cell body, dendrites,

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Schwann cell (myelin sheath). Nodes of Ranvier, and axon terminals are clearly labeled to differentiate between the myelinated and unmyelinated structures.

[Generated by AI]

Unmyelinated nerve fibres

In unmyelinated nerve fibres, the myelin sheath is absent. The nerve impulses move continuously down the length of the axon but less rapidly.

Grey and white matter

You might have heard of grey matter and white matter (**Figure 5**). These terms are linked to myelin as myelin gives white matter its colour. The grey matter is composed of cell bodies of neurons while the white matter is composed of the myelinated axons. The orientations of grey matter and white matter differ in the brain and spinal cord. For example, in the cerebrum, the grey matter is exterior to the white matter while in the spinal cord this organisation is switched to form the H-shaped spinal grey matter.

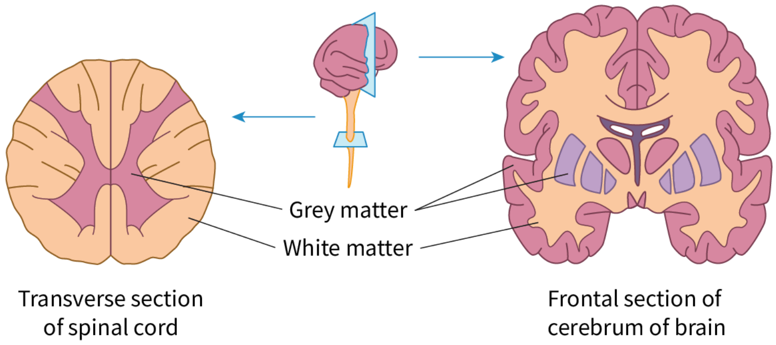

Figure 5. Grey and white!

More information for figure 5

This diagram shows the transverse section of the spinal cord and the frontal section of the cerebrum. The left side of the image illustrates the transverse section of the spinal cord, highlighting the H-shaped grey matter in the center and the surrounding white matter. On the right side, the frontal section of the cerebrum is depicted with its grey matter on the exterior and white matter on the interior. Arrows and labels point out the grey matter and white matter in both sections. Arrows link these sections to a central diagram showing the orientation of the brain and spinal cord, emphasizing the differences in their structures.

[Generated by AI]

Try the activity to make a model of a myelinated nerve fibre.

Activity

- **IB learner profile attribute:** Communicator

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- **Approaches to learning:** Communication skills — Clearly communicating complex ideas in response to open-ended questions
- **Time required to complete activity:** 20 minutes
- **Activity type:** Group activity

Prepare a model of myelinated nerve fibres.

Materials

Modelling clay, wire, twine, paper, any other suitable scrap material.

Instructions

1. Form groups of four.
2. Study the structure of myelinated nerve fibre given in the transverse section of a myelinated fibre and read through the accompanying text.
3. Use materials like modelling clay and wire to create a model of the myelinated nerve fibres.
4. Label the model.
5. Present it in class, including a description of the myelin and its role in transmission of nerve impulses.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Reflex arcs and role of the cerebellum

C3.1.9: Pain reflex arcs C3.1.10: Role of the cerebellum

Learning outcomes

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

- Describe the structure of a pain reflex arc.
- Explain the role of the cerebellum in coordination and balance.

Stroke the palm of a newborn baby – immediately the fingers close and the baby grasps your finger tightly. This is an example of a reflex which was probably necessary for the arboreal life of newborn primates, helping them to cling to the branches or to their mother's fur. These reflexes act as survival mechanisms. However, what is a reflex?

Reflex action

If you accidentally step on a thorn or touch a hot pan, your body reacts instantaneously in a more or less similar way. These are examples of reflexes. A reflex action is an automatic and spontaneous response to a stimulus. It acts as a survival mechanism to minimise injury to the body from potentially harmful situations.

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Reflex arc

The pathway followed by a reflex action is called a reflex arc. Let us have a look at a simple pain reflex arc which is activated when you touch a hot pan. Nerve endings in the hand that respond to potentially damaging stimuli act as pain receptors (nociceptors) initiating a nerve impulse in the sensory (afferent) neuron. The impulse travels down the sensory neuron (which enters the spinal cord) to the interneuron (within the spinal cord) to the motor (efferent) neuron (which exits the spinal cord). The impulse transmitted by the motor neuron causes the muscle to contract causing the hand to withdraw (see section B3.3.2–4 (/study/app/bio/sid-422-cid-755105/book/muscle-contraction-hl-id-44815/)).

Keep in mind that the pathway remains the same for all reflex arcs (**Figure 1**).

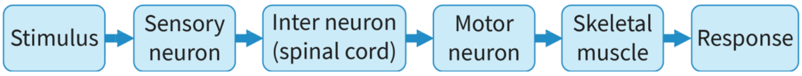

Figure 1. Generalised pathway of a reflex arc.

More information for figure 1

The image is a flowchart diagram illustrating the pathway of a reflex arc. It consists of six main components connected by arrows indicating the flow of information. The sequence begins with "Stimulus", which connects to "Sensory neuron". This is followed by a link to "Inter neuron (spinal cord)", then "Motor neuron", followed by "Skeletal muscle", and finally leading to "Response". Each component is enclosed in a box, and the arrows between them indicate the direction of the reflex arc process. The diagram provides a clear sequence of events in a reflex action that starts from receiving a stimulus and ends with the body's response.

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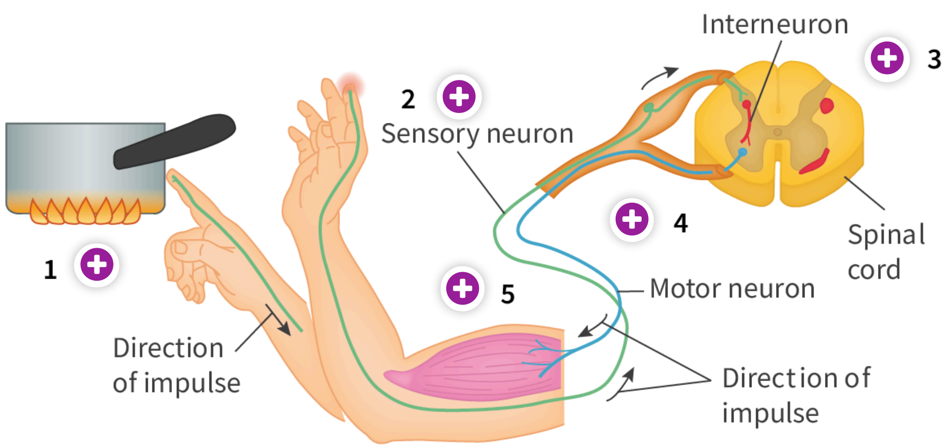
Click on the labels in **Interactive 1** to read about the steps in a reflex arc.



Interactive 1. Reflex Arc.

More information for interactive 1

The interactive diagram illustrates the neural pathway of reflex action, specifically demonstrating how the body generates instantaneous, involuntary responses to harmful stimuli (e.g. touching a hot pan) without direct brain involvement. The reflex arc is a survival mechanism designed to minimize injury through rapid signal transmission.

The reflex arc diagram consists of a hot pan on the left. In the middle, there are two images of hands, where one is shown touching the pan, and the other is shown retreating from the pan. There is an image of the spinal cord with an interneuron on the right. The spinal cord and hand are connected through

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sensory neurons and motor neurons. The sensory neuron extends to the tip of the fingers while the motor neuron extends to the muscle in the bicep. The arrows in the diagram indicate the unidirectional flow of the impulse. The interactive consists of five key stages, labeled 1-5 in the diagram. Each stage consists of a hotspot represented by a plus sign. Clicking on these hotspots reveals information regarding the corresponding stage.

Read below to learn about each stage and text in the corresponding hotspot:

Stage 1 is Stimulus detection. Pain receptors located in the skin detect harmful stimuli (e.g. heat from a hot pan). An arrow shows the impulse moving toward the spinal cord. The hotspot reads “Touching a hot pan stimulates the pain receptors and initiates the impulse.

Stage 2 is the Afferent pathway and is labeled “Sensory neuron”. The sensory neuron carries the impulse from the receptor to the spinal cord’s gray matter. The arrow shows the impulse moving toward the spinal cord. The hotspot reads “The impulse travels down the sensory neuron to the spinal cord (grey matter).”

Stage 3 shows the location of the interneuron within the spinal cord. The impulse is relayed to an interneuron (connector neuron) within the spinal cord. This ensures rapid signal transmission bypassing the brain for speed. The hotspot reads “The impulse passes to the connecting interneuron in the spinal cord.”

Stage 4 shows the Efferent pathway. The interneuron passes the impulse to a motor neuron, which exits the spinal cord. The arrow shows the impulse moving away from the spinal cord. The hotspot reads “From the interneuron, the impulse travels down the motor neuron to the muscles of the hand.”

Stage 5 demonstrates the Effector response. The motor neuron triggers muscle contraction (e.g. biceps contract to pull the hand away), pulling the hand away from the pan. The hotspot reads “The muscles of the hand contract pulling the hand away from the pan.” Effector muscles execute the protective response within milliseconds.

This interactive demonstrates efficiency (how the reflex arc’s design ensures speed) and autonomy (independence from brain processing for critical protective actions). Similar reflex actions apply to all reflexes (e.g. blinking, gagging).

Although the reflex does not involve the brain, it is interesting to note that the brain can modify the reflex action if needed. Yawning, sneezing, coughing and vomiting are other examples of reflexes.

Cerebellum in balance and coordination

Located at the back of the brain, the cerebellum (Latin for ‘little brain’) plays an important role in motor control and posture. Like the cerebrum, the cerebellum is composed of two hemispheres. The left cerebellar hemisphere works with the right hemisphere of the cerebrum to control muscle movements on the left side of the body, while the right cerebellar hemisphere and the left hemisphere of the cerebrum control the right side of the body. Most of the inputs to the cerebellum come from the cerebrum. The cerebellum also receives inputs from the brainstem and spinal cord.

Some of the functions of the cerebellum include:

- **Coordination of voluntary muscle movements**
  When you walk or jump or pick up a pen to write, different muscle groups work together in a coordinated manner to bring movement. The cerebellum coordinates the timing and force of contraction of these muscle groups to bring in

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coordination.

- **Maintenance of balance and posture**
  The cerebellum utilises the inputs from proprioceptors and other receptors to bring in shifts in body position, helping to maintain balance.

- **Motor learning**
  Whether it is learning to swing a cricket bat or play the piano, the cerebellum plays an important role in motor learning and helps in the fine-tuning of the movements.

Nature of Science

Aspect: Observations

For a long time, scientists thought that the role of the cerebellum was restricted to coordinating muscle movements. Advances in technology have led to brain imaging tests like PET (positron emission tomography), MRI (magnetic resonance imaging) and functional MRI. These tests show the areas of the brain that are active during certain tasks and thereby allow researchers to understand how a normally functioning brain works.

Recent studies show that the cerebellum is involved in a multitude of roles like remembering emotional experiences, social behaviour and cognition. This in turn has opened up new areas of research like mapping the non-motor roles of the cerebellum.

Try the activity to draw the steps of a reflex arc.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual activity

As you pick a lemon, a thorn pierces your finger. An involuntary 'ouch' escapes you; however, a lot more happens within your body.

Draw a labelled diagram that illustrates the reflex arc.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

More about the endocrine system

C3.1.11: Modulation of sleep patterns by melatonin secretion C3.1.12: Epinephrine secretion C3.1.13: Control of the endocrine system

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Learning outcomes

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

- Explain the impact of melatonin on circadian rhythms.
- Analyse the effects of epinephrine on the body.
- Describe the feedback mechanisms that regulate the functioning of the endocrine system.

For travellers, who cross several time zones rapidly, jet lag is a common disorder. Jet lag results primarily in sleep problems along with trouble in staying alert and daytime fatigue. However, within a couple of days, the effects of jet lag abate. What causes jet lag? How is it related to the endocrine system?

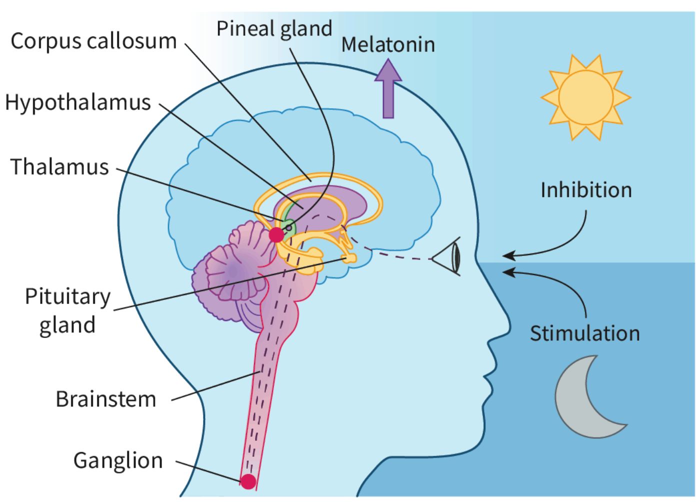
Circadian rhythms and melatonin

Just as the sun rises and sets every day, the human body also goes through a daily cycle of physical, mental and behavioural changes. Many physiological processes such as blood pressure or body temperature or even hormone levels show daily fluctuations. Not only that, but the ability to concentrate, to learn or to remain alert changes during the course of the day. This 24-hour sleep–wake cycle is known as the circadian rhythm (Latin *circa diem* meaning 'about a day'). The circadian rhythm is controlled primarily by the light (day) and dark (night) and the ways our bodies respond to these environmental stimuli. This control is often referred to as an internal 'biological clock'.

The pineal gland is a tiny endocrine gland in the brain. It secretes a hormone called melatonin, which helps to set the biological clock and thereby the circadian rhythm as outlined below.

- Changes in the levels of light are detected by the photoreceptors of the eye.
- This is conveyed to the principal circadian clock of the body, a small structure located in the hypothalamus.
- During the day, the circadian clock detects the high levels of light and 'instructs' the pineal gland to reduce the secretion of melatonin, whereas at night, the reverse happens.
- The rise in melatonin level leads to the body's preparation for sleep, with a lowering of the core temperature and hence, melatonin is often called the sleep hormone.

Thus, the highest amounts of melatonin are secreted by the pineal gland during the night and the lowest during the day (**Figure 1**).



(a)

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More information

This diagram illustrates the secretion and regulation of melatonin in the human brain. The diagram is a side view of a human head highlighting several brain parts. The pineal gland, responsible for melatonin secretion, points upwards towards a label indicating 'Melatonin.' Various brain components such as the corpus callosum, hypothalamus, thalamus, pituitary gland, brainstem, and ganglion are labeled. There are arrows depicting information flow: sunlight is shown as inhibiting melatonin secretion, represented by the sun symbol, while the moon symbol suggests stimulation, representing nighttime conditions. The diagram simplifies the relationship between light exposure and melatonin production, indicating that melatonin is secreted primarily at night.

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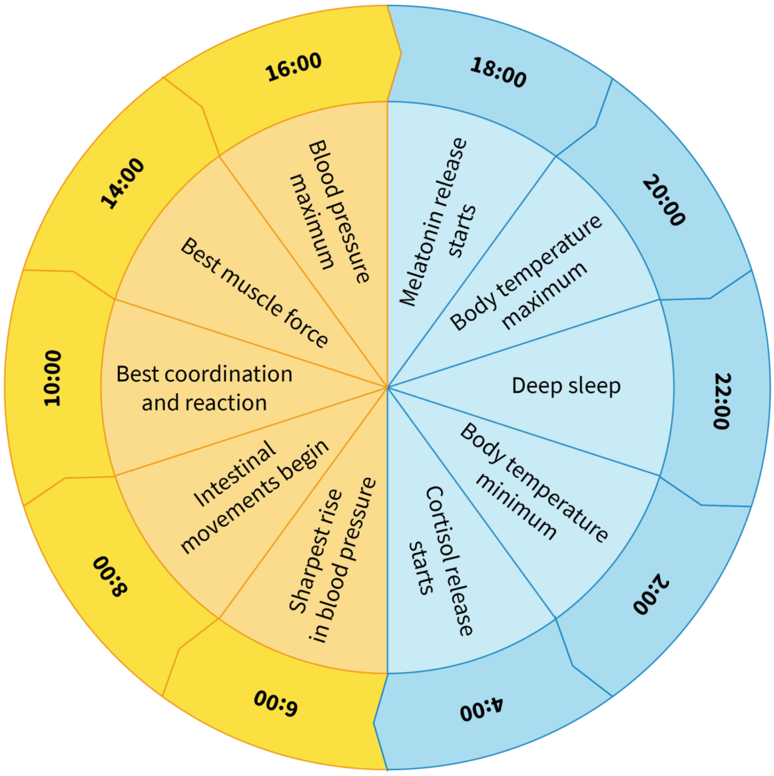

(b)

More information

The image is a circular diagram representing human biological rhythms over a 24-hour period. The diagram is divided into two colored halves: one yellow and one blue. The yellow section covers from 06:00 to 18:00, while the blue section spans from 18:00 to 06:00. Each section is further divided into smaller pie slices, each labeled with a specific biological function and corresponding time of day.

In the yellow section: - 06:00 - Sharpest rise in blood pressure - 08:00 - Intestinal movements begin - 10:00 - Best coordination and reaction - 14:00 - Best muscle force - 16:00 - Blood pressure maximum

In the blue section: - 18:00 - Melatonin release starts - 20:00 - Body temperature maximum - 22:00 - Deep sleep - 02:00 - Body temperature minimum - 04:00 - Cortisol release starts

This diagram visually represents key biological functions that align with specific times, illustrating the circadian rhythm.

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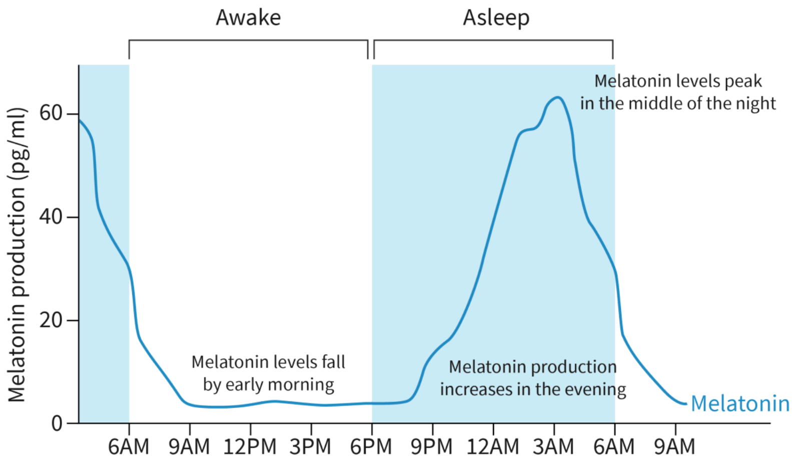

(c)

Figure 1. (a) Mechanism of secretion of melatonin. (b) A typical circadian rhythm. (c) Melatonin levels during the day.

More information for figure 1

The graph depicts the levels of melatonin production (measured in pg/ml) over a 24-hour period, showing variations between awake and asleep states. The X-axis represents time in hours, starting from 6 AM and ending at 9 AM the next day. The periods of being awake and asleep are marked at the top of the graph.

The Y-axis represents melatonin production in picograms per milliliter (pg/ml), ranging from 0 to 60. The graph starts with a high melatonin level, around 60 pg/ml, at 6 AM and quickly drops to under 20 pg/ml by 9 AM, indicating a decrease in melatonin levels once awake. Between 9 AM and 6 PM, melatonin production remains low, fluctuating around 10 pg/ml.

Starting from 6 PM, melatonin production begins to increase notably, with a steeper rise after 9 PM. It reaches a peak around 3 AM, at approximately 60 pg/ml, before descending again towards 6 AM, where the cycle repeats. Annotations on the graph state, "Melatonin levels fall by early morning" and "Melatonin production increases in the evening," indicating how melatonin peaks in the middle of the night and decreases in the morning.

[Generated by AI]

International Mindedness

Both the 12-hour clock and the 24-hour clock are used to state time. They are used interchangeably by people across the world. The 12-hour cycle divides the day into two cycles of 12 hours each. The first cycle starts from midnight to noon and then from noon to midnight. Analogue clocks use the 12-hour clock. A 24-hour clock looks at one cycle of 24 hours that extends from 00:00 to 23:59. This is used by people in many Asian, African and European countries. It is also used in computers and by the armed forces.

Role of epinephrine

Have you ever felt your heart pounding and your palms clammy when you speak before an audience? If you have, this is a natural response of your body to stress. The body is conditioned to respond to stress (or potentially dangerous situations) with what is called the ‘fight or flight mechanism’.

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The adrenal glands are small triangular-shaped glands located above both the kidneys and are composed of two parts, the cortex and the medulla. Epinephrine (adrenaline) is one of the hormones secreted by the adrenal medulla. However, what causes the levels of epinephrine to spike?

During a stressful situation:

- The hypothalamus sends impulses through the nerves of the autonomic nervous system.
- This activates the adrenal glands.
- The glands secrete epinephrine (see section C2.1.10 (/study/app/bio/sid-422-cid-755105/book/mechanism-of-action-of-various-signal-receptors-hl-id-46146/)) into the bloodstream.

Circulation of epinephrine through the body results in a number of physiological changes (**Interactive 1**) that gets the body ready to swing into action.

- The heart beats faster, the pulse rate increases and the blood pressure goes up. A greater volume of blood is delivered to the rest of the body (see section B3.2.14–16 (/study/app/bio/sid-422-cid-755105/book/adaptations-of-the-heart-hl-id-44448/)).
- The breathing rate (see section B3.1.5–6 (/study/app/bio/sid-422-cid-755105/book/ventilation-in-the-lungs-id-44439/)) increases to provide the body with more oxygen.
- Oxygen supply to the brain increases, resulting in enhanced alertness and reduced reaction time.
- The smooth muscles of the blood vessels delivering blood to the major skeletal muscles (see section B3.3.2–4 (/study/app/bio/sid-422-cid-755105/book/muscle-contraction-hl-id-44815/)) dilate, ensuring an increased supply of nutrients and oxygen.
- Breakdown of glycogen in the liver increases and blood sugar levels go up to provide the additional energy.
- Sight, hearing and other senses become sharper.

These changes help with skeletal muscle contraction, enabling the body to stand and fight or to flee.

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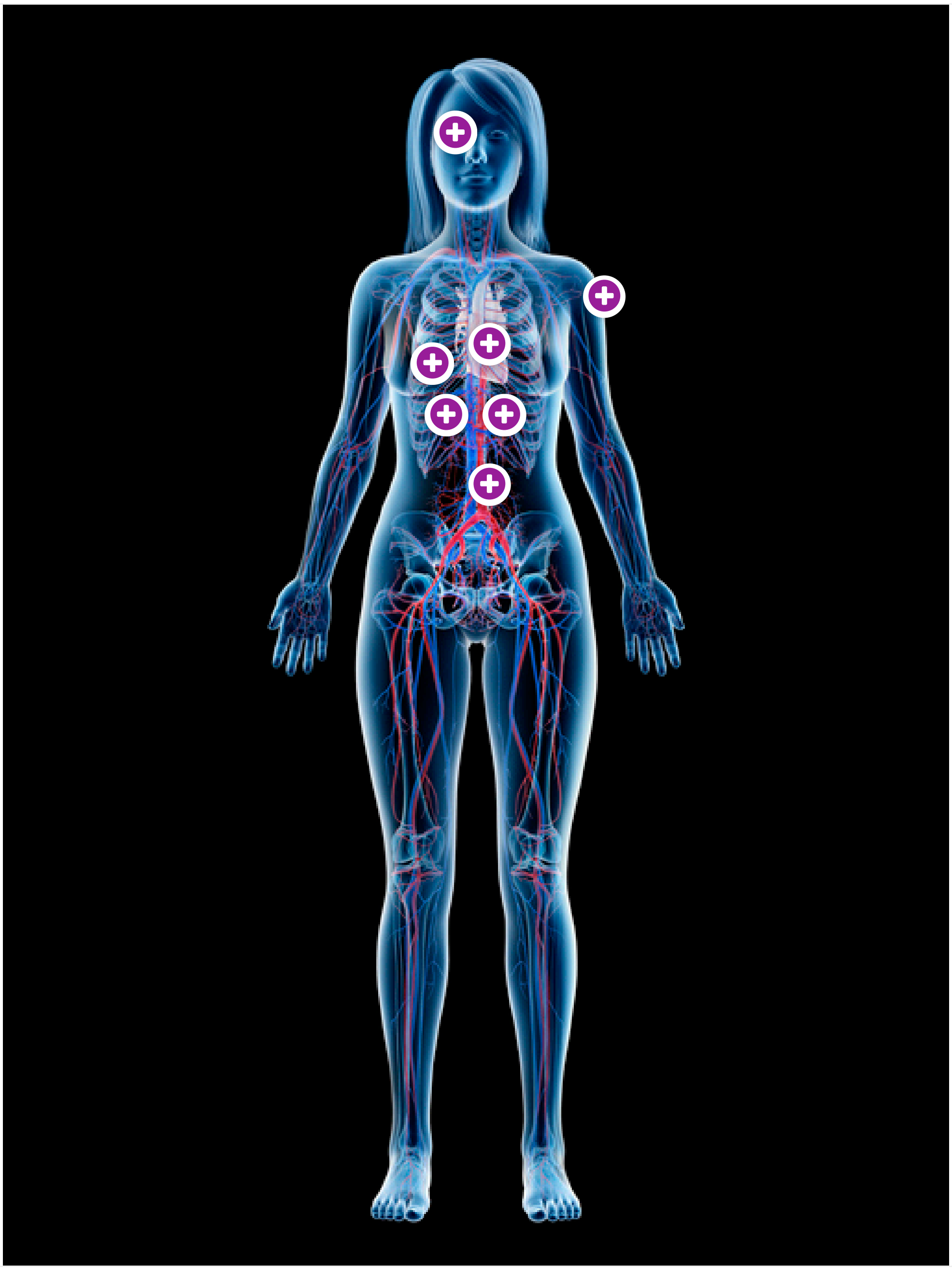

Rights of use

Interactive 1. The Stress Response.

More information for interactive 1

The interactive is a 3D anatomy of a girl. The illustration emphasizes the arteries (in red) and veins (in blue) of the circulatory system present across the body. The illustration aims to explain how certain body organs change as a response to stress.

The organs discussed are indicated as hotspots or plus signs with numbers. Read below to understand how certain organs respond to stressful situations.

Hotspot 1 - Eyes - The pupils dilate when the body encounters stress.

Hotspot 2 - Skin - The skin exhibits increased sweating.

Hotspot 3 - Heart - The heart rate increases.

Hotspot 4 - Lungs - The breathing rate increases.

Hotspot 5 - Liver - The liver aids in the conversion of glycogen to glucose.

Hotspot 6 - Stomach - The digestion process slows down.

Hotspot 7 - Blood vessels - The blood vessels experience increased blood pressure.

Student view

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Interactive 1. The stress response.

Creativity, activity, service

Strand: Activity
Learning outcome: Demonstrate how to initiate and plan a CAS experience

While epinephrine is essential for our body to deal with stressful conditions, a fallout is panic or anxiety attacks over tasks or thoughts that may seem inconsequential to others. This causes people to often feel on edge and 'jittery'. Develop a campaign that helps people deal with anxiety. You could initiate an awareness campaign or organise events like support groups or yoga classes or mindful meditation (https://www.uclahealth.org/programs/marc/free-programming-resources/ucla-mindful-app) that help people deal with these issues.

Control of the endocrine system by the hypothalamus and pituitary gland

The endocrine system consists of glands that secrete hormones directly into the bloodstream. These hormones play a major role in regulating the functions of the body.

Concept

Endocrine glands are glands without ducts, they release their secretions (hormones) directly into the bloodstream. On the other hand, exocrine glands like the tear glands, mammary glands, salivary glands and digestive glands have ducts through which the secretions are released.

Two of these glands, the hypothalamus and the pituitary gland, play a major role in controlling the endocrine system and act as the 'command centre' (**Table 1**).

The hypothalamus is the main link between the nervous system and the endocrine system. It maintains the stable state of your body or, in other words, maintains homeostasis (see subtopic D3.3 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43551/)). One way the hypothalamus does this is by secreting hormones that either stimulate or inhibit the activity of the pituitary gland.

The pituitary gland is a pea-shaped gland that is attached to the hypothalamus. The pituitary has two lobes: the anterior pituitary and the posterior pituitary. These hormones either directly stimulate the cells and tissues of the body or act on other glands regulating their secretions. As it controls the work of other endocrine glands, the pituitary gland is sometimes referred to as the 'master gland'.

Table 1 Roles of the hypothalamus and pituitary.

Hypothalamus	Causes the anterior pituitary to	Effect on the body
Growth hormone releasing hormone.	Release growth hormone.	Growth of the bones and muscles.

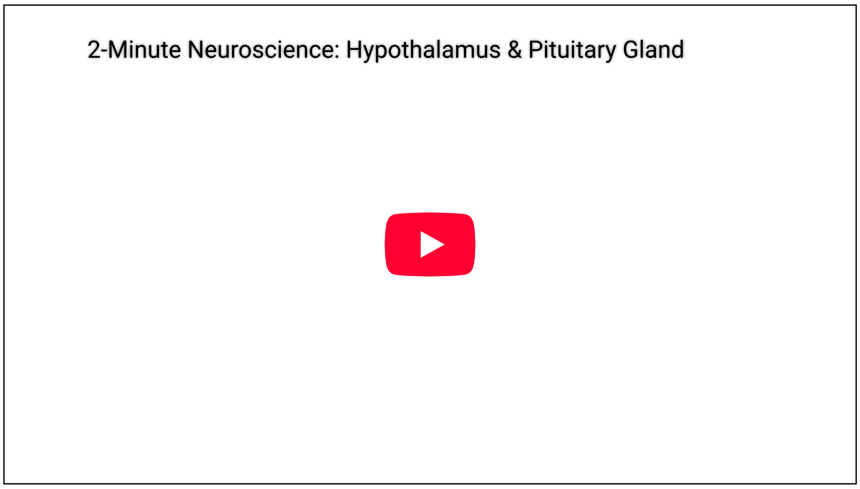
Student view

Overview (/study/app/bio/sid-422-cid-755105/o

Hypothalamus	Causes the anterior pituitary to	Effect on the body
Gonadotropin-releasing hormone.	Release of 1. follicle stimulating hormone (FSH) 2. luteinising hormone (LH) (see section D3.1.5—7 (/study/app/bio/sid-422-cid-755105/book/menstrual-cycle-and-fertilisation-id-45415/)).	Acts on the reproductive organs including the gonads. In males, LH stimulates the testes to produce testosterone. In females, both FSH and LH stimulate the ovary to release oestradiol and progesterone leading to the menstrual cycle.
Corticotropin-releasing hormone.	Release of adrenocorticotropic hormone.	Acts on the adrenal gland and causes the release of a hormone called cortisol.
Thyrotropin releasing hormone.	Release of thyroid stimulating hormone (TSH).	Causes thyroid to release triiodothyronine and thyroxine.
Prolactin inhibiting hormone.	Inhibition of prolactin.	Prevents secretion of breast milk.
Somatostatin	Inhibit secretion of growth hormone and TSH.	

In addition to the information in **Table 1**, the hypothalamus also synthesises oxytocin (see section D3.1.19 (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-46148/)) and antidiuretic hormone (or vasopressin); however, these hormones are stored in the posterior pituitary. Oxytocin plays an important role in uterine contractions during childbirth and breastfeeding, whereas antidiuretic hormone is essential for the reabsorption of water in the kidney (see section D3.3.9–11 (/study/app/bio/sid-422-cid-755105/book/osmoregulation-hl-id-44810/)).

Video 1 summarises the role of the hypothalamus and the pituitary as the command centres of the body.



Video 1. Command centres.

Student view

Try the group activity to look at the differences in pattern of melatonin release between adults and adolescents.

Overview
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Activity

- **IB learner profile attribute:** Balanced
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 15—20 minutes
- **Activity type:** Group activity

Work in groups of four.

The graph in **Figure 2** shows the melatonin levels of an adult and a teenager.

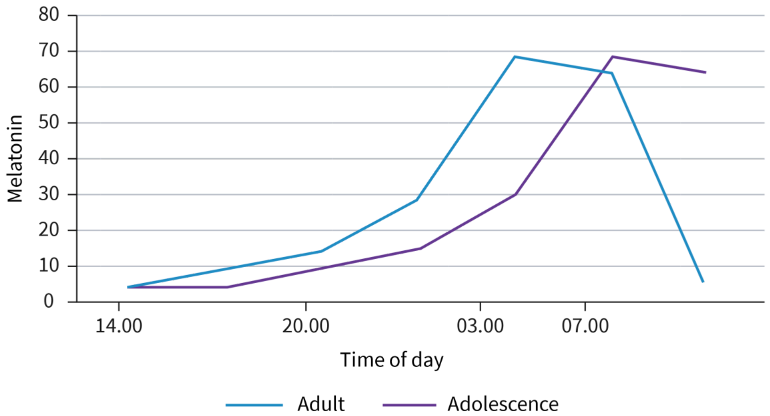

Figure 2. Daily variations in melatonin levels.

More information for figure 2

The graph illustrates daily variations in melatonin levels for an adult and a teenager across different times of day. The X-axis represents the time of day, ranging from 14:00 to 07:00. The Y-axis represents melatonin levels, measured from 0 to 80. Two lines are plotted: a blue line for adults and a purple line for teenagers.

Both lines start at low melatonin levels around 14:00, under 10 units. As the evening progresses, melatonin levels increase steadily. By 03:00, levels peak, with adults reaching around 70 units and teenagers peaking slightly lower. After 03:00, teenage melatonin levels begin to decline slightly, while adult levels remain relatively high until they both start dropping towards 07:00.

[Generated by AI]

Questions

1. State the times at which the melatonin level peaks in both adolescents and adults.
2. Referencing the graph, describe the general trend that you see in melatonin levels.
3. Discuss the data (in groups) and prepare a compelling argument about an ideal schedule for teenagers.
4. Share your ideas in class.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Feedback mechanisms in regulating body functions

Student view

C3.1.14: Feedback control of heart rate C3.1.15: Feedback control of ventilation rate C3.1.16: Control of peristalsis in the digestive system

Overview
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Learning outcomes

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

- State the role of baroreceptors and chemoreceptors in the feedback control of the heart rate.
- Describe the role of chemoreceptors in controlling the rate of ventilation.
- Outline the mechanism for peristaltic control by the CNS and ENS.

As you begin to exercise vigorously, you will notice that your heart rate and your breathing rate increases. This ensures that your body gets the required amount of oxygen and that the carbon dioxide produced is eliminated. What are the internal mechanisms that trigger the changes in heart rate and breathing rate?

Control of heart rate

The cardiovascular centre of the medulla oblongata plays an important role in regulating the heart rate, cardiac output and respiratory rate. Specialised receptors – baroreceptors and chemoreceptors – are located in the carotid sinus and the arch of the aorta. The baroreceptors are mechanoreceptors and detect changes in the pressure of the blood (arterial stretch) as it flows through the arteries (**Figure 1**). The chemoreceptors detect changes in the pH of blood and levels of oxygen and carbon dioxide. Both the chemoreceptors and baroreceptors respond to the stimuli by sending signals to the cardiovascular centre of the medulla oblongata.

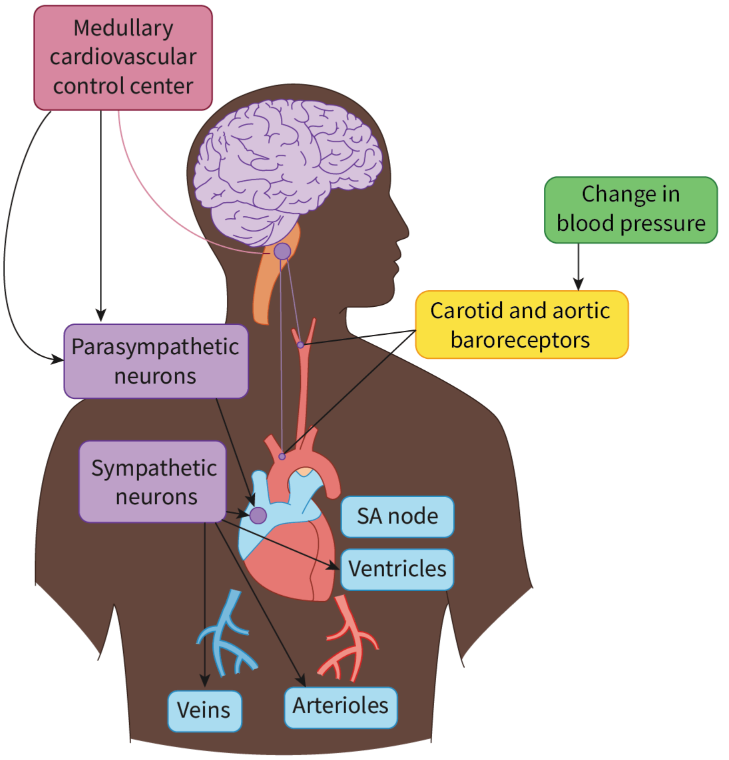


Figure 1. Baroreceptors in regulation of heart rate.

More information for figure 1

Diagram showing the role of baroreceptors in regulating the heart rate. The image depicts a profile of a human torso with a brain, heart, veins, and arteries highlighted. Labels indicate: Medullary cardiovascular control center, Parasympathetic neurons, Sympathetic neurons, SA

Student
view

node, Ventricles, Veins, Arterioles, Carotid and aortic baroreceptors, and Change in blood pressure. Arrows show connections between these elements. Baroreceptors, located in the carotid and aortic regions, detect blood pressure changes and send signals to the medullary cardiovascular control center, which influences parasympathetic and sympathetic neurons, affecting the heart rate through the SA node and ventricles.

[Generated by AI]

Concept

The autonomic nervous system has three distinct divisions: the sympathetic nervous system, the parasympathetic nervous system and the enteric system. The sympathetic nervous system and the parasympathetic nervous system often have opposing effects on the same organ and help to maintain homeostasis. For example, the sympathetic nervous system increases heartbeat whereas the parasympathetic nervous system slows it down. The enteric nervous system is the nervous system of the gastrointestinal tract.

How do baroreceptors work?

The baroreceptor reflex involves baroreceptors that monitor the blood pressure on a minute-to-minute basis and quickly adjust blood pressure.

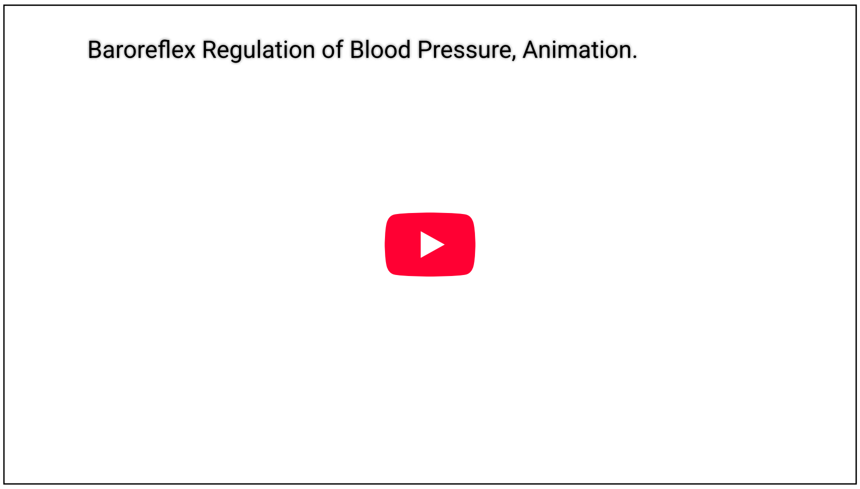
When the blood pressure decreases:

- The baroreceptors sense the decreased stretch of the arteries.
- The information is sent to the cardiovascular centre of the medulla oblongata.
- In response, the medulla oblongata activates the sympathetic nervous system (and inhibits the parasympathetic nervous system).
- Activation of the sympathetic nervous system causes an increase in both heart rate and stroke volume (or the volume of blood pumped by the left ventricle in each beat). The blood vessels also constrict, increasing the blood pressure.

When the blood pressure increases:

- The baroreceptors sense the increased stretch of the arteries.
- The information is sent to the cardiovascular centre of the medulla oblongata.
- In response, the medulla oblongata activates the parasympathetic nervous system (and inhibits the sympathetic nervous system), resulting in vasodilation, and decrease in heart rate and stroke volume. This, in turn, causes the blood pressure to decrease.

Both these mechanisms keep the blood pressure at a relatively constant level. **Video 1** summarises the process.



Video 1. Regulation of blood pressure by baroreceptors.

How do chemoreceptors work?

Chemoreceptors detect changes in the concentration of carbon dioxide and oxygen as well as the pH of the blood (see section B3.1.11–13 (/study/app/bio/sid-422-cid-755105/book/transport-of-oxygen-hl-id-44441/)). Take the example of decreased blood flow to tissues. This results in an increase in the carbon dioxide levels of blood (and a corresponding decrease in blood pH). The chemoreceptors detect these changes and send signals to the medulla oblongata. This, in turn, stimulates the sympathetic nervous system which sends signals to the heart, resulting in an increase in heart rate. The increase in heart rate increases the blood flow to the tissues bringing in oxygen and removing carbon dioxide.

Control of ventilation rate

Carbon dioxide is a normal byproduct of cellular respiration. The carbon dioxide dissolves in blood to form carbonic acid, a weak acid. When the amount of carbon dioxide produced is more, as often seen during exercise, the pH of the blood decreases slightly (due to the production of H^+ from carbonic acid). This is detected by the central chemoreceptors located in the medulla oblongata. The ventilation centres in the medulla oblongata respond, resulting in increased contraction and relaxation of the respiratory muscles – the diaphragm and the intercostal muscles (see section B3.1.5–6 (/study/app/bio/sid-422-cid-755105/book/ventilation-in-the-lungs-id-44439/)). The ventilation rate increases, expelling the excess carbon dioxide.

Role of the enteric nervous system

Hidden in the walls of the gastrointestinal tract lies the enteric nervous system (ENS) composed of millions of neurons. A part of the autonomic nervous system, the ENS extends from the oesophagus to the rectum and is often referred to as the 'little brain' as it can function independently.

Once the food is swallowed, the ENS controls and coordinates the process of digestion. This means that the passage of material through the gut is coordinated by the ENS. This movement starts from peristalsis (or the movement of food down the tract due to rhythmic contractions of the muscles) to the release of digestive enzymes, to the mixing of food with the digestive enzymes, to the control of blood flow needed for absorption of nutrients, to even vomiting.

Studies show that the ENS is connected to the central nervous system (CNS), and this link plays a crucial role in understanding gut disorders.

Overview (/study/app/422-cid-755105/o

It must be remembered that the initiation of swallowing is a voluntary process under the control of the CNS. However, once swallowed, the process is involuntary and controlled by the ENS until defaecation. The egestion of faeces is normally voluntary and under the control of the CNS.

Nature of Science

Aspect: Evidence

New studies have revealed that the connection between the gut, ENS and the CNS is stronger than previously thought. It is well known that the brain has a direct effect on the gut. For example, psychological stress can affect the gut or the thought of food can release gastric juices. Emerging research shows that the reverse is also true. Studies show that experimental changes in the gut microbiome affect the emotional and cognitive responses of the brain. Researchers are investigating the link between the gut microbiome and brain disorders. This is a paradigm shift as traditionally, the gut microbiome has not been considered significant in human brain disorders.

In pairs, try the brainstorming activity to build on your understanding of the ENS.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Engaging with, and designing linking questions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair activity

The ENS is an area of emerging research. While the ENS acts like a 'little brain' controlling the functions of the gastrointestinal tract, recent studies have shown that the microbes living in the gut play an important role in keeping the ENS running smoothly. Read the articles given here (https://www.hsph.harvard.edu/nutritionsource/microbiome/) and here (https://theconversation.com/hangry-bacteria-in-your-gut-microbiome-are-linked-to-chronic-disease-feeding-them-what-they-need-could-lead-to-happier-cells-and-a-healthier-body-199486).

Form pairs and brainstorm ways to regulate your diet to have a healthy gut microbiota.

Present your strategies in class.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Tropisms and role of phytohormones (HL)

C3.1.17: Observations of tropic responses in seedlings (HL) C3.1.18: Positive phototropism (HL) C3.1.19: Phytohormones as signalling chemicals (HL)

Student view

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Higher level (HL)

Learning outcomes

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

- Observe tropic responses in seedlings.
- Describe positive phototropism.
- Outline the functions of the different types of phytohormones.

According to Greek mythology, Clytie, a water nymph, was dazzled by Apollo, the Sun god, who took little notice of her. Venus, the goddess of love, took pity on her and transformed her into a plant who could follow the movement of Apollo. This is a myth, but for many years, scientists have been studying movement in plants. What sort of movements do plants exhibit? Are these movements in response to stimuli?

Tropic movements in seedlings

Tropic movements are directional movements of the plant that happen in response to stimuli. As plants cannot move from place to place, they grow towards conditions that are favourable and away from those that are unfavourable. In other words, plants alter their growth so as to reach more optimal conditions. These growth responses are known as tropic movements.

Apart from his theory of evolution (see subtopic A4.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43246/)), Darwin conducted a number of studies on plant growth responses to various stimuli. In his book *The power of movements in plants* he described, in detail, the differential growth of plants to a directional stimulus. The experiment described in the activity at the end of this section is similar to the one done by Darwin and will help you to observe and gather data on tropic responses in seedlings.

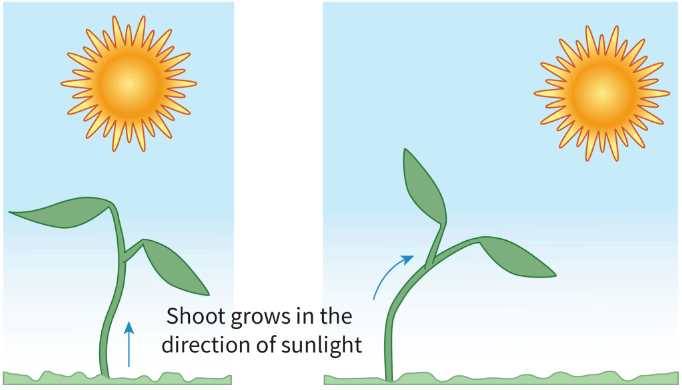
Positive phototropism

Plants require sunlight and water to carry out photosynthesis. Tropic movements are responses by plants to meet these requirements. These tropic movements could be:

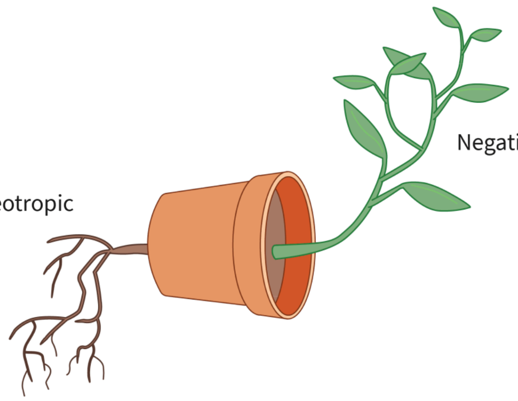
- Positive tropism or movement towards the stimulus.
- Negative tropism or movement away from the stimulus.

One of the tropic movements seen in plants is phototropism, where the stem of the plant grows towards a source of light (**Figure 1**). As the growth of the stem is towards the light it is called positive phototropism. In most cases, the roots exhibit negative phototropism as they grow away from the light. It is of interest to note that if the source of light is above the plant, the stem grows vertically upwards. However, if the source of light is lateral, the plant grows towards the source of light. Thus, positive phototropism is the directional growth of plant shoots in response to light.

Student
view



(a)



(b)

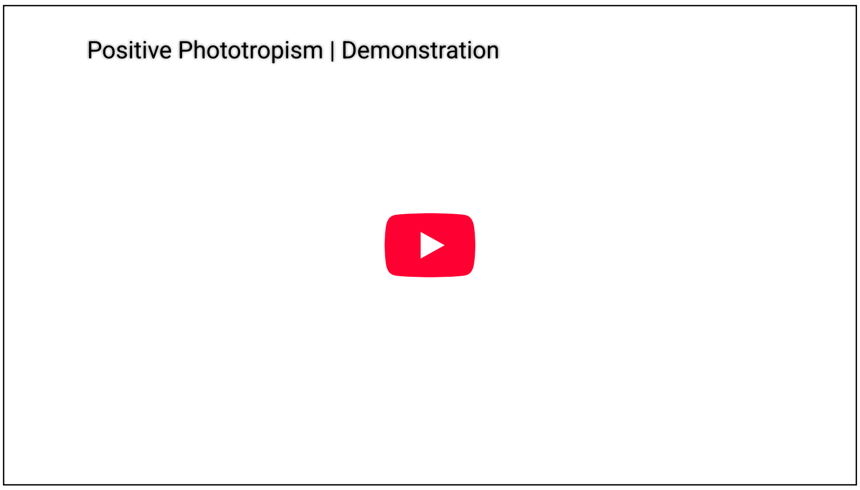
Figure 1. (a) Phototropic movement in response to lateral light. (b) Geotropic movements.

More information for figure 1

The diagram illustrates a potted plant on its side, demonstrating geotropic movement. The roots, labeled "Positive geotropic," are growing downward in the direction of gravity. Meanwhile, the stem and leaves, labeled "Negative geotropic," are growing upward against gravity. This shows the natural growth behavior of plants responding to gravitational forces.

[Generated by AI]

Video 1 shows phototropism in cress.



Video 1. Phototropism.

More information for video 1

Overview
(/study/app/bio/sid-422-cid-755105/o

The video opens against a completely black backdrop, establishing a focused and distraction-free environment. A white rectangle appears, featuring the word “GPhase”. A small black plastic pot filled with dark soil comes into view, its top layer neatly covered with evenly spaced brown cress seeds. The stark contrast between the black background and the earthy tones of the pot and seeds serves to emphasize the central subject—the germination and growth of the seedlings.

In the bottom left corner, the on-screen text begins with “Hour 2,” marking the initial phase of the time-lapse, while “GPhase” remains consistently displayed in the bottom right corner. As the hours progress, tiny white-green sprouts begin to push through the surface of the soil. These delicate structures represent the early stages of plant growth. The sprouting process continues as timestamps such as “Hour 6,” “Hour 9,” “Hour 13,” and “Hour 16” appear sequentially, creating a clear chronological record of development.

By "Hour 20," the seedlings have become more robust, exhibiting longer stems and clearer green pigmentation. The hulls of the seeds remain partially attached at the base, anchoring the visual memory of the original seeds and reinforcing the continuity of the life cycle. As time continues—marked by indicators such as “Hour 23,” “Hour 30,” “Hour 34,” and up to “Hour 48"—the elongation of the stems becomes more pronounced, with the pale lower stems contrasting against the greener tops. Subtle leaning in some of the seedlings begins to emerge, indicating the early signs of phototropic behavior.

From “Hour 52” through “Hour 77,” the sprouts begin to display a clearer directional curvature. Although not explicitly labeled with direction or light source within the video, the visible lean of the seedlings implies a response to an external stimulus—most likely light, given the context of the practical. This directional bending of the stem is an observable demonstration of phototropism, where plant growth is guided by the light source's position. The increasing angle of curvature represents the dependent variable in this investigation and reflects the measurable outcome of phototropic response.

A subtle shift in lighting or camera perspective introduces a slight yellow-green hue to the seedlings, enhancing their visual appeal and signifying a transition in growth or health. As the final hours—labeled as “Hour 50” through “Hour 60”—play out, the seedlings seem more animated, swaying gently or adjusting their orientation, possibly due to either the light source or the setup conditions evolving.

Through this extended time-lapse, the viewer is provided with a visual exploration of phototropism—how plant stems, specifically cress seedlings, respond to a directional light stimulus over time. The primary learning outcome centers on recognizing that phototropism is a vital adaptive behavior in plants, enabling them to maximize light absorption for photosynthesis. This process is evidenced by the gradual curvature of the seedling stems toward the source of light. Additionally, the video highlights how the angle of curvature can serve as a measurable dependent variable in experimental design, allowing for quantitative analysis of plant responses. Overall, the content underscores the importance of light in regulating plant growth and development while also demonstrating how time-lapse technology can enhance the understanding of slow biological processes.

Plants also exhibit geotropic or gravitropic movements in response to gravity (geotropism) (**Figure 1**). The roots of plants normally display positive geotropism as they grow downwards while the stems display negative geotropism. The growing of roots into the soil helps them to absorb water and necessary minerals as well as anchor the plant firmly.

Other tropic movements in plants include hydrotropism (water), thigmotropism (touch) and chemotropism (chemicals). (You do not need to know about these other tropisms – just positive phototropism.)

The role of phytohormones

Phytohormones are plant hormones that regulate multiple physiological processes in plants like growth, development, flowering, reproduction, protection from pathogens, ripening of fruits and even death. Phytohormones act as chemical messengers. They are secreted in almost all the parts of the plant and are then transported to specific regions via the vascular tissues such as the xylem and phloem.

There are five major types of phytohormones each with their own distinct set of functions (**Figure 2**).

Auxins

Auxins (indole-3-acetic acid or IAA is the main active form) are growth hormones produced predominantly in the shoot apical meristem (shoot tips). From there, auxins are transported by a combination of diffusion and carrier-mediated transport, from one cell to another down the stem. They mediate a number of processes such as:

- Cell elongation responsible for tropic movements (see section C3.1.20—22 (/study/app/bio/sid-422-cid-755105/book/more-on-auxins-and-cytokinins-hl-id-45755/))
- Apical dominance, i.e. inhibition of the growth of the lateral (axillary) buds. This causes the plant to grow vertically.

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

Cytokinins

As the name implies, cytokinins promote cell division – cytokinesis (see sections D2.1.1–3 (/study/app/bio/sid-422-cid-755105/book/cytokinesis-id-44288/) and D2.1.4–6 (/study/app/bio/sid-422-cid-755105/book/shared-features-of-mitosis-and-meiosis-id-45676/)) – and are abundant in growing tissues. They are normally synthesised in the roots and pass into the leaves and fruits where they:

- promote cell division
- stimulate differentiation of the meristem
- delay senescence or ageing.

Gibberellins

Gibberellins are a group of related plant hormones that play an important role in plant growth. These hormones are synthesised in the apical meristems of roots and shoots, young leaves and embryos. They help in:

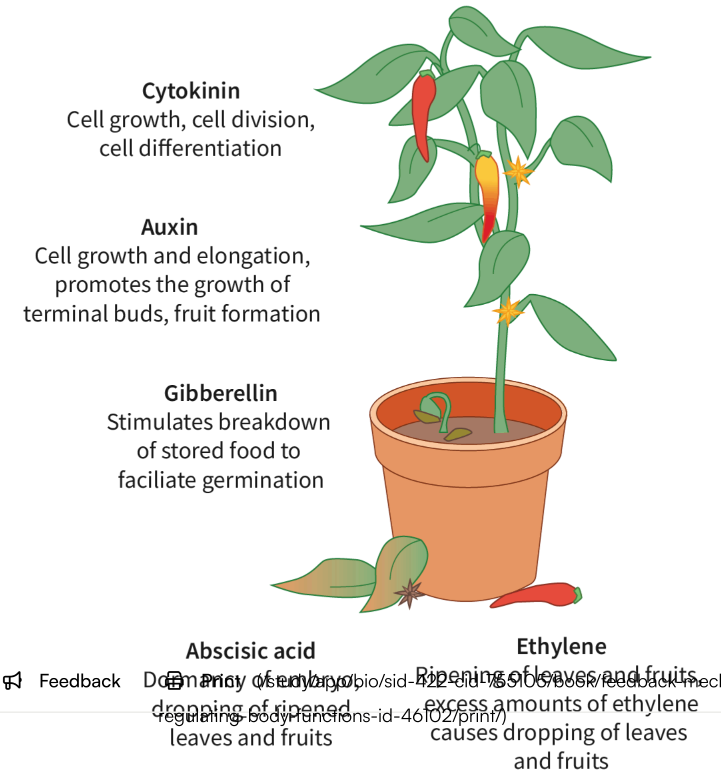
- elongation of the shoot
- seed germination
- maturation of flowers and fruits
- breaking seed dormancy
- delaying senescence.

Abscisic acid

Abscission means to cut off. One of the key effects of abscisic acid (ABA) is the dropping or abscission of leaves. The levels of ABA increase during stressful environmental conditions like intense cold or reduced water levels and inhibits growth. In addition, ABA inhibits elongation of stems and induces dormancy in seeds.

Ethylene

Unlike the other phytohormones, ethylene is a gas and is produced by ageing tissues. Ethylene (see section C3.1.23 (/study/app/bio/sid-422-cid-755105/book/role-of-ethylene-hl-id-46104/)) plays a major role in ripening of fruits. It also causes abscission of leaves, fruits and flowers.



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Student view

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Overview (/study/app/bio/sid-422-cid-755105/o

Figure 2. Roles of phytohormones. Auxins, cytokinins and gibberellins promote plant growth while ABA and ethylene act as growth inhibitors.

More information for figure 2

The diagram features a potted plant with different parts labeled to show the roles of various phytohormones.

1. At the top left, there is text reading "Cytokinin" followed by a description: "Cell growth, cell division, cell differentiation." This text is linked to the leaves of the plant.
2. Below it, the text reads "Auxin" with the description: "Cell growth and elongation, promotes the growth of terminal buds, fruit formation." This is associated with the top part of the plant.
3. At the mid-bottom left, there is text saying "Gibberellin" along with: "Stimulates breakdown of stored food to facilitate germination." This is connected to the seedling and lower part of the plant.
4. At the bottom left, "Abscisic acid" is described as "Dormancy of embryo, dropping of ripened leaves and fruits." This is associated with a fallen leaf next to the pot.
5. On the right, "Ethylene" is described as "Ripening of leaves and fruits, excess amounts of ethylene causes dropping of leaves and fruits." This is linked to both the fruits on the plant and fallen fruits.

[Generated by AI]

Aspect: Observations

Quantitative data refer to the numerical and statistical aspects of observations, whereas qualitative data refer to the non-numerical data (data which are not measured), such as descriptions. Both forms of data are useful although they provide different outcomes. A researcher must look at potential outcomes prior to deciding whether they would like to gather quantitative data or qualitative data or, ideally, both.

While carrying out research, there are several factors that could impact the accuracy and reliability of observations. This could be anything from contaminated or uncalibrated glassware to a change in the environmental conditions the experiment is being carried out in. In addition, there is also the chance of human errors taking place. In the tropism experiments for example, if different pots had soil from different sources or were exposed to varying intensities of light, the outcomes may vary. One of the easiest ways to prevent and identify such errors is to have controls alongside the experimental samples (see section 1.5.4 (/study/app/bio/sid-422-cid-755105/book/data-analysis-id-46700/) for data processing).

Try the practical activity to observe tropic movements in seedlings in response to sunlight.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Reflecting on credibility of results

Tool 1: Experimental techniques — Measuring variables

- **Inquiry 2:** Collecting and processing data
  - Collecting data

Processing data

Interpreting results

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

- **Time required to complete activity:** 7—10 days
- **Activity type:** Pair activity

Observe tropic movements in seedlings in response to sunlight.

Materials

- Three small pots (approx. 7 cm in diameter and 7 cm in height) filled with soil to the brim. Use loamy soil (soil that contains a mix of clay and sand and is fertile due to the presence of humus) if possible and ensure you use soil from the same source in all the pots.
- A box or similar non-opaque container into which all three pots will fit.
- Corn or oat or any other type of seed.
- Shoot caps: cut 5 cm × 8 cm pieces of regular thickness aluminium foil and fold each piece to create a thimble-like cap that can be placed at the tip of the growing shoot. You can create the thimble-like cap by moulding the foil around the eraser end of a pencil.
- Base sleeves: take 1 cm × 8 cm pieces of regular thickness aluminium foil, wrap in such a way that this can be kept at the base of the growing shoot.
- Water.
- Sticky notes.

Method

1. Label the cups as follows:

   • control
   • tip
   • base.

2. Plant four seeds 1.2 cm below the soil in each of the cups. One way of doing this is to mark 1.25 cm from the eraser end of the pencil and use this to create the hole to plant the seeds.
3. Make sure that the seeds are evenly spaced (approx. 1 cm between the seeds). If you plant the seeds corresponding to compass points and mark the same on the pot as north, east, south and west (N, E, S, W), you can keep track of the growth of individual seedlings.
4. Place the box on the windowsill so that the open end faces the light. The light should fall from an angle (and not from above).
5. Place the three pots inside the box.
6. Before you begin, predict the outcomes of the experiment.
7. Water (approx. 100 ml) daily and watch the seeds sprout. Make diagrams to illustrate the growth.
8. Once the seedlings are about 2.5 cm in height, place a shoot cap on the tip of each of the growing shoots of the seedlings in the pot labelled 'tip'. Similarly place the base sleeve around the base of the seedling in the cup labelled 'base'. These act as light exclusion devices. As seedlings grow rapidly, make sure to check the position of the light exclusion devices on a daily basis. The control remains as it is.
9. Continue to water the seeds.
10. Construct a data table. Make sure that you include the following parameters: day/date and length of the stem.
11. Record your observations as follows:

    • Measure the length of the stem from the base to the tip of the stem. You can do this by placing a string along the length of the stem and marking the ends on the string. Then measure the length of the string using a ruler.
    • Draw labelled diagrams to record your observations.
    • If possible, take photographs to observe changes in the curvature of the stems.

12. Process the results and describe the growth patterns seen in the seedlings of the three pots.

Student view

Overview
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Precautions

1. Make sure that all three pots are identical in all aspects. In other words, all three pots should be of the same size, made of the same material, filled with the same type and amount of soil and so on.
2. The stems of the seedlings are fragile and need to be handled with care.
3. If you are taking pictures to record the changes in the curvature of the stem, make sure that the position of the camera remains the same. You could do this by mounting the camera in a fixed place.

Conclusion

Write down your conclusion.

Check your understanding

1. Qualitative data are descriptive, non-numerical data. What were the qualitative data that you collected?
2. Quantitative data are numerical data. What were the quantitative data that you collected?

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

More on auxins and cytokinins (HL)

C3.1.20: Auxin efflux carriers (HL) C3.1.21: Promotion of cell growth by auxin (HL) C3.1.22: Interactions between auxin and cytokinin (HL)

Higher level (HL)

Learning outcomes

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

- Explain the movement and concentration of auxins within plant cells.
- Describe the role of auxins in cell growth.
- Study the regulation of root and shoot growth by the interaction between cytokinins and auxins.

Section C3.1.17–19 (/study/app/bio/sid-422-cid-755105/book/tropisms-and-role-of-phytohormones-hl-id-46103/) states that auxins cause cell elongation resulting in tropic movements. But how do auxins elicit this growth?

Polar auxin transport

Indole-3-acetic acid or IAA is the predominant form of auxin seen in plants. It is synthesised by the apical meristems (shoot tips) and diffuses to other parts of the stem or the roots, playing an important role in cell elongation and differentiation. Tropic movements are caused by uneven distribution of auxin (**Figure 1**).

When light is overhead, the auxin produced at the tip of the shoot diffuses evenly down the stem. As auxin is evenly distributed, all the cells grow at the same rate and the shoot grows vertically upward. On the other hand, if the light source is to one side, the auxin molecules move towards the shaded side of the shoot. The increased

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concentration of auxin at the shaded side causes rapid cell elongation and growth on that side. The uneven growth causes the stem to bend toward the light source.

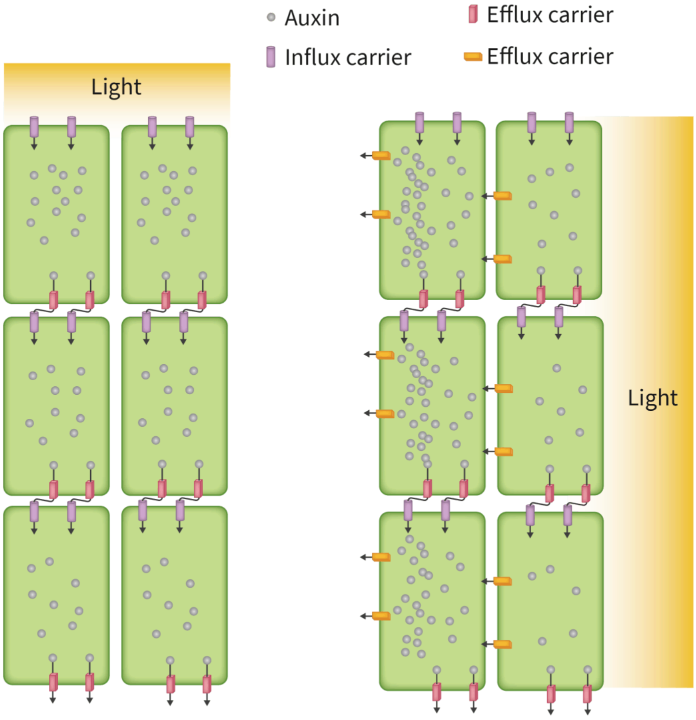

Figure 1. Uneven distribution of auxin.

More information for figure 1

The image is a diagram depicting the movement of auxin in plant cells in response to light. On the left, four green rectangles representing plant cells show evenly distributed small gray circles labeled "Auxin." These cells are under direct light, indicated by a yellow gradient labeled "Light." Purple rectangles labeled "Influx carrier" are at the top and bottom of the cells, and red rectangles labeled "Efflux carrier" at the bottom allow downward movement of auxin. On the right, another set of four plant cells is shown responding to light coming from the side. Auxin is congregated towards the left sides of the cells, marked with larger clusters of gray circles. The red and orange rectangles labeled as "Efflux carrier" and "Influx carrier" facilitate this lateral movement, with arrows indicating the direction of auxin transport toward the shaded side. The diagram highlights how auxin accumulates on the shaded sides of the cells, leading to differential growth.

[Generated by AI]

It is evident that the differential distribution of auxin is needed for plants to grow towards light. To ensure this, the transport of auxins needs to be directional. This mechanism of transport is called polar auxin transport. One of the major methods of transport of auxin is the active directional cell-to-cell movement of auxin and involves:

- Entry of auxin into the cell passively or via membrane proteins called auxin influx carriers.
- Exit of auxin out of the cell via membrane proteins called auxin efflux pumps.

The active cell-to-cell movement of auxin is outlined below. Make sure that you refer to the annotations in **Figure 2** as you read through this.

- Auxin (IAA) influx or entry into a cell occurs by diffusion and is facilitated by influx carriers (the primary group of which are AUXIN 1/LIKE AUXIN 1 (AUX1/LUX1)).
- Within the cell, IAA dissociates. The resulting negatively charged ions (IAA^-) are unable to exit the cell.
- Auxin efflux carriers pump out these ions using ATP; however, the carriers are localised on a particular side of the cell so as to direct the flow of the ions in the required direction. This ensures directionality in the movement of auxin. (It is important to note that the position of the efflux carriers can change based on various factors.)
- This creates a higher concentration of auxin in the intercellular space (apoplast) and a lower concentration in the adjacent cell. Auxin flows down its concentration gradient into the adjacent cell resulting in an auxin influx.

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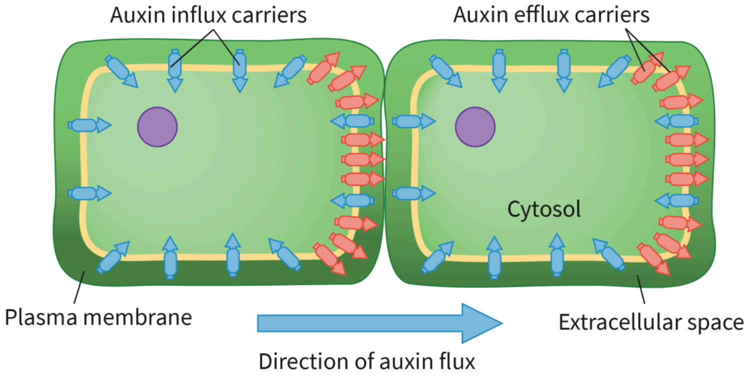
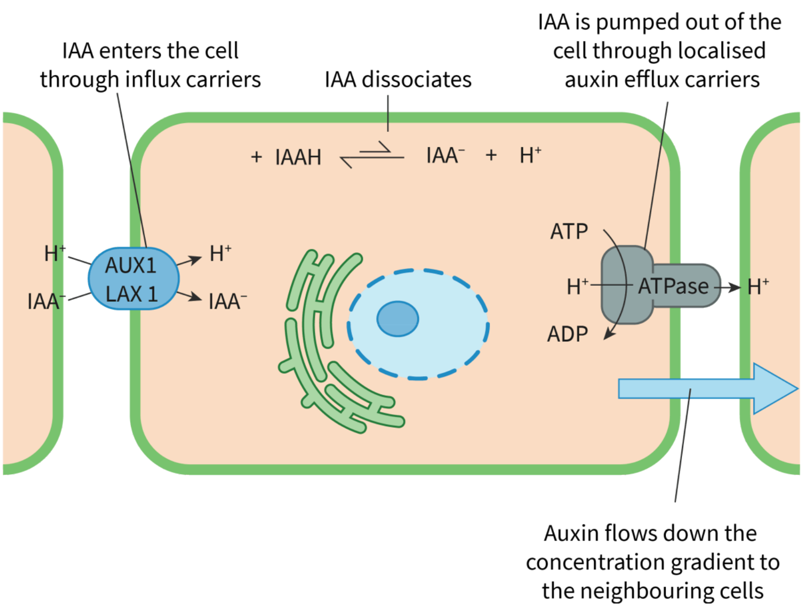
- Coordination between the cells can lead to localisation of the carriers on the same side. As the mechanism of auxin transport continues, auxin accumulates on the shaded side of the plant.
- This results in greater elongation of the cells on the shaded side of the stem and thereby curvature towards the light source.



More information

This diagram illustrates the transport of auxin, a plant hormone, across the plasma membrane. It shows two rectangular cells side by side with labeled components. Auxin influx carriers are represented by blue arrows and are located on the plasma membrane of the left cell, showing the entry of auxin from the extracellular space into the cytosol. Auxin efflux carriers, depicted with red arrows, are located on the plasma membrane of the right cell, indicating the exit of auxin from the cytosol to the extracellular space. Between the two cells, the direction of auxin flux is indicated by a large blue arrow pointing to the right. The left cell is labeled 'Auxin influx carriers' above the blue arrows, and the right cell is labeled 'Auxin efflux carriers' above the red arrows. The areas within the cells are labeled 'Cytosol,' indicating the region where auxin is located during transport. The outer boundary of each cell is marked and labeled as the 'Plasma membrane.'

[Generated by AI]



More information

The diagram illustrates the process of IAA (Indole-3-acetic acid) transport across a plant cell membrane. On the left, IAA enters the cell through influx carriers labeled AUX1 and LAX 1. Hydrogen ions (H+) accompany the IAA into the cell. Inside the cell, IAA dissociates into its ionic form (IAA-) and hydrogen ions (H+).

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To the right, the diagram shows localized auxin efflux carriers, where IAA is pumped out of the cell. This process involves the enzyme ATPase, which converts ATP (adenosine triphosphate) to ADP (adenosine diphosphate), releasing a proton (H+). The expelled IAA can then flow down the concentration gradient to neighboring cells as indicated by an arrow pointing toward an adjacent cell.

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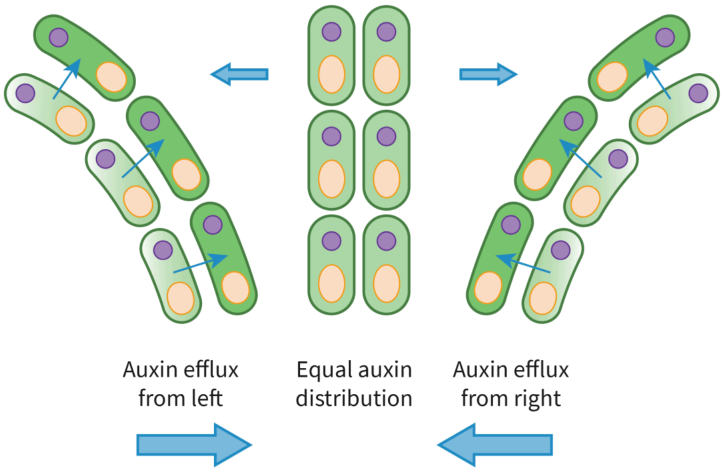

Figure 2. Directional movement of auxin.

More information for figure 2

The diagram illustrates the movement of auxin, a plant hormone, across three separate sections of cells. On the left, cells are arranged in a tilted formation with arrows indicating auxin efflux moving from left to right. The central section shows cells aligned vertically, suggesting equal auxin distribution without directional arrows. On the right, cells are again angled with arrows pointing to the left, indicating auxin efflux from the right. Each cell contains two distinct regions, likely representing nuclei and other organelles, highlighting cellular structure within each section. Text under each section labels the movements and states: 'Auxin efflux from left,' 'Equal auxin distribution,' and 'Auxin efflux from right.'

[Generated by AI]

Nature of Science

Aspect: Models

In science, a model is often used to represent an idea or a process to help visualise and understand it better. If you look at the model for explaining the transport of auxin, it provides a clear framework for understanding the mechanism and probably helps to predict the movement of auxin. At the same time, the model has its limitations — for example, it is unable to explain the precise molecular mechanism of auxin transport. These limitations need to be identified and factored in by scientists while using the model.

Cell growth by auxin

While the mechanism given above explains the movement of auxin, how does auxin cause cell elongation?

In plants, the structural support is provided by the cell walls. In other words, the cell walls are 'load-bearing'. For plant cells to elongate, the cross-links between the cellulose molecules of the cell wall need to be broken or cleaved. The Acid Growth Theory explains this mechanism (**Figure 3**).

- Auxin binds to receptor proteins on the membranes of cells on the side away from the light.

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- Binding of auxin activates proton pumps called H^+-ATPases present in the plasma membrane.
- H^+-ATPases pump protons (H^+) at an increased rate into the cell wall leading to acidification or lowering of the pH of the cell wall.
- Acidification loosens the bonds between the load-bearing cellulose molecules. This is facilitated by proteins called expansins.
- Simultaneously, K^+ channels in the plasma membrane open, resulting in an influx of potassium ions into the cell and a lowering of the internal water potential.
- Water enters cells by osmosis (see section D2.3.1—3 (/study/app/bio/sid-422-cid-755105/book/solvent-properties-of-water-id-46196/))
- The internal turgor pressure of the cell increases and the cell wall stretches, resulting in cell elongation.

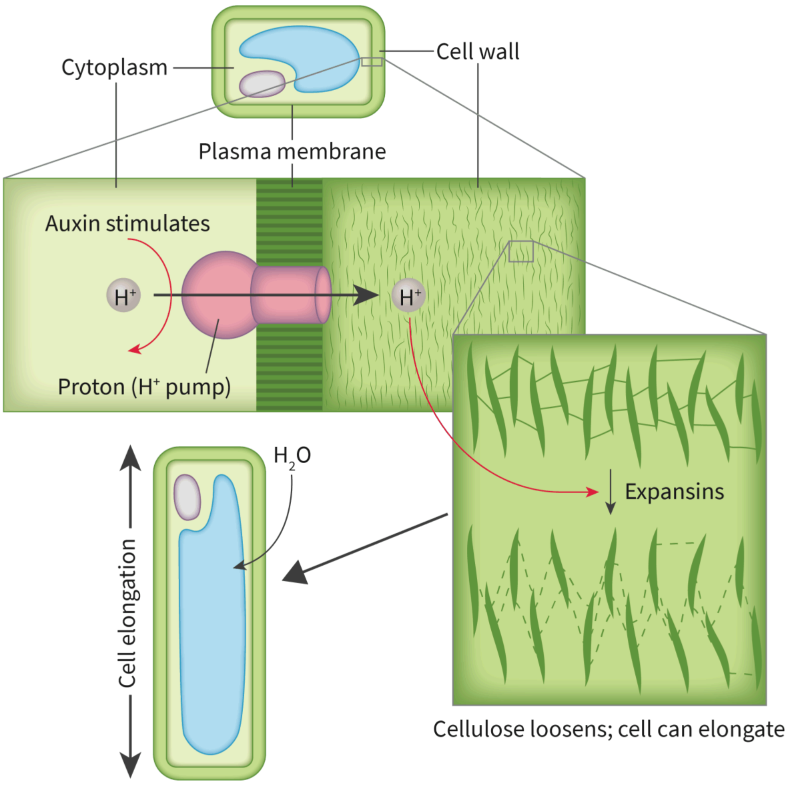

Figure 3. Mechanism of cell growth by auxin.

More information for figure 3

This diagram illustrates the mechanism of cell growth by auxin. In the top section, a cross-section of a plant cell shows a labeled cytoplasm, cell wall, and plasma membrane. Below this, there's a detailed view of the plasma membrane with a proton (H+) pump, showing that auxin stimulates the pump to move H+ ions out of the cell. This increases acidity outside the cell, which is depicted by the arrow flowing from the proton pump to the exterior space.

To the right, a close-up view shows the cell wall with labeled expansins that are activated in the acidic environment, leading to the loosening of cellulose fibers. Annotations explain that this action enables cell elongation. Below these components, another plant cell is illustrated with a reference to water (H2O) influx.

Arrows indicate the directions of processes, showing how auxin stimulation through H+ ion transport facilitates the loosening of the cell wall and subsequently allows for water uptake and cell expansion.

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Theory of Knowledge

In this section, you have learnt about the role of auxin as a chemical signalling molecule. Language is often defined as a system of communication. Keeping this in mind, can the signalling between the parts

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of the plant be considered as 'language'?

Interplay of auxin and cytokinin

While both auxins and cytokinins promote growth in plants, their combined action regulates the growth of the roots and stems.

Meristems are rapidly growing tissues consisting of undifferentiated cells. Shoot meristems give rise to the parts of the plant that are normally seen above the ground, whereas the root meristems give rise to the parts of the plant below the ground. The interaction between auxin and cytokinin plays an important role in regulating meristem development.

Auxins are synthesised by the stem meristem while cytokinins are synthesised by the root meristems. The auxin then moves downward towards the root resulting in geotropism while the cytokinin moves upward towards the shoot through the vascular tissues (see subtopic B3.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43215/)).

Studies have shown that the ratio of auxin to cytokinin determines the development of roots and shoots. Experiments have shown that a high auxin to cytokinin ratio favours development of roots while a high cytokinin to auxin ratio favours shoot and bud development.

The ratio also determines apical dominance. As auxin is transported down the apical meristem, lateral bud formation is inhibited. On the other hand, the upward movement of cytokinins from the root stimulates lateral bud formation.

Auxins lead to meristematic cell division while cytokinins lead to differentiation of cells, i.e. cytokinins inhibit the meristematic activity of auxins, hence together they regulate cell division and differentiation.

Try the group activity to help with your understanding of the action of auxins.

Summary: comparison of auxin and cytokinin

Auxin: Cytokinin Ratio	Effect on Plant Tissue	Typical Applications/ Responses
High Auxin, Low Cytokinin	Promotes root formation	Used in root induction during tissue culture
Balanced Ratio	Stimulates callus formation (undifferentiated cell growth)	Common in initial stages of micropropagation
Low Auxin, High Cytokinin	Encourages shoot formation	Applied in shoot multiplication and generation protocols

Quick insight:

- **Auxin** leans toward cell elongation and rooting.
- **Cytokinin** pushes cell division and shoot development.

Activity

Student view

- **IB learner profile attribute:** Knowledgeable

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- **Approaches to learning:** Social skills — Actively seeking and considering the perspective of others
- **Time required to complete activity:** 30 minutes
- **Activity type:** Group activity

Write each prompt on a separate piece of large chart paper and place the pieces of paper on tables around the room.

- A brief introduction to auxin.
- The role of auxin in plants.
- The mechanism of auxin transport.
- The mechanism of cell elongation.
- Interplay between auxins and other hormones.

Form five groups. Each group should select a prompt by moving to the table with the relevant chart paper. This is your starting place. Write a brief description of the topic as per the prompt given.

You will, in the course of the activity, circulate from one table to another. Make sure that you spend at least 4—5 minutes at each table. You can (at each table):

- Build on the prompt by adding facts.
- Elaborate on the ideas shared by others.
- Ask for more details.
- Ask questions.
- Draw diagrams.
- Comment on the details shared by other groups.

Select different pen colours for each group, so that your annotations are evident.

Return to the starting place and read what others have written on your chart paper.

Modify (as needed) and share.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Role of ethylene (HL)

C3.1.23: Positive feedback in fruit ripening (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to explain the positive feedback mechanism in the production of ethylene by ripening fruit.

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The sycamore figs (*Ficus sycomorus*) were first identified 5000 years ago in Egypt, from where they spread to Israel and Lebanon. It is believed that the ancient Egyptians used knives to make circular cuts on the fruits. This was believed to have hastened the ripening of the fruit. The practice is followed even today and the ripe fruit sold in the markets of Egypt often have gaping circular cuts. What is the relationship between ripening of fruits and the cuts?

Role of ethylene

A gaseous phytohormone, ethylene (IUPAC name, ethene), plays a major role in the ripening of fruit. All the changes that signal that the fruit is ripe are caused due to ethylene. In other words, ethylene:

- Breaks down cell walls to soften the fruit.
- Breaks down starch into sugars accounting for the sweeter taste.
- Decreases the amount of bitter phenolic compounds.
- Causes the green fruits to change colour due to the conversion of chlorophyll to other coloured pigments.
- Releases complex volatile compounds into the air, giving the typical aroma of ripening fruit.

Ethylene works on a positive feedback mechanism – the presence of ethylene leads to the synthesis of more ethylene. The unripe fruit produces very low levels of ethylene; however, as the fruits ripen, they produce larger and larger amounts accelerating the ripening process. The production of ethylene depends on the type of the fruit, with some fruits producing prodigious amounts of ethylene. Coming back to the sycamore figs, the gashing of the fruits is known to release ethylene which speeds up the ripening process.

The positive feedback mechanism has a flip side, too. The continued production of ethylene after the fruit is harvested leads to a decrease of its shelf-life and spoiling of the fruit.

International Mindedness

The United Nations Sustainable Development Goals (SDGs) are the 'blueprint to achieve a better and more sustainable future for all'. SDG 3 is based around good health and well-being, focusing on a healthy lifestyle. The consumption of fruits that are artificially ripened using unauthorised chemicals seriously jeopardises this goal (**Figure 1**).

Figure 1. Artificially ripened bananas (top) versus naturally ripened bananas (bottom).
Credit: Joe_Potato, Getty Images

Try the activity to discuss the arguments for using ethylene to artificially ripen fruit following transport.

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Activity

- **IB learner profile attribute:** Principled
- **Approaches to learning:** Thinking skills — Evaluating and defending ethical positions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Group activity

Some fruits are harvested before ripening. Common examples include tomatoes and bananas. This ensures that the fruit can be stored and transported to distant places. Thereafter, the fruits are artificially ripened using ethylene. Thus, in one way, artificial ripening can be seen as beneficial as the shelf-life of the fruit is increased. However, this artificial ripening can happen using other chemicals including calcium carbide.

Read the articles given here (https://foodsafetyhelpline.com/artificial-ripening-fruits/) and here (https://www.thehindubusinessline.com/news/science/dangers-of-artificial-ripening-of-fruits-and-vegetables/article29431570.ece).

Form groups of four and discuss the following questions:

1. What are the benefits of artificial ripening?
2. What are the disadvantages of artificial ripening?
3. When does the process of artificial ripening become unethical?

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/tropisms-and-role-of-phytohormones-hl-id-46103/print/) Assign

Brainstorm on ways to arrive at a win—win situation for all the stakeholders: farmer, trader and consumer.

5 section questions

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Summary and key terms

- Cells, tissues, organs and organ systems integrate forming multicellular living organisms. This integration gives rise to emergent properties.
- Hormonal and nervous signalling help in the control and coordination in animal bodies. The electrical signals sent by the nervous system are quicker but short-lived, whereas the chemical signals sent by the endocrine system are slower but long-lived. In the nervous system, the brain integrates both conscious and unconscious processes while the spinal cord integrates only unconscious processes. The endocrine system is controlled by the hypothalamus and the pituitary.
- Learning and memory are two different functions of the brain. Learning results in plasticity of the brain.
- The circuit of sensory neurons, interneurons and motor neurons helps to convey messages from the receptors to the effectors. Nerves are bundles of neurons and could be myelinated or unmyelinated. Reflexes are spontaneous, involuntary responses. The pain reflex arc is the neuronal pathway triggered when pain receptors are stimulated.
- The cerebellum plays an important role in coordination of voluntary muscle movements, maintenance of balance and posture, and motor learning.
- The secretion of melatonin or the sleep hormone by the pineal gland in response to light establishes circadian rhythms. Melatonin secretion is inhibited by light. Epinephrine secreted by the adrenal glands prepares the body for

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potentially harmful situations. The signal for epinephrine secretion is sent from the hypothalamus.

- Sensory inputs from various mechanoreceptors like baroreceptors and chemoreceptors helps to regulate heart rate and ventilation rate.
- The enteric nervous system regulates the movement of food through the gastrointestinal tract as well as all physiological processes associated with digestion. Only swallowing and egestion of faeces is under the control of the CNS.

Higher level (HL)

- Tropic movements are directions, growth movements in plants. Two major categories include phototropism or growth towards/away from light and geotropism or movement towards/away from gravity.
- Phytohormones like auxins, gibberellins, cytokines, ABA and ethylene control growth, development and response to stimuli in plants. Auxin is responsible for growth associated with tropic movements while ethylene controls fruit ripening through positive feedback mechanisms. Auxin efflux carriers help in the directional transport of auxin.
- Interaction between cytokinin and auxin serves as a mechanism to regulate plant growth.

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Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Properties that arise in a system due to integration of subsystems are known as properties.
2. The endocrine system controls and coordinates the function of the body by secreting . The and the gland act as command centres of the endocrine system.
3. Learning causes neural networks in the brain to change and this is known as . Memory is the storage and retrieval of information. Riding a bike is an example of , whereas recalling capital cities would be an example of .
4. neurons carry information from receptors to the CNS while neurons carry information from the CNS to the effectors.
5. is released in response to darkness by the gland.
6. Slamming on the brakes in response to a moose crossing the road is due to the action of secreted by the glands.
7. Changes in the blood pressure are detected by whereas changes in the blood pH are detected by .
8. The nervous system is responsible for peristaltic movements of the gut.
9. [HL] The growth of the plant stem towards light is known as and is caused due to the secretion of from the shoot meristem.
10. [HL] A ripe mango is sweet unlike an unripe one which is sour due to the effects of .

phototropism | Sensory | pineal | epinephrine | hormones | motor | hypothalamus | explicit memory | pituitary | auxins | emergent | chemoreceptors | plasticity | Melatonin | adrenal | implicit memory | ethylene | baroreceptors | enteric

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/role-of-ethylene-hl-id-46104/print/) Assign

Check

Interactive 1. Understanding Neuroendocrine System Key Terms.

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Checklist

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What you should know

After studying this subtopic you should be able to:

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/checklist-id-46106/print/) Assign

- Describe the importance of integration of body systems.
- Explain the hierarchy of biological organisation.
- Compare the roles of the nervous system and endocrine system in signalling.
- Describe the roles of the brain and spinal cord in processing information.
- Compare the roles of sensory and motor neurons.
- Examine a transverse section of a myelinated nerve.
- Describe the structure of a pain reflex arc.
- Explain the role of the cerebellum in coordination and balance.
- Explain the impact of melatonin on circadian rhythms.
- Analyse the effects of epinephrine on the body.
- Describe the feedback mechanisms that regulate the functioning of the endocrine system.
- State the role of baroreceptors and chemoreceptors in the feedback control of the heart rate.
- Describe the role of chemoreceptors in controlling the rate of ventilation.
- Outline the mechanism for peristaltic control by the CNS and ENS.

Higher level (HL)

- Observe tropic responses in seedlings.
- Describe positive phototropism.
- Outline the functions of the different types of phytohormones.
- Explain the movement and concentration of auxins within plant cells.
- Describe the role of auxins in cell growth.
- Study the regulation of root and shoot growth by the interaction between cytokinins and auxins.
- Explain the positive feedback mechanism in the production of ethylene by ripening fruit.

Practical skills

Once you have completed this subtopic, go to Practical 8: Using seedlings to investigate tropic responses in plants (/study/app/bio/sid-422-cid-755105/book/using-seedlings-to-investigate-id-46707/).

C3. Interaction and interdependence: Organisms / C3.1 Integration of body systems

Investigation

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-id-46107/print/) Assign

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills – Combining different ideas in order to create new understandings
- **Tool 3:** Mathematics – Apply measures of dispersion: range, standard deviation (SD), standard error (SE), interquartile range (IQR), Apply the t-test, Construct and interpret tables, charts and graphs for raw and

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processed data including bar charts, histograms, scatter graphs, line and curve graphs, logarithmic graphs, pie charts, and box-and-whisker plot

- **Time required to complete activity:** 60–90 minutes
- **Activity type:** Individual activity

Your task

Analysing data

Vermifiltration is a wastewater treatment process using worms, resulting in nutrient-rich water. You can read more about the process here (https://www.vermifilter.com/why-vermifiltration).

Download the table using the button below. The data in this table show the growth of onion plants (*Allium cepa*) in water (control) and in vermifiltered water (experimental).

Data table (https://d3vrb2m3yrmyfi.cloudfront.net/media/edusys_2/content_uploads/Biology C3.1.26 Data Table.7e446e668116cbd6b648.pdf)

Analyse the data (across months)

1. Draw a bar graph to show the average (mean) growth of the control and experimental groups. Use the data for all four months.
2. Create a table like the sample shown in **Table 1** to calculate the standard deviation for each data set. The mean values for the control and the experimental groups are provided in the data table at the link above.

   For example, standard deviation of control, with mean = 0.93 (as given in **Table 1**).

Table 1. Sample data table.

Sample	Plant height (in feet)	Calculate the deviation of each data point from the mean	Square the value
1	0.9	0.9 − 0.93 = −0.03	0.0009
2	0.8		
3	1.0		
4	1.2		
5	1.1		
6	0.7		
7	0.9		
8	1.0		
9	0.8		

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Sample	Plant height (in feet)	Calculate the deviation of each data point from the mean	Square the value
10	0.9		
Mean	*0.93*		**Calculate the mean of the squared values**
			Find the square root of the mean variance

In a similar way calculate the standard deviation for the experimental data. Do this for all the data sets.

Higher level (HL)

3. Use the standard deviation to mark error bars on the graph.

Interpret the analysed data

1. For each data set, what is the relationship between the standard deviation, control mean and variable mean?
2. Identify any visible trends and arrive at a conclusion based on the data.

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46886/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43542/).

- What are the roles of nerves and hormones in integration of body systems?
- What are the roles of feedback mechanisms in regulation of body systems?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

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- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/more-on-auxins-and-cytokinins-hl-id-45755/print/) Assign

Rate subtopic C3.1 Integration of body systems

Help us improve the content and user experience.

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