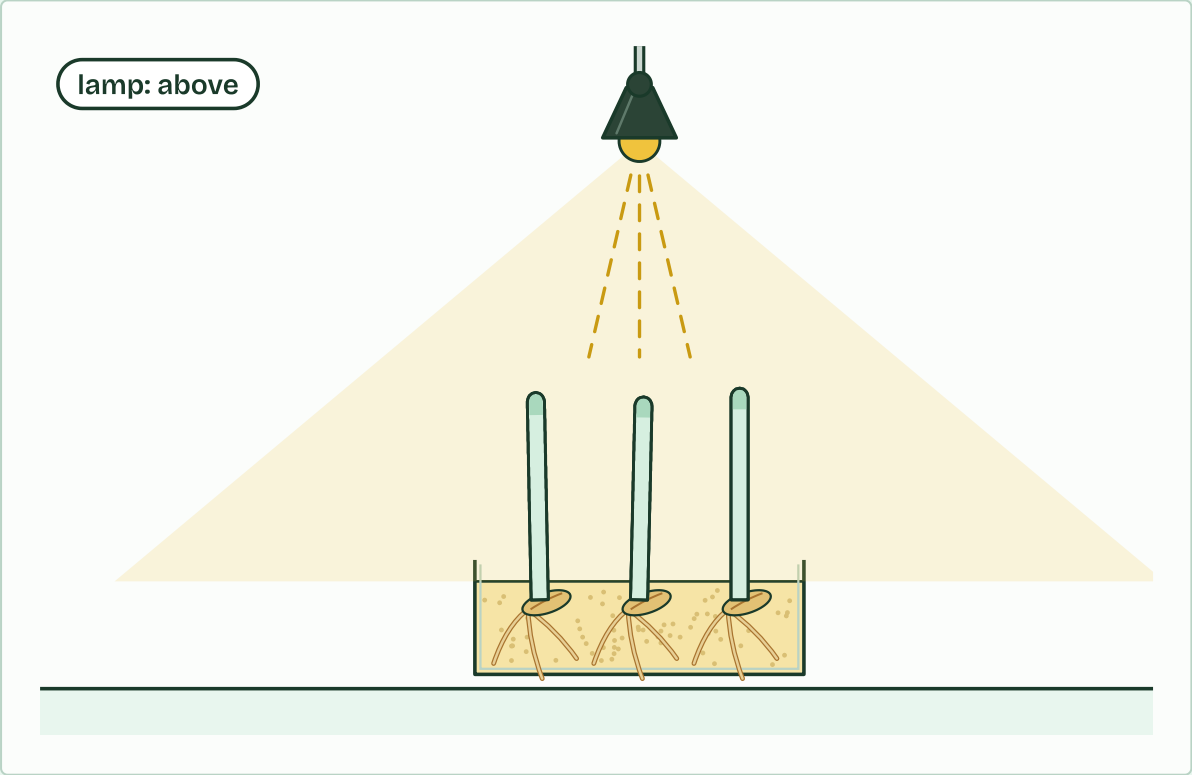
REVISION GUIDE

How a body and a plant *decide*

Integration of body systems

A hand pulls away from heat before you feel it, a hormone readies you to run, and loops hold your heart and breathing steady: nerves and hormones join a body into one animal. A plant has no nerves and no blood, yet its signals pass from cell to cell. The plant half comes first, at higher level; the body, at standard level, follows it.



21 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems

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By the end you can

- [ ] Record a tropism in seedlings with annotated drawings and by measuring the angle of curvature, and say what limits the precision and accuracy of the measurements C3.1.17
- [ ] Explain positive phototropism as growth towards light from one side C3.1.18
- [ ] Outline what phytohormones are, with examples of what several of them do C3.1.19
- [ ] Explain how auxin efflux carriers move auxin from cell to cell and concentrate it in one part of a plant C3.1.20
- [ ] Explain how auxin makes cells grow longer, and how a gradient of auxin makes a shoot bend C3.1.21
- [ ] Explain how auxin from shoot tips and cytokinin from root tips keep root and shoot growth in step C3.1.22
- [ ] Explain the positive feedback between ethylene and fruit ripening, and why it makes ripening fast and together C3.1.23
- [ ] Explain why the parts of an animal must work in a coordinated way, and give an example of an emergent property C3.1.1
- [ ] Place cells, tissues, organs and body systems in order, and explain how their integration gives a property none of them has alone C3.1.2
- [ ] Compare nervous and hormonal signalling, and say what the blood carries between organs C3.1.3
- [ ] Describe how the brain brings together several inputs, and its part in learning and memory C3.1.4
- [ ] Tell conscious from unconscious processes, and say what the spinal cord does for the unconscious ones C3.1.5
- [ ] Explain how sensory neurons bring messages from receptor cells to the spinal cord and the cerebral hemispheres C3.1.6
- [ ] Explain how motor neurons carry messages from the cerebral hemispheres to muscles, which contract C3.1.7
- [ ] Describe a nerve in section as a bundle of sensory and motor fibres, some myelinated, inside a protective sheath C3.1.8
- [ ] Trace a pain reflex arc through its receptor, sensory neuron, interneuron, motor neuron and muscle, and say why it is involuntary C3.1.9
- [ ] Explain how the cerebellum coordinates the timing of muscle contractions and keeps balance C3.1.10
- [ ] Explain how the pineal gland's melatonin, set by light and dark, helps set the cycle of sleeping and waking C3.1.11
- [ ] Explain how epinephrine from the adrenal glands prepares the body for vigorous activity C3.1.12
- [ ] Explain how the hypothalamus and pituitary gland control the other endocrine glands C3.1.13
- [ ] Explain how baroreceptors and chemoreceptors, the medulla and nerves control heart rate by negative feedback C3.1.14
- [ ] Explain how chemoreceptors and the brainstem control ventilation rate by negative feedback C3.1.15
- [ ] Explain which parts of swallowing, peristalsis and egestion are under the CNS and which under the enteric nervous system C3.1.16

Tick each one when you can do it without the book.

C3.1.17 HL OBSERVATIONS OF TROPIC RESPONSES IN SEEDLINGS

01 Watching seedlings *grow*

A plant cannot walk to the light, but it can grow towards it. A **tropism** is a growth response whose direction is set by where a stimulus comes from. Growth towards the stimulus is a **positive tropism**, and growth away from it is a **negative tropism**. Seedlings are good for studying one: they grow fast, and a young shoot lit from one side starts to turn within an hour. (Shoots and roots respond to gravity too, but light is the one you need here.)

There are two ways to record what happens. A drawing gives **qualitative** data: draw the same tray of seedlings at set times, say 0, 6 and 24 hours, with an arrow for the direction of the light, the shoots drawn to scale against a scale bar, and short notes on what you see, such as how many have bent and where along the shoot the bend is. A measurement gives **quantitative** data. Here it is the **angle of curvature**: the angle between the vertical, the way the shoot grew before, and the line its tip now points along. You can read it with a protractor held up to the seedling or, better, on a photograph.

Every measurement has limits. **Precision** is how finely you measure and how closely repeats agree. **Accuracy** is how close a measurement is to the true value. A shoot curves gradually rather than bending at a point, so where you draw the tip line is a judgement: two people, or one person twice, draw it slightly differently. That limits precision, and so does a protractor read only to the nearest 5 degrees.

A camera that is not square-on to the bend makes every angle look smaller or larger than it is. That is a **systematic error**, and it limits accuracy, however carefully you read the protractor. And the seedlings go on growing while you measure.

So take the photographs from the side, with the camera fixed square-on and a grid or ruler behind the tray. Draw the tip line the same way every time, say along the top 5 mm of the shoot. Measure every seedling, not just the neat ones. Use many seedlings and more than one tray, with a control tray lit evenly from above, and give the mean with its spread, such as a standard deviation. Many seedlings and repeat trays make the result more **reliable**.

KEY POINTS

- A tropism is growth whose direction is set by where a stimulus comes from: towards it is positive, away from it negative.
- An annotated drawing gives qualitative data; the angle of curvature, in degrees, gives quantitative data.
- Precision is how fine and repeatable a measurement is; accuracy is how close it is to the truth. A slanted camera is a systematic error: it spoils accuracy, however precise the reading.

KEY TERMS

tropism
A growth response whose direction is set by the direction a stimulus comes from, such as light from one side.

positive tropism
Growth towards the stimulus: a shoot growing towards light from one side, for example.

negative tropism
Growth away from the stimulus.

qualitative
Observations that describe, in words or pictures, without measuring: the shape of a shoot, its colour, which way it bends.

quantitative
Observations recorded as numbers, measured with an instrument and given a unit: an angle in degrees, a length in millimetres.

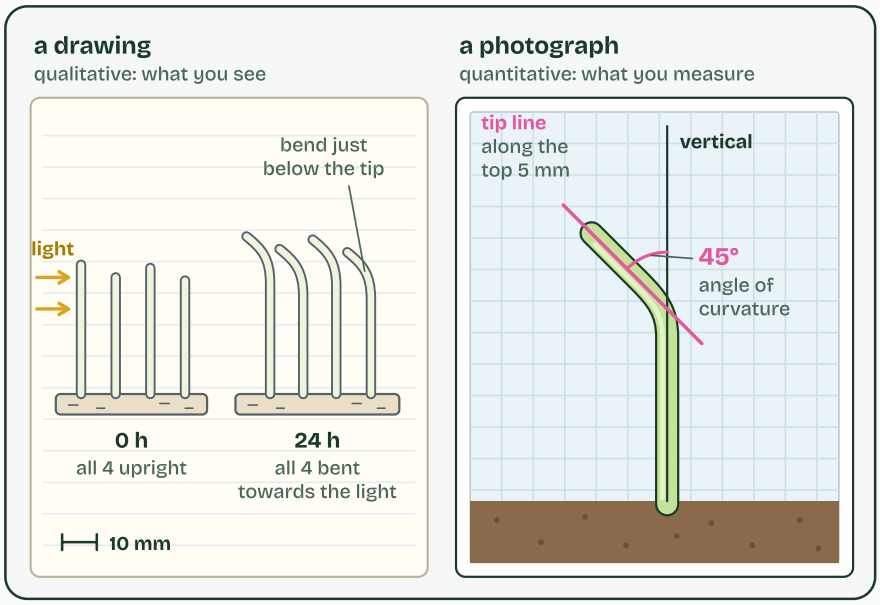
angle of curvature
The angle between the vertical, the way the shoot grew before, and the line the tip of the shoot now points along.

precision
How finely a measurement is made, and how closely repeated measurements agree with each other.

accuracy
How close a measurement is to the true value.

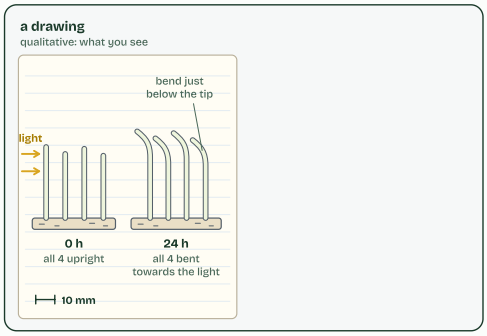
systematic error
An error that shifts every reading the same way, such as a camera at a slant. Repeating the measurement does not remove it.

reliable
How far a result can be trusted to come out the same when the experiment is repeated.



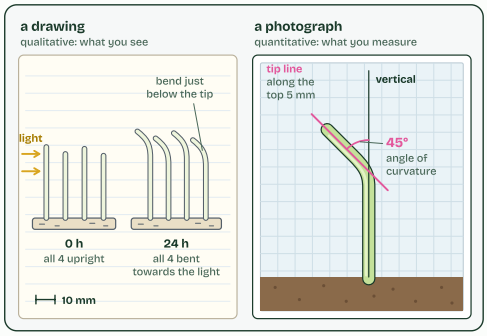
STEP BY STEP 2 STEPS

1



A **drawing** of tray A at 0 and 24 hours, lit from the left: the light's direction, a scale bar and notes on what you see. Qualitative data.

2



A side-on **photograph** of one seedling at 24 hours: a vertical line, a line along the top 5 mm of the shoot, and the angle between them, measured with a protractor. Quantitative data.

PREDICT

Two students measure the same seedling's angle of curvature. One photographs it square-on from the side; the other from above and to one side. Whose angle is more accurate?

(A) Both the same, because both of them read it with the same protractor

(B) The slanted one, because more of the seedling is in view from above

(C) The square-on one, as at a slant a bend looks smaller or larger

(D) Whoever reads to half a degree, as a finer scale is more accurate

Decide before you look. Answer on page 78.

WATCH OUT

"Precise means accurate." A protractor read to half a degree on a photograph taken at a slant gives a precise reading, and a wrong one. Make the readings accurate by removing the systematic error (put the camera square-on), and precise by measuring finely and repeating.

C3.1.18 HL POSITIVE PHOTOTROPISM AS A DIRECTIONAL GROWTH RESPONSE TO LATERAL LIGHT IN PLANT SHOOTS

02 Growing *towards* the light

Grow a seedling on a windowsill and it leans towards the window. That is **positive phototropism**: a shoot lit from one side grows towards the light. It is growth, not movement. Cells on the shaded side of the shoot grow longer than cells on the lit side, so the shaded side grows more and the shoot curves towards the light. The lit side still grows, just more slowly. Turned to the light, the leaves catch more of it for photosynthesis.

The classic experiments were done on grass seedlings, whose young shoot grows up inside a pointed sheath called the **coleoptile**. The bending happens in the growing region just below the tip.

In a grass seedling the tip senses the light, with light-absorbing proteins called phototropins, which respond to blue light. As the bend is lower down, something must pass from the tip to the growing region: a chemical signal, auxin (chapters 3 to 5). Not every shoot senses light at its tip: seedlings of thale cress, the small plant most used in plant research, sense it a little lower, in the upper part of the stem.

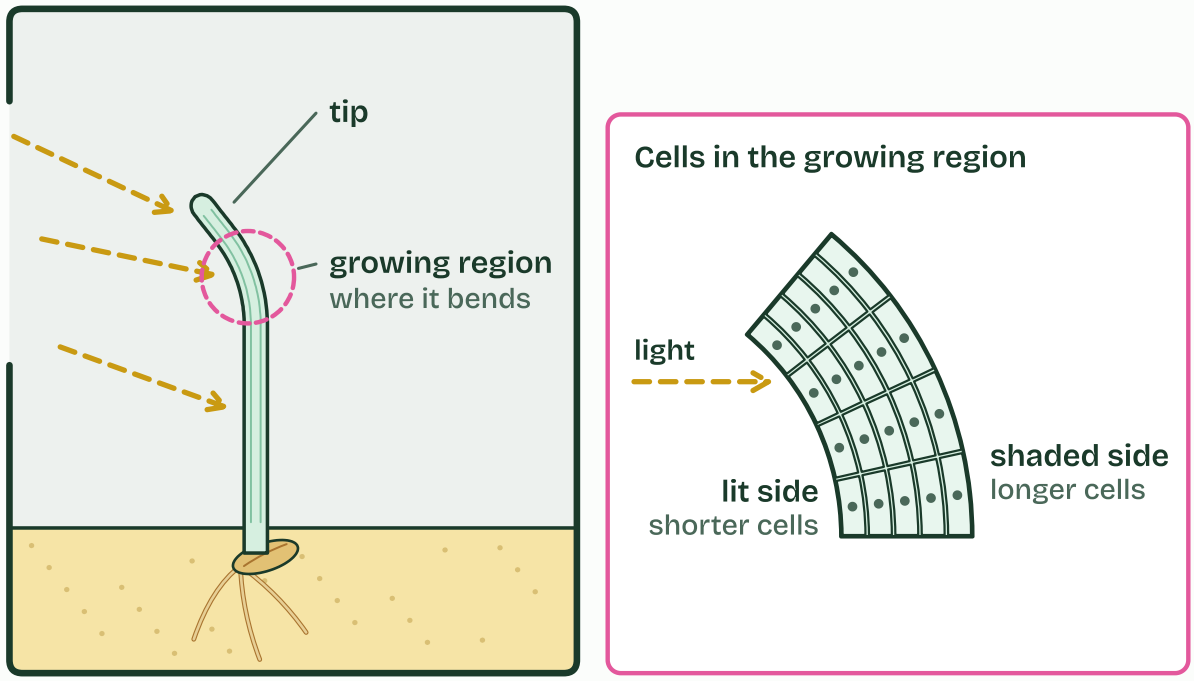
KEY POINTS

- Positive phototropism: a shoot lit from one side grows towards the light, because cells on its shaded side grow longer than those on its lit side.
- In a grass seedling the tip senses the light; the bend happens in the growing region just below it.
- A cap on the tip stops the bend; a collar below the tip does not; a seedling without its tip neither bends nor grows much in the first few hours.

KEY TERMS

positive phototropism
Growth of a shoot towards light that comes from one side: a positive tropism.

coleoptile
The pointed sheath that covers the young shoot of a grass seedling as it grows up through the soil.

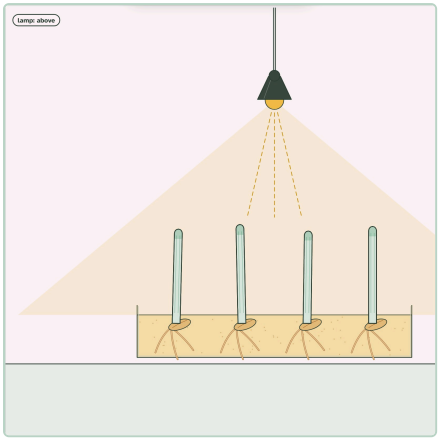


The growing region just below the tip bends. Cells on the shaded side grow longer than those on the lit side, so the shoot curves towards the light. The difference in cell length is exaggerated.

ANIMATION · A SEEDLING FINDS THE LIGHT

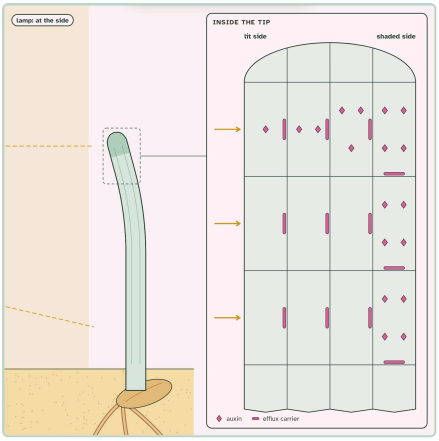
4 MOMENTS

1 1 H 05 MIN



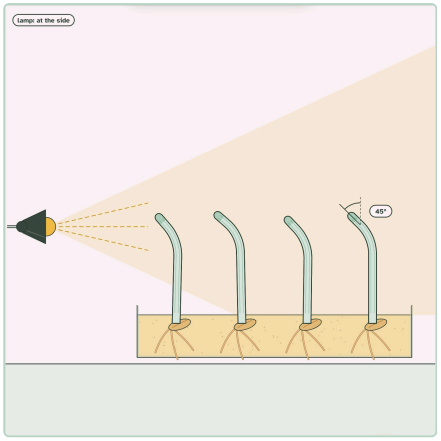
Oat seedlings lit from **above** grow straight up. The clock counts the hours.

2 2 H 55 MIN



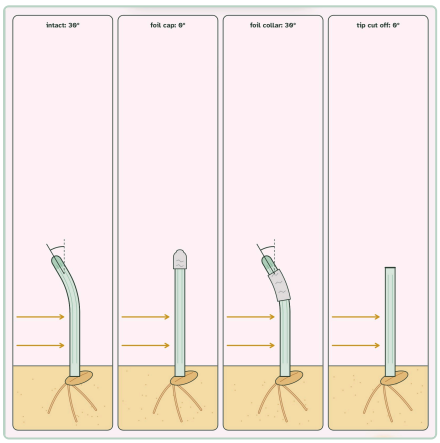
Lit from one side, cells in the tip move their **auxin efflux carriers** to the shaded side: auxin flows there, then down.

3 7 H 35 MIN



The shaded side grew more, so each shoot curves towards the light: **positive phototropism**.

4 AFTER 2 H



After 2 hours lit from the side: shoots with intact tips or foil collars bend towards the light; capped and cut ones stay straight, and cut ones barely grow.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#phototropism

PREDICT

The tip of a grass seedling is covered with a foil cap, and the seedling is lit from one side. What happens?

(A) It bends further, because the foil reflects extra light onto it

(B) It grows straight up: the part that senses light is in the dark

(C) It bends away from the light, towards the darker side of the box

(D) It stops growing, because the foil cuts off the tip's oxygen

Decide before you look. Answer on page 78.

HOW WE KNOW (BEYOND THE GUIDE)

The evidence came from grass seedlings lit from one side. In 1880 Charles Darwin and his son Francis reported that canary grass seedlings with their tips under caps that let no light through did not bend, while seedlings under caps of clear glass still bent towards the light. Later work showed that a seedling with its tip cut off neither bends nor grows much in the first few hours after the cut, and that the signal from the tip is a chemical. In 1926 Frits Went stood cut tips on small blocks of agar, then put a block on one side of a cut stump: that side grew faster, and the stump bent away from the block, even in the dark.

WATCH OUT

"The light pulls the shoot round." Nothing pulls: the shaded side grows more, so the shoot grows round. And "the lit side shrinks." It grows too, just less than the shaded side.

TRY IT

The site's cress maze is a practical you can run at home or in class: cress seedlings in a box find their way round its walls to the only gap that lets light in. The maze page says the tip senses the light; in cress, read that as the upper stem, as above.

C3.1.19 HL PHYTOHORMONES AS SIGNALLING CHEMICALS CONTROLLING GROWTH, DEVELOPMENT AND RESPONSE TO STIMULI IN PLANTS

03 Plant *hormones*

A plant has no nerves, no glands and no blood, yet its parts work together. They do it with **phytohormones**: signalling chemicals, made in small amounts, that control how a plant grows and develops and how it responds to what happens around it. A phytohormone is made by ordinary tissues, not in a gland, and no heart pumps it round. It moves from cell to cell, in the sap of the xylem or the phloem, or, for one of them, as a gas through the air spaces and out into the air.

Plants use a variety of chemicals as phytohormones. Five groups are the best known:

Auxin makes cells in shoots grow longer, steers tropisms, holds back the side buds below a shoot tip and helps new roots form.
Cytokinins make cells divide, help shoots and side buds grow and slow the ageing of leaves.
Gibberellins make stems grow longer and set seeds germinating.
Abscisic acid closes the stomata when water is short, and keeps seeds dormant.
Ethylene makes fruit ripen, and leaves and fruit fall.

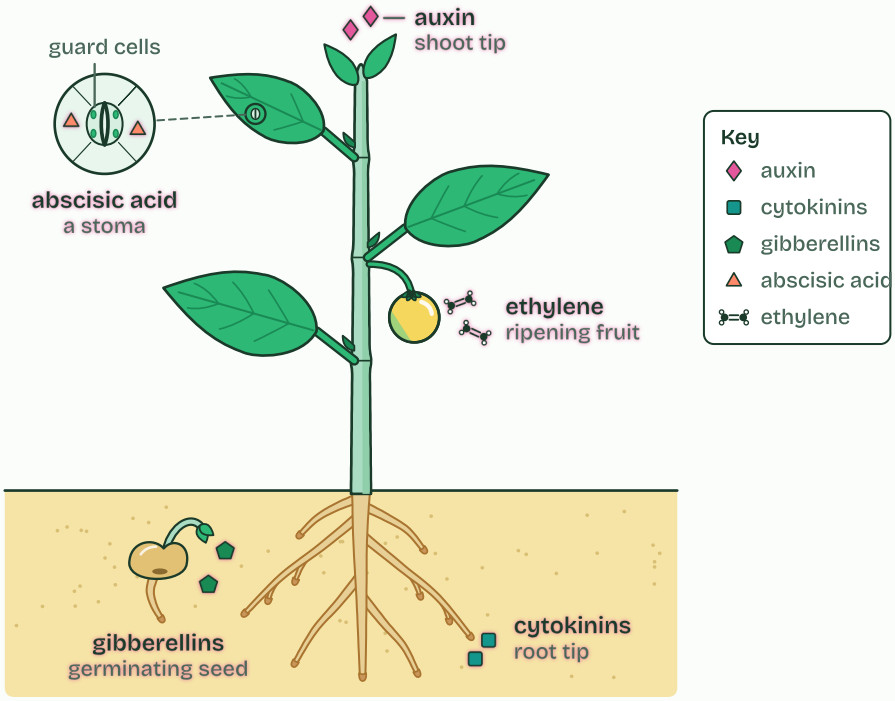
There are others, such as brassinosteroids and jasmonates (beyond the guide). Several often act on the same tissue at once, and what the tissue does depends on the balance between them (chapter 6). Seed germination is in D3.1.

KEY POINTS

- Phytohormones are signalling chemicals made in small amounts that control growth, development and responses to stimuli.
- With no blood, they move from cell to cell, in the xylem or phloem sap, or as a gas.
- Auxin, cytokinins, gibberellins, abscisic acid and ethylene each have several roles, and often act together.

KEY TERMS

phytohormones
Signalling chemicals that plants make in small amounts to control their growth, their development and their responses to stimuli. Also called plant hormones.



Five phytohormones and where each works in a plant. Each is drawn as a small shape: the key shows which is which.

Auxin Made in the shoot tip and young leaves. It makes cells in the shoot grow longer, steers tropisms, holds back the side buds below the tip and helps new roots form.

Ethylene A gas, given off by ripening fruit and spreading into the air. It makes fruit ripen, and leaves and fruit fall.

Cytokinins Made mainly in root tips and carried up in the xylem sap. They make cells divide, help shoots and side buds grow and slow the ageing of leaves.

Abscisic acid Made when a plant is short of water. It makes the guard cells close the stomata, and it keeps seeds dormant.

Gibberellins In a seed, they set germination going; in a shoot, they make the stem grow longer.

Auxin Made in the shoot tip and young leaves. It makes cells in the shoot grow longer, steers tropisms, holds back the side buds below the tip and helps new roots form.

Ethylene A gas, given off by ripening fruit and spreading into the air. It makes fruit ripen, and leaves and fruit fall.

Cytokinins Made mainly in root tips and carried up in the xylem sap. They make cells divide, help shoots and side buds grow and slow the ageing of leaves.

REMEMBER IT

The five best-known phytohormones

A	C	G	A	E
A	Cheeky	Gardener	Always	Experiments
Auxin	**Cytokinins**	**Gibberellins**	**Abscisic acid**	**Ethylene**
shoot cells grow longer	cells divide	stems grow, seeds germinate	stomata close	fruit ripen

WATCH OUT

"Plant hormones travel in the blood." Plants have no blood: their hormones move from cell to cell, in the sap, or as a gas. "Abscisic acid makes leaves fall." Its name is left over from when people thought it did; its main jobs are closing stomata and keeping seeds dormant, and it is ethylene that makes leaves fall. And ethylene is a phytohormone, not a phytochrome: a phytochrome is a protein that detects light.

GUIDING QUESTION

What are the roles of nerves and hormones in integration of body systems? A plant has no nerves, so its parts are coordinated mainly by hormones, moved through its tissues.

PREDICT

Abscisic acid is sprayed on the leaves of a well-watered plant in bright light. What happens to its rate of photosynthesis over the next hour?

(A) It rises, because abscisic acid opens its stomata wider in bright light

(B) It stays the same, because the plant already has all the water it needs

(C) It stops at once, because abscisic acid breaks down its chlorophyll

(D) It falls, because its stomata close and less carbon dioxide gets in

Decide before you look. Answer on page 78.

C3.1.20 HL AUXIN EFFLUX CARRIERS AS AN EXAMPLE OF MAINTAINING CONCENTRATION GRADIENTS OF PHYTOHORMONES

04 Moving auxin *one way*

Auxin gets into a plant cell easily, but it cannot get out on its own. The reason is chemistry. Auxin (its chemical name is indole-3-acetic acid) is a weak acid. In the cell wall, which is acidic, part of it carries no charge, and a small molecule with no charge can diffuse through the cell membrane. The cytoplasm inside is less acidic, so there almost every auxin molecule loses a hydrogen ion and becomes a negative ion. A charged ion cannot diffuse through the membrane, so the auxin is trapped.

To leave, auxin needs **auxin efflux carriers**, proteins in the membrane (called PIN proteins) that move it out of the cell. A cell can place its carriers on one side only. Then auxin leaves through that side into the **apoplast**, the cell walls and spaces between the cells, and the next cell along takes it in. If all the cells of a tissue place their carriers on the same side, auxin is passed from cell to cell in one direction, and builds up in one part of the plant: a **concentration gradient** that the cells keep up.

The cells spend energy on this. Proton pumps in their membranes use ATP to keep the walls acidic (chapter 5), and that is what lets auxin in and keeps it moving. So the movement counts as **active transport**, and it can build auxin up where there is already more of it.

In phototropism, light from one side makes cells near the tip move their carriers to the sides facing away from the light, so auxin flows across to the shaded side, then down that side. Chapter 5 shows what it does when it gets there.

KEY POINTS

- Auxin diffuses into cells, but inside it becomes a negative ion that cannot diffuse back out: it is trapped.
- Auxin efflux carriers move it out, through whichever side of the cell they are placed on.
- When every cell in a tissue has its carriers on the same side, auxin is actively transported one way, cell to cell, and becomes concentrated in one part of the plant.

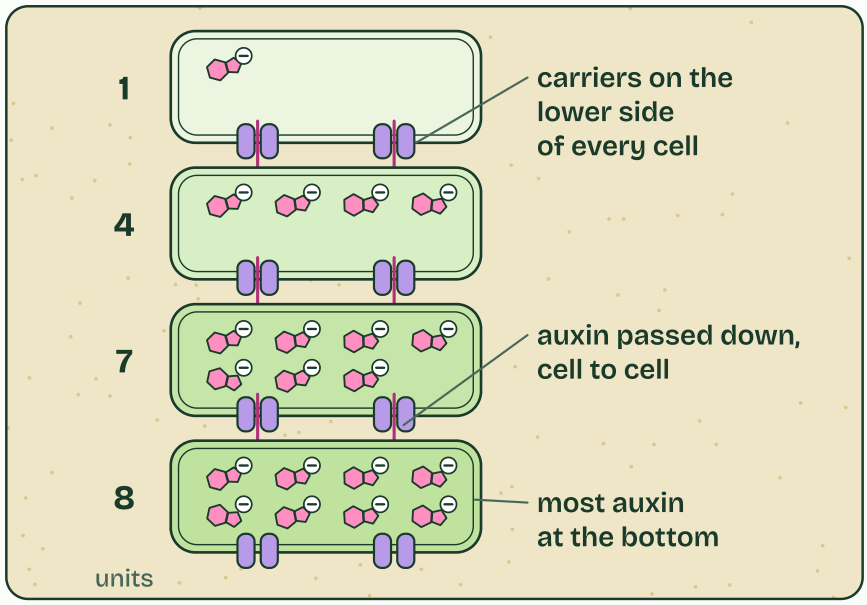
KEY TERMS

auxin efflux carriers
Proteins in a plant cell's membrane that move auxin out of the cell. A cell can place them on one side only, so auxin leaves through that side.

apoplast
The cell walls and the spaces between plant cells: everything outside the cells' membranes.

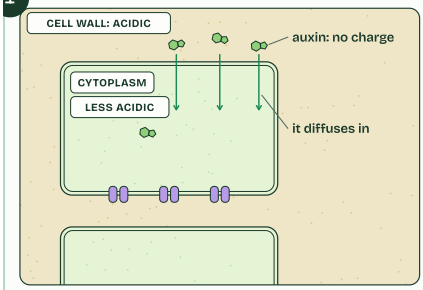
concentration gradient
A difference in concentration between two places, such as more auxin at one end of a tissue than at the other.

active transport
Moving a substance across membranes using energy from ATP. It can move a substance towards where it is already more concentrated.



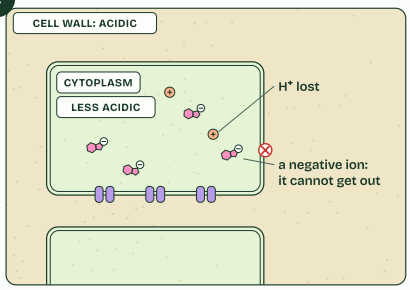
STEP BY STEP 4 STEPS

1



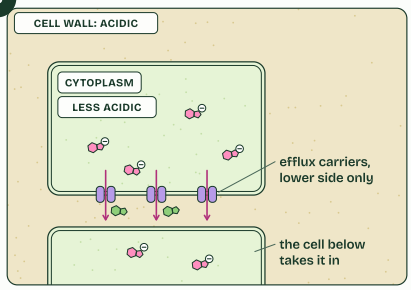
In the acidic cell wall, part of the auxin carries **no charge**, so it diffuses through the membrane into the cell.

2



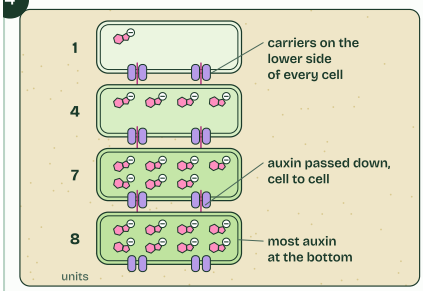
The cytoplasm is less acidic. There almost every auxin molecule loses a hydrogen ion and becomes a **negative ion**, which cannot diffuse back out through the membrane: it is trapped.

3



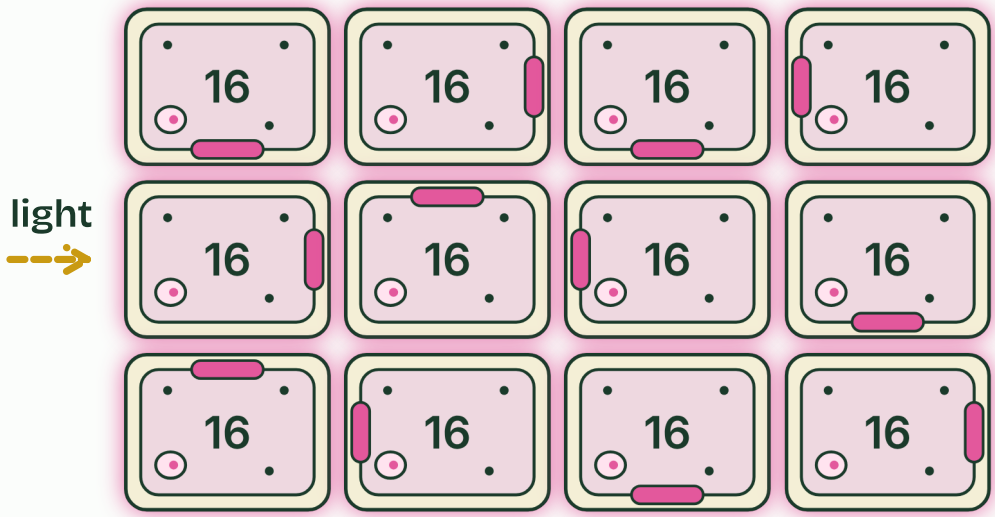
Efflux carriers on the cell's lower side move it out, into the wall below, and the cell below takes it in.

4



Every cell has its carriers on its lower side, so auxin is passed **down**, cell to cell. Each started with 8 units and has passed half of what it holds down three times: most is now at the bottom.

Point the pumps



WATCH OUT

"Auxin is pumped into cells." It need not be: with no charge, it diffuses in from the acidic wall. The carriers move it out, and where they sit decides which way it goes.

PREDICT

In a row of five cells, every cell has its auxin efflux carriers on its left side, but the middle cell's carriers are blocked by a chemical. Auxin is added to the right-hand cell. Where does it build up?

(A) In the left-hand cell, because each cell in turn passes it to the left

(B) Evenly along the whole row, as it diffuses freely from cell to cell

(C) In the middle cell, which takes the auxin in but cannot pass it on

(D) In the right-hand cell, because auxin cannot leave the cell it enters

Decide before you look. Answer on page 78.

05 C3.1.21 HL PROMOTION OF CELL GROWTH BY AUXIN

How auxin *stretches* a cell

A young plant cell grows mostly by getting longer. Water enters its vacuole by osmosis and pushes out on the cell wall, but the wall holds it in. The wall is built of long fibres of cellulose wrapped round the cell, held to each other by **cross-links**. To grow, the cell has to loosen its wall.

Auxin does this in a chain of steps. It makes the cell pump hydrogen ions out of its cytoplasm into the apoplast, through **proton pumps** in the plasma membrane, which use ATP. The wall becomes more acidic: its pH falls by as much as one unit, from about 6 to about 5.

In acid, proteins in the wall called expansins loosen the cross-links between the cellulose molecules, so the fibres can slide apart. Water still enters by osmosis, and the pressure inside now stretches the loosened wall: the cell grows longer, and adds new wall material as it does. That is **cell elongation**.

Now put this in a shoot lit from one side. Auxin has been moved to the shaded side (chapter 4), so the cells there pump out more hydrogen ions, their walls loosen more, and they grow longer than the cells on the lit side. The shaded side grows faster, so the shoot curves towards the light. A concentration gradient of auxin across the shoot makes the difference in growth rate that phototropism needs.

KEY POINTS

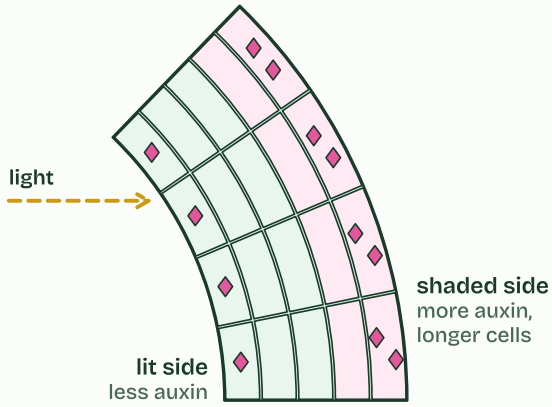
- Auxin makes the cell pump hydrogen ions into its wall, using ATP, so the wall becomes more acidic.
- In acid, the cross-links between cellulose fibres loosen, and water entering by osmosis stretches the wall: the cell elongates.
- More auxin on the shaded side makes cells there grow longer, so the shoot bends towards the light.

KEY TERMS

cross-links
Links between the cellulose fibres of a plant cell wall, made by other carbohydrates bonded to them. Loosening them lets the wall stretch.

proton pumps
Proteins in the plasma membrane that use energy from ATP to pump hydrogen ions (protons) out of the cell.

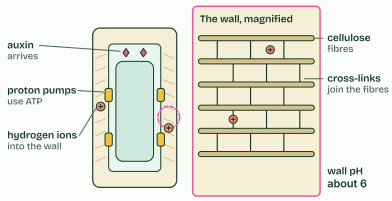
cell elongation
Growth of a plant cell by getting longer, as its loosened wall is stretched by the pressure of the water inside.



STEP BY STEP

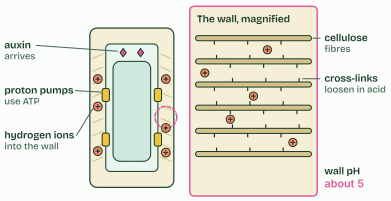
4 STEPS

1



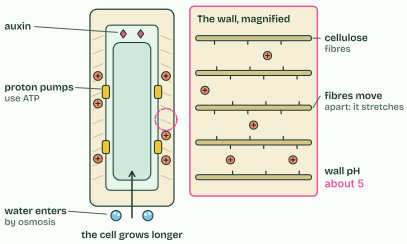
Auxin arrives. **Proton pumps** in the membrane use ATP to pump hydrogen ions out of the cell, into its wall.

2



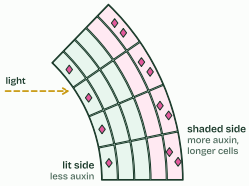
The wall becomes **more acidic**, its pH falling from about 6 to about 5. In acid, the **cross-links** between the cellulose fibres loosen.

3



Water enters by osmosis and pushes on the loosened wall, which stretches: the cell **grows longer**.

4



In a shoot lit from one side, the **shaded side** has more auxin, so its cells grow longer, and the shoot curves towards the light.

PREDICT

Short pieces of shoot, with their tips cut off, are floated in an acidic buffer instead of an auxin solution. What happens?

(A) They grow longer, as if given auxin: the acid loosens the walls

(B) Nothing, because only auxin can switch growth on in a plant cell

(C) They shrink, because the acid kills the cells and they lose water

(D) They bend towards the light, because acid acts like extra auxin

Decide before you look. Answer on page 78.

WATCH OUT

"The acid dissolves the wall." It loosens the links between the cellulose fibres, so they can slide apart. The cellulose stays, and the cell adds more wall as it grows.

C3.1.22 HL INTERACTIONS BETWEEN AUXIN AND CYTOKININ AS A MEANS OF REGULATING ROOT AND SHOOT GROWTH

06 Roots and shoots *in step*

A plant needs its roots and shoots in proportion. The roots take up water and mineral ions for the whole plant, and the leaves make sugar for the whole plant. A big shoot on a small root system would run short of water, and a big root system under a small shoot would run short of sugar. Two hormones, travelling in opposite directions, keep the two in step.

Shoot tips and young leaves make auxin, which is moved down the stem to the roots, mostly from cell to cell by the efflux carriers of chapter 4 (some also travels, faster, in the phloem sap). Root tips make **cytokinin**, which travels up to the shoots in the xylem sap, with the water (B3.2).

Each acts where it arrives. Auxin from the shoot helps new side roots form, so the root system branches and spreads. Cytokinin from the roots makes cells in the shoot divide, and side buds grow into new shoots. So a big, healthy shoot sends more auxin down, and the root system grows; a big root system sends more cytokinin up, and the shoot grows. The growth of each depends on signals from the other, so root and shoot growth are integrated.

The balance between them matters too, and this part goes beyond the guide. At a shoot tip, the auxin moving down the stem holds back the side buds just below it, so the main shoot grows up rather than out: **apical dominance**. Cytokinin pushes the same buds to grow.

Cut off the tip, and with its auxin gone the buds grow out into side shoots: the plant branches. In plant tissue culture, a clump of cells given more auxin than cytokinin grows roots, and given more cytokinin than auxin it grows shoots.

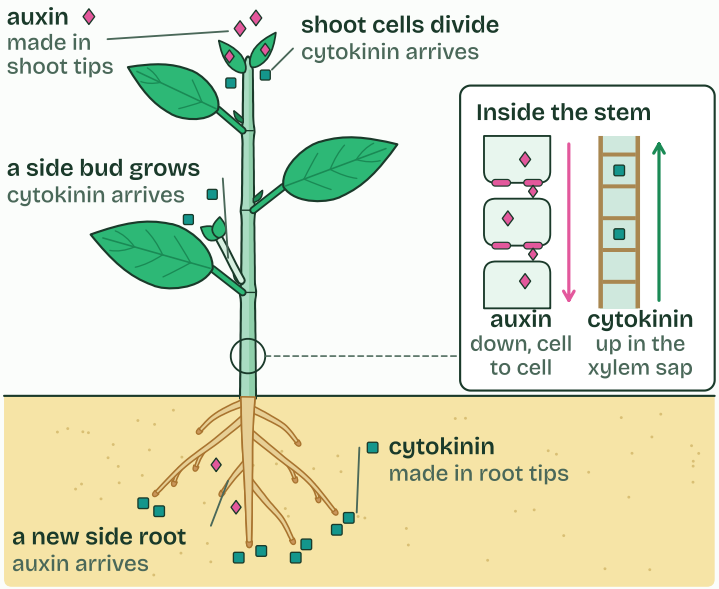
KEY POINTS

- Shoot tips make auxin, which is moved down to the roots; root tips make cytokinin, which travels up to the shoots in the xylem sap.
- Auxin from the shoot helps roots grow and branch; cytokinin from the roots makes shoot cells divide and side buds grow.
- The balance matters: auxin from the tip holds back the side buds and cytokinin pushes them.

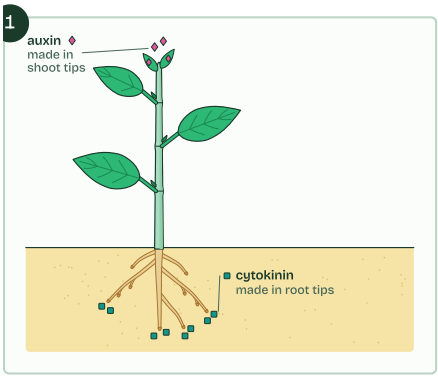
KEY TERMS

cytokinin
A phytohormone that makes plant cells divide. Made mainly in root tips, it travels up to the shoots in the xylem sap.

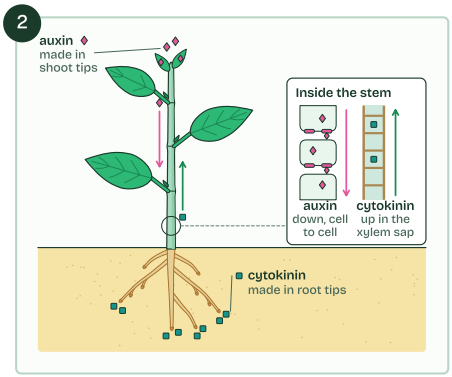
apical dominance
The main shoot tip holding back the growth of the side buds below it, by the auxin it sends down the stem.



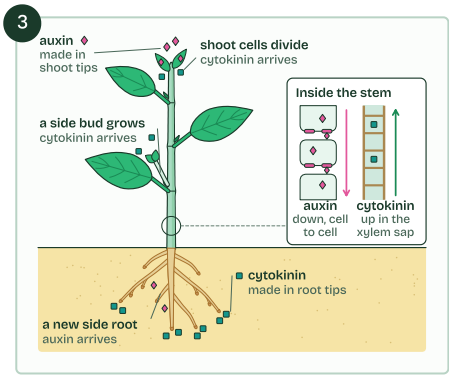
STEP BY STEP 3 STEPS



Where each is made: **auxin** in the shoot tip and young leaves, **cytokinin** in the root tips.



Auxin is passed **down** the stem from cell to cell, by its efflux carriers; cytokinin travels **up** in the xylem sap, with the water.



Where auxin arrives, **new side roots** form. Where cytokinin arrives, **side buds** grow into shoots and cells at the shoot tip **divide**.

PREDICT

A gardener pinches out the growing tip of a basil plant. What happens over the next two weeks?

(A) It stops growing until a new tip forms where the old one was

(B) Its roots grow faster, as more of its auxin now reaches them

(C) It wilts, because its tip was making the cytokinin it needs

(D) Side buds lower down grow into new shoots: it gets bushier

Decide before you look. Answer on page 78.

WATCH OUT

"Auxin stops shoots growing." Auxin makes shoot cells grow longer (chapter 5). What it holds back is the side buds below the tip.

LINKING QUESTION

What are examples of branching (dendritic) and net-like (reticulate) patterns of organization? A shoot that loses its tip branches as its side buds grow out, and a root branches into side roots. The veins of a broad leaf join up into a net.

07 One *ripe* banana

C3.1.23 HL POSITIVE FEEDBACK IN FRUIT RIPENING AND ETHYLENE PRODUCTION

Ethylene is a phytohormone that is a gas: a small molecule, C_2H_4, whose chemical name is ethene. Ripening fruit make it. It spreads through the air spaces inside a fruit and out into the air around it, so it reaches the fruit's neighbours too.

Ethylene sets off **ripening**. The green chlorophyll is broken down, so yellow or red pigments show through or are made. Starch is turned into sugars, so the fruit gets sweeter. Enzymes break down the substances that hold the cell walls together, so it softens. And it gives off a scent. A ripe fruit draws animals that eat it and carry its seeds away (D3.1).

Then comes the loop. Ethylene stimulates ripening, and ripening stimulates the fruit to make more ethylene. More ethylene speeds up the ripening, which makes still more ethylene. A loop like this, where a change causes more of the same change, is **positive feedback**. The gas reaches the fruit nearby too: they start to ripen, and make ethylene of their own.

The benefit is speed and timing. Once ripening starts, the loop drives it on fast, and the fruits on a plant ripen together, synchronized, so animals come when the fruit is ready and the seeds inside are mature. The consequence is that one ripe fruit sets off the rest: a ripe banana in a bag of green fruit hurries them all, and one rotting apple can spoil a barrel, as its ethylene ripens the apples round it too far. Positive feedback runs until something ends it; here, the fruit is fully ripe.

Most feedback loops in living things are the other kind. **Negative feedback** pulls a value back towards a set point, as you will see in the human body. Positive feedback pushes it further from where it started.

Beyond the guide: not every fruit does this. Bananas, tomatoes, avocados and pears make a burst of ethylene as they ripen, and can be picked mature but unripe and ripened later. Grapes, citrus fruits and strawberries make no such burst, and do not ripen further once they are picked.

KEY POINTS

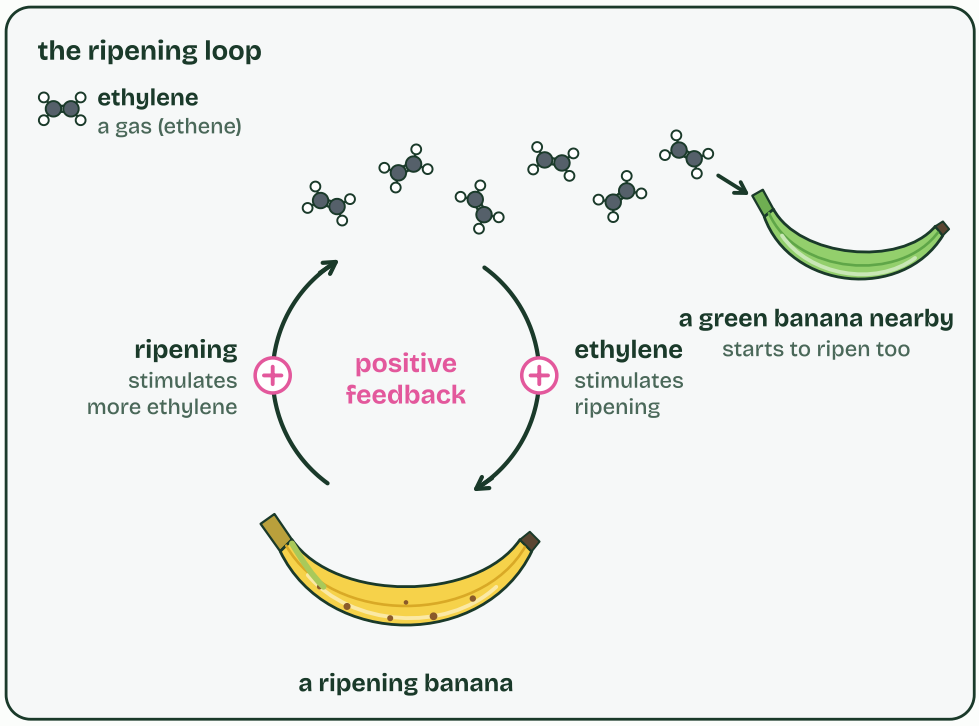
- Ethylene (ethene) is a gas that stimulates ripening: colour change, sugars from starch, softening and scent.
- Ripening stimulates more ethylene production: positive feedback, so ripening speeds up and spreads to nearby fruit.
- The benefit: fruit ripen fast and together, ready for the animals that spread their seeds.

KEY TERMS

ripening
The changes that make a fruit ready to eat: its colour, sweetness, softness and scent.

positive feedback
A loop in which a change sets off a response that pushes the change further, so it speeds up until something stops it.

negative feedback
A loop in which a change sets off a response that reverses it, bringing a value back towards its set point.

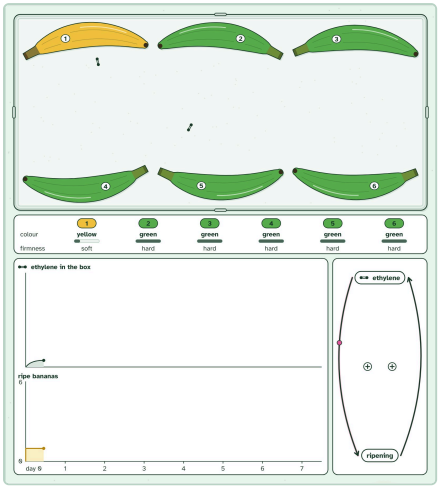


The ripening loop. Ethylene stimulates ripening, and ripening stimulates more ethylene, so each round pushes ripening further: positive feedback. The gas also reaches the fruit nearby.

ANIMATION · ONE RIPE BANANA

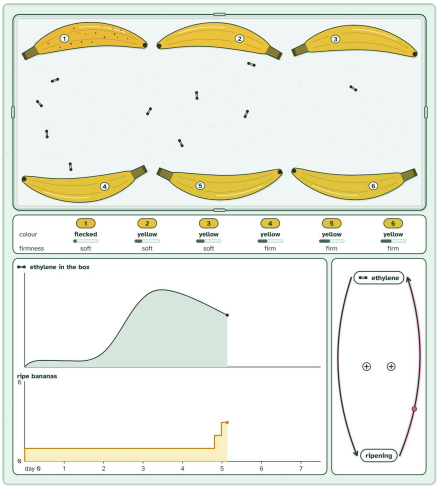
4 MOMENTS

1 DAY 0 · 1 OF 6 RIPE



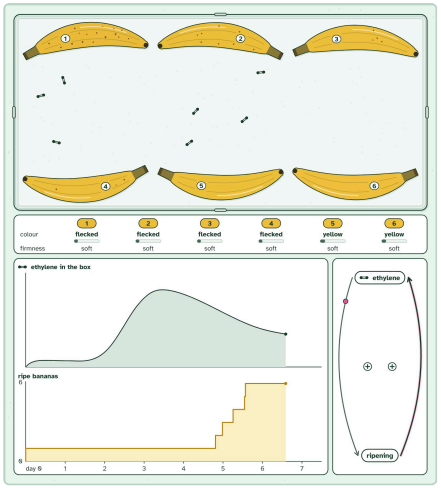
The ripe banana gives off **ethylene**, a gas that spreads through the air in the box.

2 DAY 5 · 3 OF 6 RIPE



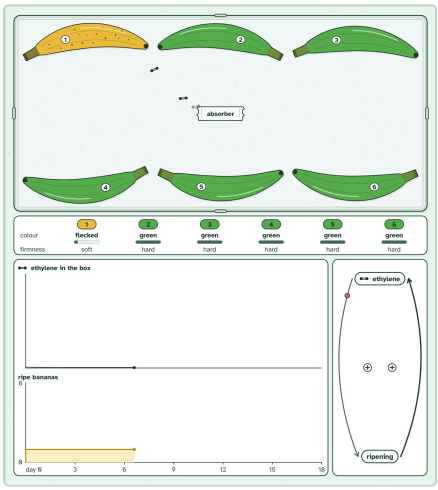
One ripening banana sets off the next, so the whole box ripens **fast and together**.

3 DAY 6 · 6 OF 6 RIPE



All six are ripe. The loop runs out: ripe fruit give off less ethylene, and the gas falls.

4 DAY 6 · 1 OF 6 RIPE



The same day with an ethylene absorber in the box: the five green bananas have not yet started to ripen.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#ripening

PREDICT

A box of green bananas is stored with a sachet that absorbs ethylene from the air. What happens?

(A) They ripen faster, because the sachet takes away a gas that ages fruit

(B) They ripen later and less together, as the gas is taken up first

(C) Nothing changes, because each banana ripens on a clock of its own

(D) They ripen on time but stay green, as their colour needs the gas

Decide before you look. Answer on page 79.

WATCH OUT

"Positive feedback means good feedback." Positive means the response pushes the change further, whether that helps or harms. Ripening helps the plant; one rotting apple in a barrel does not help the grocer.

LINKING QUESTION

What are the consequences of positive feedback in biological systems? A change that feeds itself speeds up and spreads until something stops it: one ripe fruit ripens the bowl. And the guiding question, What are the roles of feedback mechanisms in regulation of body systems? Here positive feedback makes ripening fast and synchronized.

C3.1.1 C3.1.2 SYSTEM INTEGRATION CELLS, TISSUES, ORGANS AND BODY SYSTEMS AS A HIERARCHY OF SUBSYSTEMS THAT ARE INTEGRATED IN A MULTICELLULAR LIVING ORGANISM

08 Many parts, *one* animal

Lift your arm. Thousands of muscle fibres in your shoulder contract at the same moment, and the ones on the other side of the joint relax. None of them decided to: something told them all, at once. Getting the parts of a body to act together like this is **integration**, and every living system needs it.

An animal is built in levels. A fertilised egg divides into many cells, which become different types (a muscle fibre, a neuron, a red blood cell, a gland cell) by using different genes, not by having different genes (B2.3). Similar cells working together make a **tissue**; several tissues make an **organ**; organs that work together make an organ system, or **body system**; and the systems, integrated, make the organism. Each level is a subsystem of the one above it.

A property of the whole that none of its parts has is an **emergent property**. The cheetah is the IB's example. Its long legs, flexible spine, grippy claws, large heart and lungs and wide nostrils are its parts: adaptations, each useful. Its sprint, faster than any other land animal, is what emerges when they are integrated, and it makes the cheetah an effective predator. Its speed belongs to no single organ.

Two systems do most of the integrating, and they fill the rest of this guide: the **nervous system** and the **endocrine system**. A third, the blood system, carries materials and heat between the organs (chapter 9).

KEY POINTS

- Integration coordinates the parts of a system so they perform an overall function together.
- Cells make tissues, tissues make organs, organs make body systems, and the systems make the organism.
- An emergent property belongs to the whole and to none of its parts: a cheetah's sprint.

KEY TERMS

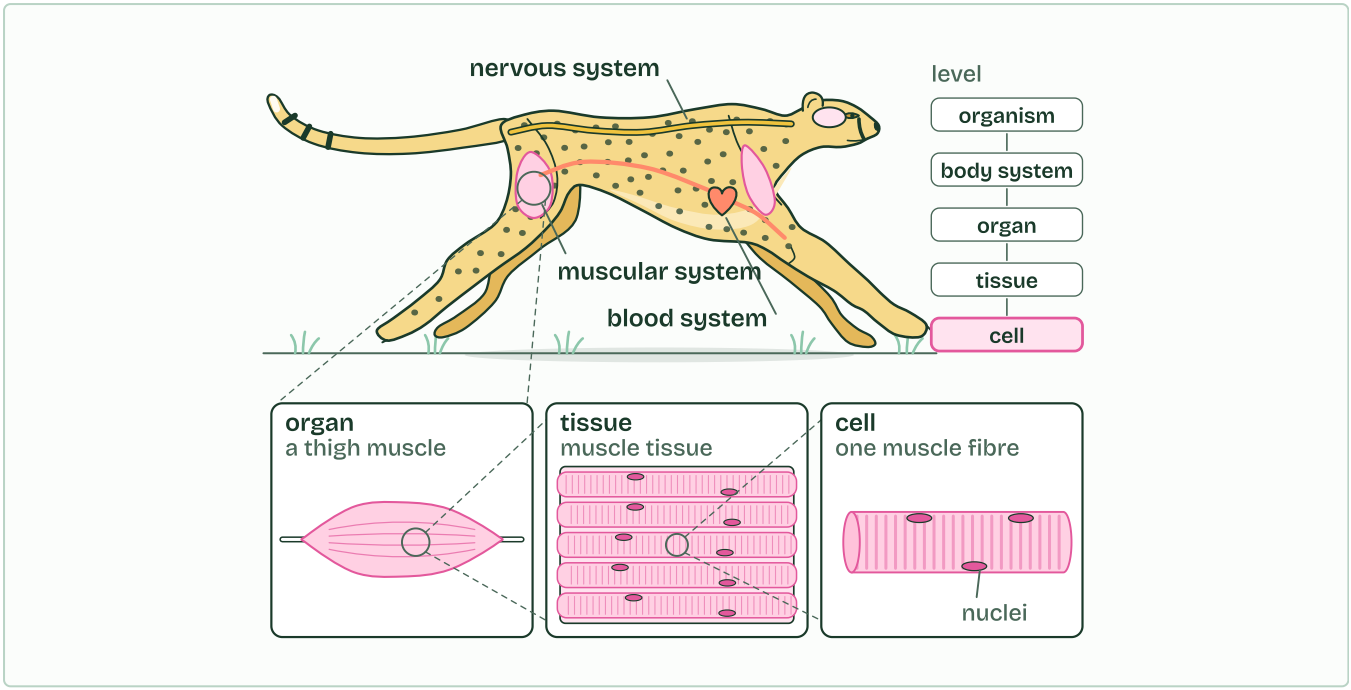
integration
Coordinating the parts of a system so that together they carry out an overall function that none of them could do alone.

tissue
A group of similar cells that work together to carry out one function, such as muscle tissue.

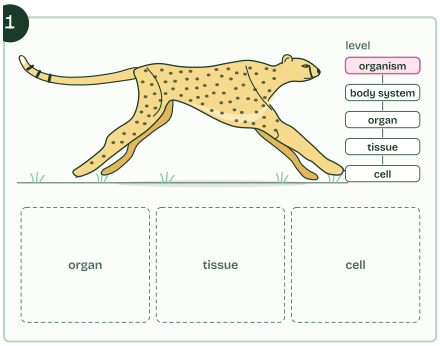
organ
A structure made of several tissues that carries out a particular job, such as the heart or a leg muscle.

body system
A group of organs that work together, such as the nervous system or the blood system.

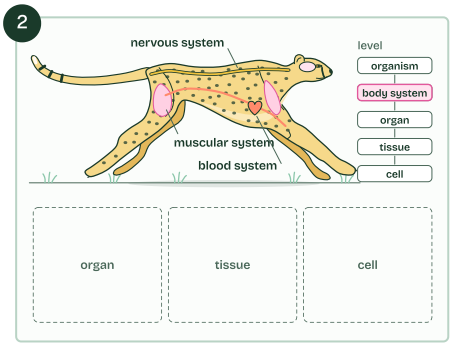
emergent property
A property of a whole system that none of its parts has alone, and that arises from how the parts interact.



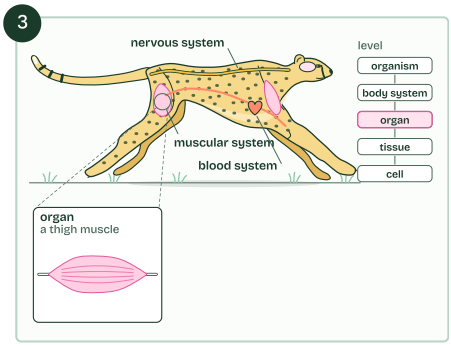
STEP BY STEP 5 STEPS



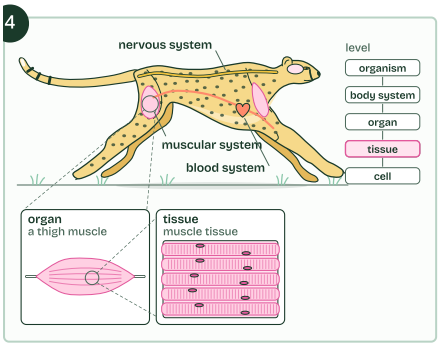
The **organism**: a cheetah at full sprint. Its speed belongs to the whole animal.



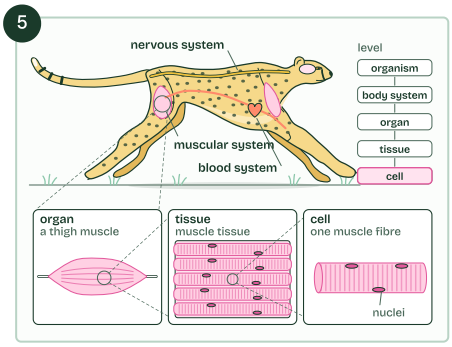
It is made of **body systems** working together: here the nervous system, the blood system and the muscles.



Each system is made of **organs**. One of them: a muscle in the thigh.



An organ is made of **tissues**. Muscle tissue: long fibres side by side, wrapped together.



A tissue is made of **cells**. One muscle fibre is a single long cell with several nuclei.

PREDICT

A cheetah's legs, lungs, heart and brain are each healthy, but none of them is connected to the others. Can it sprint?

(A) Yes, because each organ is healthy and does its own job at its full strength

(B) Yes, because the legs are the only part a sprint really needs to work hard

(C) No, because the brain is the only organ that has the power to move a body

(D) No, as a sprint needs the parts to work together, and belongs to the whole

Decide before you look. Answer on page 79.

BEYOND THIS SUBTOPIC

Thoughts and feelings may be emergent properties of the brain's neurons: no single neuron thinks. That idea is higher level, in C2.2.

WATCH OUT

"A tissue is any group of cells." Its cells are similar and share a job. "An emergent property is just a very big property of one organ." No organ has it; it comes from the parts interacting. "Organs each work on their own." Every organ depends on the others for oxygen, fuel and signals. And "integration only means nerves." Hormones and the blood integrate the body too.

C3.1.3 INTEGRATION OF ORGANS IN ANIMAL BODIES BY HORMONAL AND NERVOUS SIGNALLING AND BY TRANSPORT OF MATERIALS AND ENERGY

09 Three ways to get a message *across*

A body integrates its organs in three ways: two systems that send signals, and one that delivers.

The **nervous system** sends impulses along neurons, cells with long fibres that run the whole way to their target (it crosses the small gaps between neurons with a chemical: C2.2). The **endocrine system** works through glands that secrete **hormones** into the blood. The blood carries a hormone to every part of the body, but only a **target cell** with the right receptor responds to it.

So nerve messages are fast, go to one particular muscle or gland, and are over in a moment. Hormone messages are slower to arrive, can reach many organs at once, and often last much longer.

The blood system integrates the organs by **transport**, carrying materials and energy from the organ that supplies them to the organ that uses or removes them: oxygen from the lungs to the muscles; carbon dioxide back to the lungs; glucose from the gut and the liver to the brain; urea from the liver to the kidneys; heat from working muscle to the skin; and the hormones themselves. Signals and transport work together: a nerve message speeds the heart, and the faster blood brings more oxygen (chapter 19).

KEY POINTS

- Nerves: impulses along neurons, fast, to particular targets, short-lived.
- Hormones: secreted into the blood, slower, reach every organ, act only on cells with the receptor, often longer-lasting.
- The blood transports materials and energy between organs: oxygen, glucose, urea, carbon dioxide, heat.

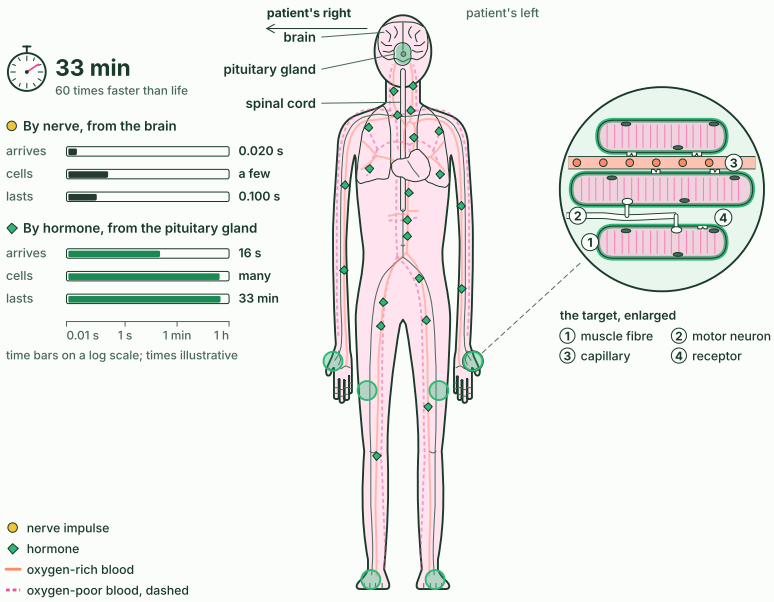
KEY TERMS

nervous system
The brain, spinal cord and nerves: neurons that carry electrical impulses to particular targets.

endocrine system
The glands that secrete hormones into the blood, and the hormones themselves.

hormones
A chemical messenger secreted by an endocrine gland into the blood, which carries it to every part of the body; it acts only on target cells with the right receptor.

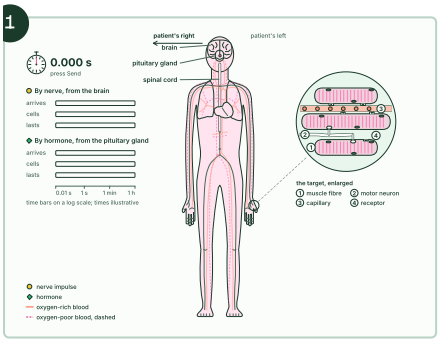
target cell
A cell with a receptor that a particular hormone binds to, so it responds to that hormone.



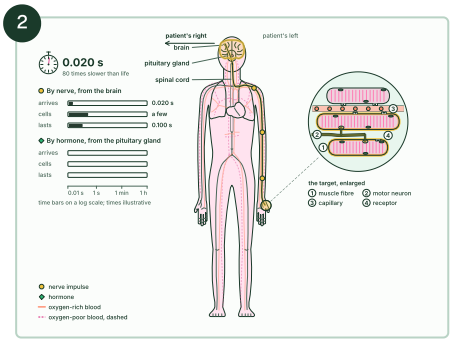
Send a message by nerve and by hormone from the same place and compare them, then follow what the blood carries between the organs. Answer the question first.

STEP BY STEP

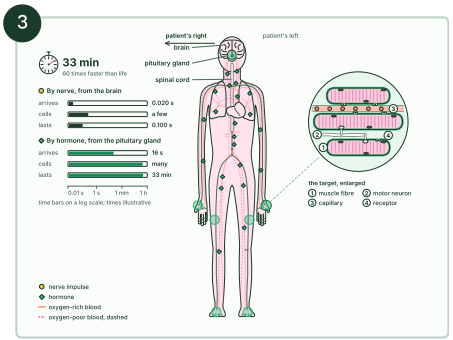
3 STEPS



Two messages will leave the head for one muscle in the patient's left hand: one by nerve from the brain, one by hormone from the pituitary gland. Nothing has been sent yet.



By nerve: impulses run from the brain, down the spinal cord and along a motor neuron to the muscle, in about 20 ms. Only the muscle fibres it reaches contract, for about a tenth of a second.



By hormone: the pituitary gland secretes it into the blood, which carries it through the heart and lungs to every part of the body. It reaches the hand after about 16 s; every cell with its receptor responds, for half an hour or more.

PREDICT

A hot pan burns a fingertip. A hormone, released at the same moment from a gland in the head, must reach the same fingertip. Which message arrives first?

(A) The hormone, because the blood reaches every tissue in the body at the same time

(B) Both together, as each one is a message that the body sends as fast as it can

(C) The nerve message, because it runs along a neuron the whole way there

(D) Neither, because the fingertip's own cells decide what to do alone

Decide before you look. Answer on page 79.

WATCH OUT

"A hormone acts on every cell it reaches." Only on cells with its receptor. "The nervous system is only electrical." Between neurons the signal is chemical. "Nerves are faster, so they are always better." Hormones suit long, widespread changes such as growth. And "the blood only carries oxygen." It carries fuel, wastes, heat and hormones too.

BEYOND THE GUIDE

Endocrine glands secrete into the blood; *exocrine* glands, such as the salivary glands, secrete along a duct onto a surface or into the gut.

C3.1.4 THE BRAIN AS A CENTRAL INFORMATION INTEGRATION ORGAN

10 The brain: many inputs, *one* picture

To catch a ball you need to know where the ball is (from your eyes), where your body is and which way is up (from the balance organs in your ears), and where your hand is (from stretch receptors in your muscles and joints), all at once. The **cerebral hemispheres** receive what the senses send, put the messages together, compare them with what is stored from before, and choose a response. That is what makes the brain the body's central organ for integrating information: many inputs, one picture, one decision.

Its other parts each have a job you will meet in this guide: the **cerebellum** (chapter 11), the **medulla oblongata** of the brainstem (heart rate and breathing, chapters 19 and 20), the **hypothalamus** and **pituitary gland** (chapter 18), the **pineal gland** (chapter 16), and the **spinal cord** below it (chapter 12).

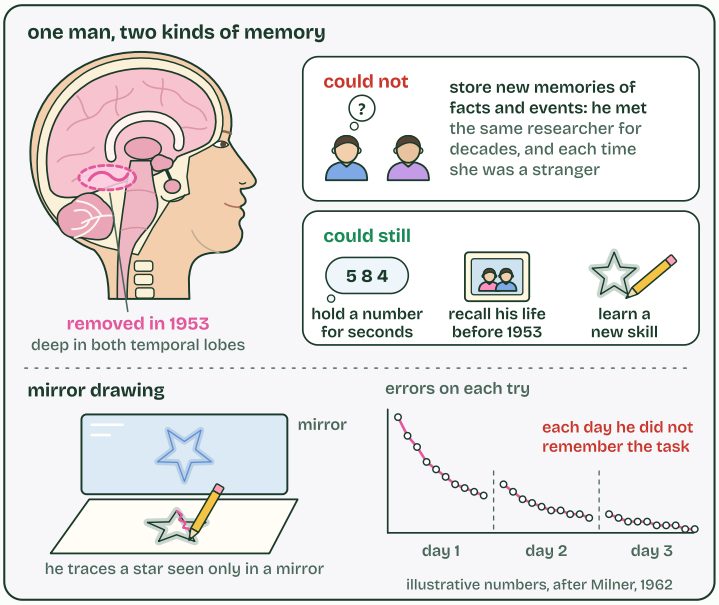
The brain also **learns** and **remembers**. Henry Molaison, known in the research as H.M., had severe epilepsy. In 1953 a surgeon removed the inner part of both his temporal lobes, including much of the hippocampus on each side. His seizures became far less severe, but from then on he could not form new long-term memories of facts and events: he met the psychologist Brenda Milner for decades and greeted her as a stranger each time. Yet he could hold a number in mind for a few seconds, remembered much of his life before the operation, and learned new skills: in a mirror-drawing task he improved over three days without remembering ever having done it. So storing a new memory of an event is the job of particular regions, and learning a skill uses others. Learning changes the connections between neurons; how it does is part of C2.2.

KEY POINTS

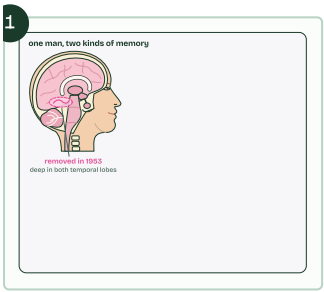
- The cerebral hemispheres combine information from several senses, compare it with memory and choose a response.
- The brain learns and remembers, and different kinds of memory depend on different regions.

KEY TERMS

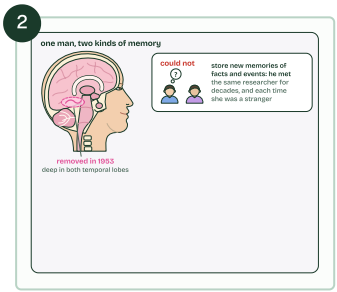
cerebral hemispheres
The two halves of the cerebrum, the large folded upper part of the brain: thought, memory, voluntary movement and the meaning of what the senses send.



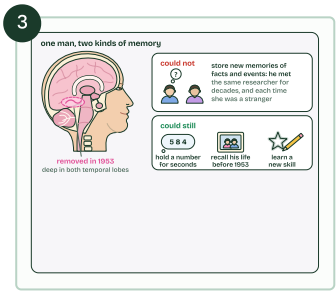
STEP BY STEP 4 STEPS



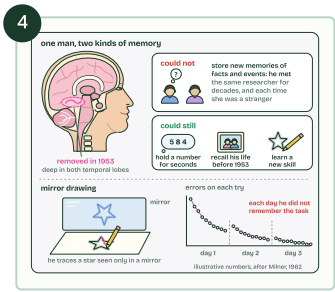
In 1953 a surgeon removed the inner part of both of Henry Molaison's **temporal lobes**, including much of the hippocampus on each side, to treat his epilepsy.



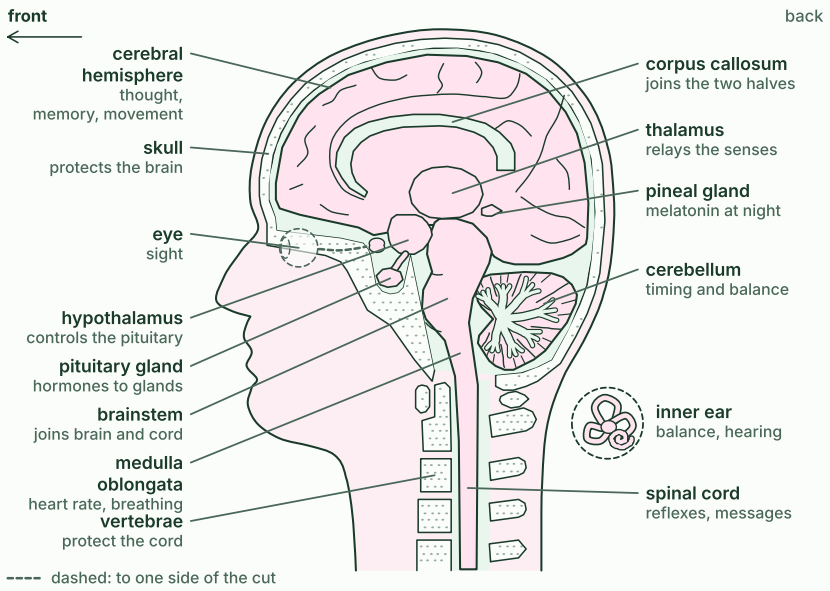
From then on he **could not** form new long-term memories of facts and events.



But he **could still** hold a number in mind for seconds, recall much of his earlier life, and learn new skills.



In **mirror drawing** his errors fell over three days, though each day he did not remember having done the task. Learning a skill and storing an event depend on different parts of the brain.

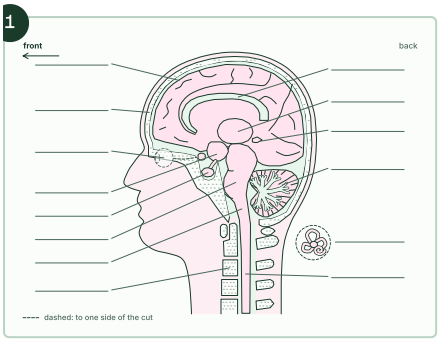


The head cut down the middle, face to the left. Tap each part for its job, then label it from memory.

STEP BY STEP

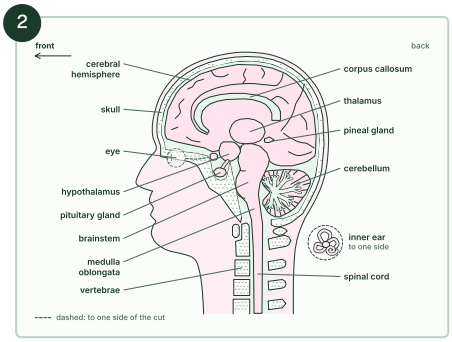
3 STEPS

1



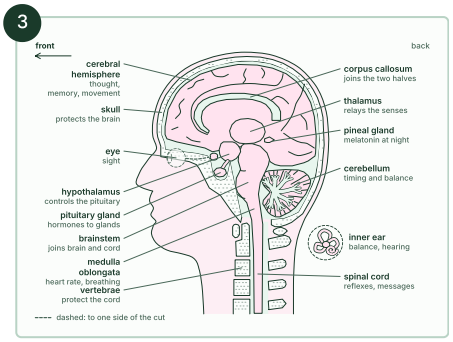
A head cut down the middle, the face to the left. Label the parts on the lines.

2



The **cerebral hemispheres** fill the top of the skull; under them the **hypothalamus** with the **pituitary gland**, the **pineal gland**, the **cerebellum** at the back, and the **brainstem** with the **medulla oblongata** running down into the **spinal cord**.

3



Each part's job. The cerebral hemispheres bring together what the senses send and store memories; the cerebellum times and balances movement; the medulla runs the heart rate and breathing; the hypothalamus controls the pituitary.

PREDICT

A patient can hold a phone number in mind for half a minute and gets faster each day at a new drawing task, but cannot remember meeting you an hour ago. What does this show?

(A) The whole brain was damaged equally, so every kind of memory got a little worse

(B) Different kinds of memory and learning depend on different parts of the brain

(C) Learning a skill uses the same region as storing events, so it should have gone

(D) The number was held in the cerebellum, and the meeting stored in the spinal cord

Decide before you look. Answer on page 79.

BEYOND THE GUIDE

Some areas of the cerebral cortex have particular jobs: the visual cortex at the back receives what the eyes send, and Broca's area, in the left frontal lobe of most people, helps produce speech.

WATCH OUT

"We use only ten percent of our brains." Scans show activity all over the brain, and damage almost anywhere has an effect. "The left half is logical and the right half creative." Most tasks use both. "A memory sits in one spot." Different kinds depend on different regions. And "the brain is a muscle that grows with use." It is nervous tissue; what changes with use is how its neurons connect.

11 C3.1.10 ROLE OF THE CEREBELLUM IN COORDINATING SKELETAL MUSCLE CONTRACTION AND BALANCE

The *little* brain

The **cerebellum** (Latin for "little brain") sits under the back of the cerebral hemispheres. You decide to move in the cerebral hemispheres. What does the cerebellum add?

The cerebellum makes a movement smooth and keeps you upright, without you being aware of it. To do this it compares the movement you meant with the movement that is happening. It takes in messages from the eyes, from the balance organs of the inner ear and from stretch receptors in the muscles and joints, and sends out signals that adjust the **timing** and the **force** of each contraction, so the right muscles contract, in the right order, by the right amount. It does the same for **balance**, adjusting the muscles of the legs and trunk as your weight shifts.

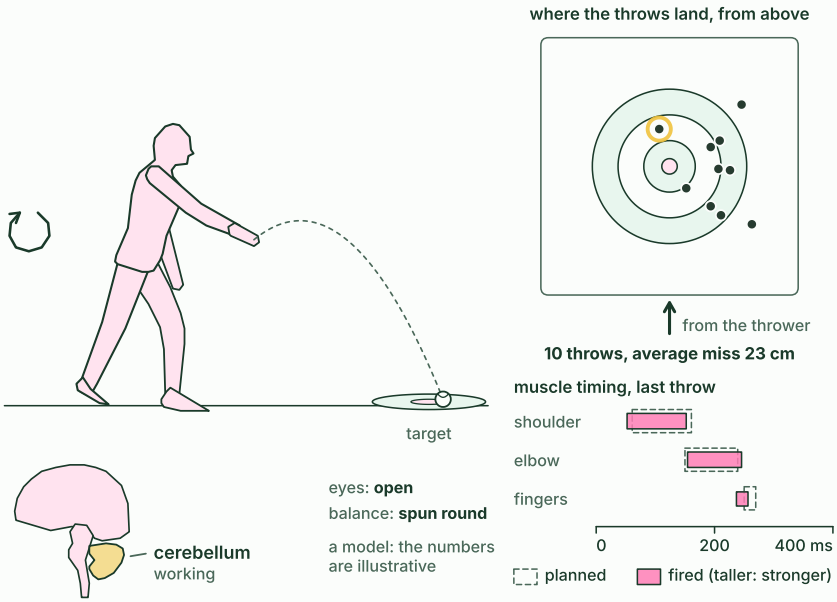
Movement is still possible without a working cerebellum, but it is clumsy, mistimed and unsteady: a hand reaching for a cup overshoots it, and the person sways and walks with the feet wide apart. A cerebellum also takes part in learning skills: practising a tennis serve or a piano piece tunes it.

KEY POINTS

- The cerebellum coordinates skeletal muscle contraction: the timing and force of each muscle in a movement.
- It keeps balance, from the eyes, the inner ear and stretch receptors.
- It does not start movements; the cerebral hemispheres do. It works without our awareness.

KEY TERMS

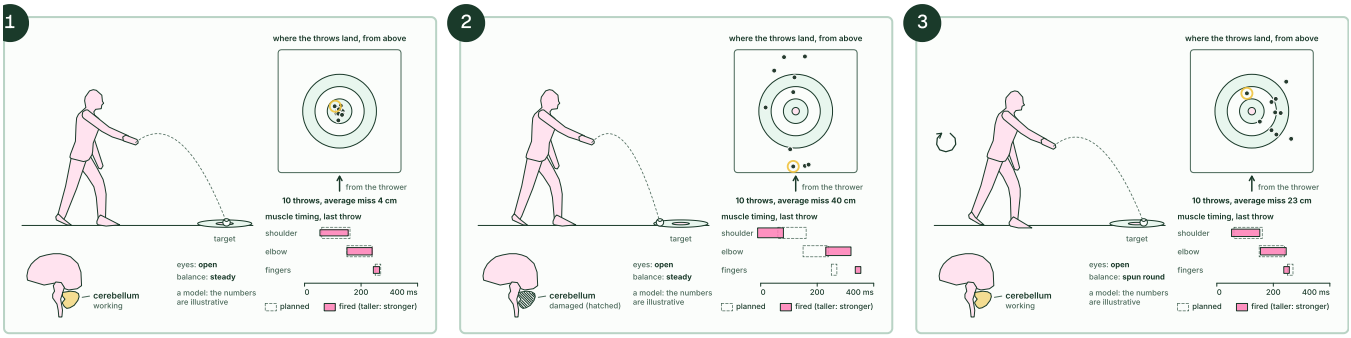
cerebellum
The part of the brain under the back of the cerebral hemispheres that coordinates the timing and force of skeletal muscle contractions, and keeps balance.



A person throws ten balls at a target. Answer the question first, then change the eyes, the balance and the cerebellum, and watch where the balls land and when the arm's muscles fire.

STEP BY STEP

3 STEPS



The cerebellum working: the muscles fire in their planned order and strength, so ten throws land close round the centre.

The cerebellum damaged: the person can still aim and move, but each muscle fires early or late, and too strongly, so the throws scatter.

Working, but just spun round: the balance organs still report turning, the body sways and the throws drift to one side.

PREDICT

A person whose cerebellum is damaged is asked to throw a ball at a target. What is most likely?

(A) They cannot move the arm at all, as the cerebellum starts every movement

(B) The throws are on target but slow, as the cerebellum only sets their speed

(C) The throws are on target, as the eyes alone steer the arm to the target spot

(D) The throws scatter, as the arm's muscles are no longer timed and measured

Decide before you look. Answer on page 79.

BEYOND THE GUIDE

The cerebellum has a middle strip, the vermis, two large hemispheres, and a small lobe underneath, the flocculonodular lobe, that works with the balance organs. You do not need these names.

WATCH OUT

"The cerebellum starts voluntary movements." The cerebral hemispheres do; the cerebellum coordinates them. "It is where we think." That is the cerebral hemispheres. "It only controls balance." It times every skilled movement too. And "damage to it paralyses." The person can move, but clumsily.

12 Aware or *automatic*?

C3.1.5 THE SPINAL CORD AS AN INTEGRATING CENTRE FOR UNCONSCIOUS PROCESSES

Why do you blink when dust blows at your eye, and could you stop yourself? Some of what your body does you are aware of and can control: speaking, reading this, swinging a bat. These are **conscious** processes, dealt with by the cerebral hemispheres. Others go on without your awareness: digesting a meal, your heart beating, a blink at a speck of dust, a hand pulled from something hot. These are **unconscious**.

The **spinal cord** runs from the base of the brain down the back, inside the vertebrae. Cut across, it has two parts. In the middle is a butterfly of **grey matter**: cell bodies and the **interneurons** that connect one neuron to another. Around it is **white matter**: myelinated fibres running up to the brain and down from it. So the cord does two jobs. It is an integrating centre for unconscious processes: in its grey matter, incoming messages are passed to outgoing neurons. And it carries messages between the brain and the rest of the body.

So a reflex is completed in the grey matter of the cord, with no help from the brain (chapter 15). The brain hears about it afterwards, through the white matter.

KEY POINTS

- Conscious processes: aware and controllable, in the cerebral hemispheres. Unconscious: without awareness.
- The spinal cord integrates unconscious processes such as reflexes, in its grey matter, and carries messages to and from the brain in its white matter.

KEY TERMS

conscious
Processes we are aware of and can control by choice, such as speaking or throwing a ball; the cerebral hemispheres deal with them.

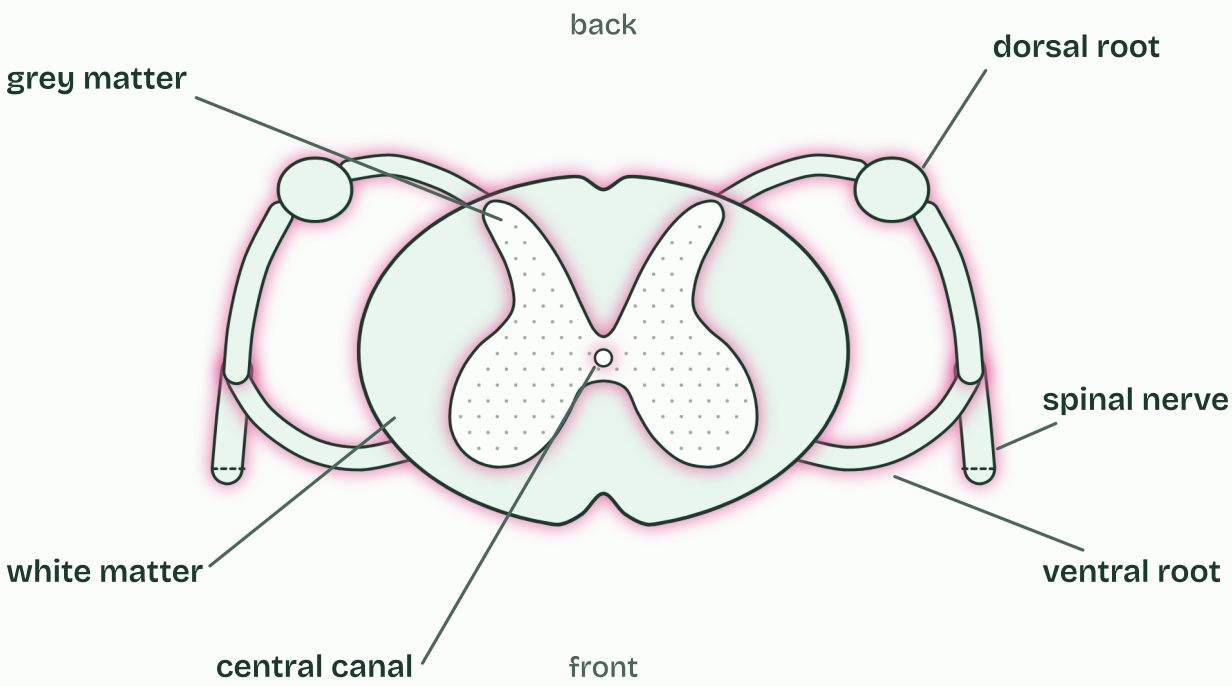
unconscious
Processes that go on without our awareness, such as reflexes, digestion and the heartbeat.

spinal cord
The column of nervous tissue that runs from the brain down the back inside the vertebrae; it integrates reflexes and carries messages between the brain and the body.

grey matter
Nervous tissue made mostly of cell bodies, dendrites and the interneurons that connect neurons; it forms the inner butterfly of the spinal cord.

interneurons
A neuron inside the brain or spinal cord that passes impulses from one neuron to another.

white matter
Nervous tissue made mostly of myelinated nerve fibres; it surrounds the grey matter of the spinal cord and carries messages up and down it.



Spinal nerve The two roots join: sensory and motor fibres together in one nerve, running out to the body (chapter 14).

Ventral root At the front. Motor fibres leave the cord this way, out to the muscles.

Dorsal root At the back. Sensory fibres come in this way; the swelling on it holds the sensory neurons' cell bodies.

White matter All round the outside: myelinated nerve fibres running up the cord to the brain and down from it. The fatty myelin makes it look pale.

Central canal A narrow channel down the middle of the cord, filled with fluid.

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Grey matter The butterfly in the middle: cell bodies of neurons, and the interneurons that connect one neuron to another. Here a message coming in can be passed straight out again: a reflex is integrated, with no help from the brain.

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Central canal A narrow channel down the middle of the cord, filled with fluid.

PREDICT

A person's spinal cord was cut across in the middle of the back months ago. A pin touches the sole of their foot. What happens?

(A) Nothing at all happens, because every response needs the brain to act

(B) The person feels the pin, but the foot cannot move, as only the brain moves it

(C) The foot pulls away by reflex, but the person does not feel the pin

(D) They feel it at once and the foot moves, as the message crosses the cut

Decide before you look. Answer on page 79.

BEYOND THE GUIDE

Sensory fibres enter the cord by the *dorsal root*, at the back, where a swelling holds their cell bodies; motor fibres leave by the *ventral root*, at the front. The two join into a spinal nerve. Chapter 15 uses this.

WATCH OUT

"The spinal cord only carries messages." It integrates reflexes too. "Unconscious means asleep." It means without awareness, awake or not. "Every unconscious process is run by the spinal cord." Breathing and the heart rate are controlled from the brainstem (chapters 19 and 20), and the gut by its own nerve net (chapter 21).

C3.1.6 C3.1.7 INPUT TO THE SPINAL CORD AND CEREBRAL HEMISPHERES THROUGH SENSORY NEURONS OUTPUT FROM THE CEREBRAL HEMISPHERES TO MUSCLES THROUGH MOTOR NEURONS

13 In by *sensory*, out by *motor*

Catching a falling ball takes a chain of cells, from the eye to the arm. Before you read how the chain is built, try to put it in order.

Your eyes, ears, skin and muscles hold **receptor cells**. Each detects one kind of stimulus. **Sensory neurons** convey their messages to the **central nervous system** (CNS: the brain and spinal cord). That is the input: some reaches the spinal cord, and some reaches the cerebral hemispheres, where you become aware of it.

The output goes the other way. **Motor neurons** carry messages from the CNS, for a voluntary movement from the cerebral hemispheres, to muscles, which are stimulated to contract. A muscle that responds is an **effector**.

A stimulus is not a feeling. Every sensory neuron sends the same sort of signal, impulses, whether it started with light, sound or heat. What you see, hear or feel is built by the brain from which neurons are firing and how often. Messages often pass between several neurons on the way: inside the CNS an interneuron can relay them from one neuron to the next. How an impulse travels along a neuron is part of C2.2.

KEY POINTS

- Sensory neurons carry messages from receptor cells to the CNS: input to the spinal cord and the cerebral hemispheres.
- Motor neurons carry messages from the cerebral hemispheres to muscles, which are stimulated to contract.

KEY TERMS

receptor cells
A cell or nerve ending that detects a stimulus, such as light, pressure or heat, and starts impulses in a sensory neuron.

sensory neurons
A neuron that carries impulses from receptor cells to the central nervous system.

central nervous system
The brain and the spinal cord.

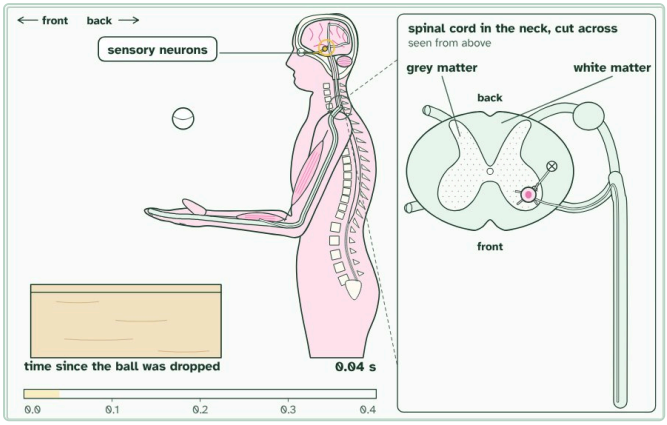
motor neurons
A neuron that carries impulses from the central nervous system to an effector, a muscle or a gland.

effector
A muscle or gland that responds to impulses from a motor neuron.

ANIMATION · CATCHING A FALLING BALL

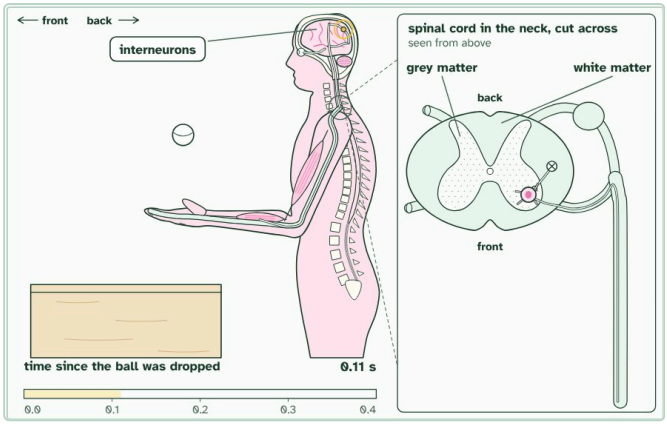
4 MOMENTS

1 0.04 S



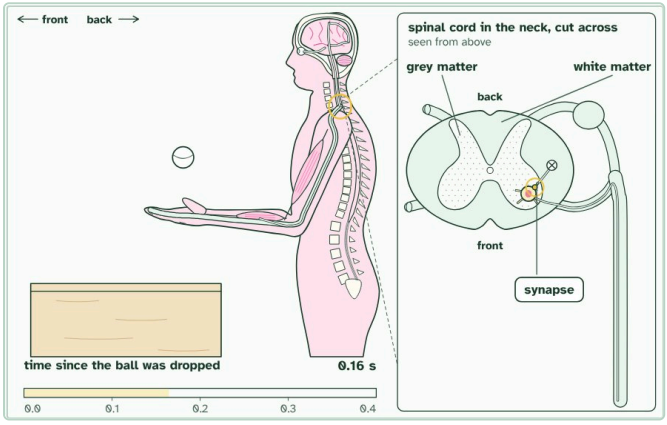
Receptor cells in the eye stimulate **sensory neurons**, which carry impulses along the optic nerve into the **cerebral hemispheres**.

2 0.11 S



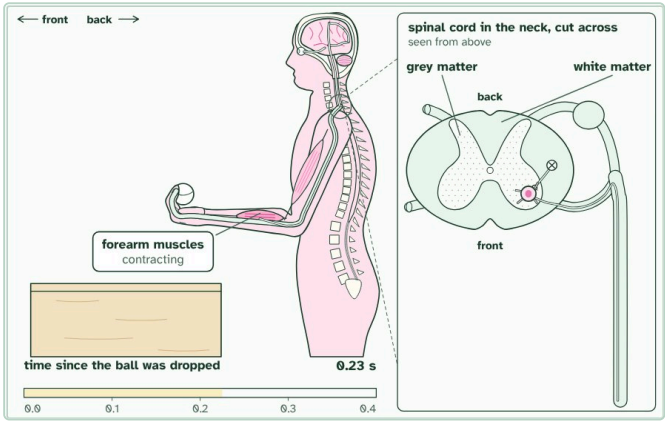
In the cerebral hemispheres, **interneurons** pass the message from the area that sees the ball to the area that plans the movement, across many synapses.

3 0.16 S



A **motor neuron** from the cerebral hemispheres carries impulses down the **white matter** of the spinal cord, then across a synapse in the grey matter to a motor neuron there.

4 0.23 S



The muscles contract and the fingers close round the ball: a **voluntary** action, decided in the cerebral hemispheres.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#neurons

PREDICT

A person watches a ball fall and catches it. Put these in order: motor neuron, receptor cells in the eye, cerebral hemispheres, arm muscle, sensory neuron. Which comes third?

(A) The sensory neuron, which must carry the signal from the eye first

(B) The cerebral hemispheres, between the neurons that bring and send it

(C) The motor neuron, since the brain acts once the arm has been told

(D) The arm muscle, since the hand moves before the brain judges the ball

Decide before you look. Answer on page 79.

WATCH OUT

"Sensory neurons carry light, sound or pain." They carry impulses; the brain makes the sensation. "Motor neurons carry messages to the brain." Away from it, to muscles. "One neuron runs from the finger to the brain." The message passes through two or three. And "a muscle tells itself to contract." A motor neuron stimulates it.

14 Inside a *nerve*

C3.1.8 NERVES AS BUNDLES OF NERVE FIBRES OF BOTH SENSORY AND MOTOR NEURONS

A neuron is one cell. A **nerve** is a bundle of hundreds or thousands of **nerve fibres**, the long axons of many neurons, running side by side like the wires in a cable.

Most nerves carry both sensory fibres, bringing messages in, and motor fibres, taking messages out: they are mixed nerves. In a transverse section through a nerve you can see how it is built. Outside is a tough protective **sheath** of connective tissue, with small blood vessels in it. Inside, the fibres are packed in bundles, each bundle with a thin wrapping of its own. Many fibres are **myelinated**: a pale ring of fatty myelin round a darker axon. Others are **unmyelinated**: thin, with no ring, often lying in small groups. Myelin insulates a fibre and makes impulses travel much faster; why it does is part of C2.2.

KEY POINTS

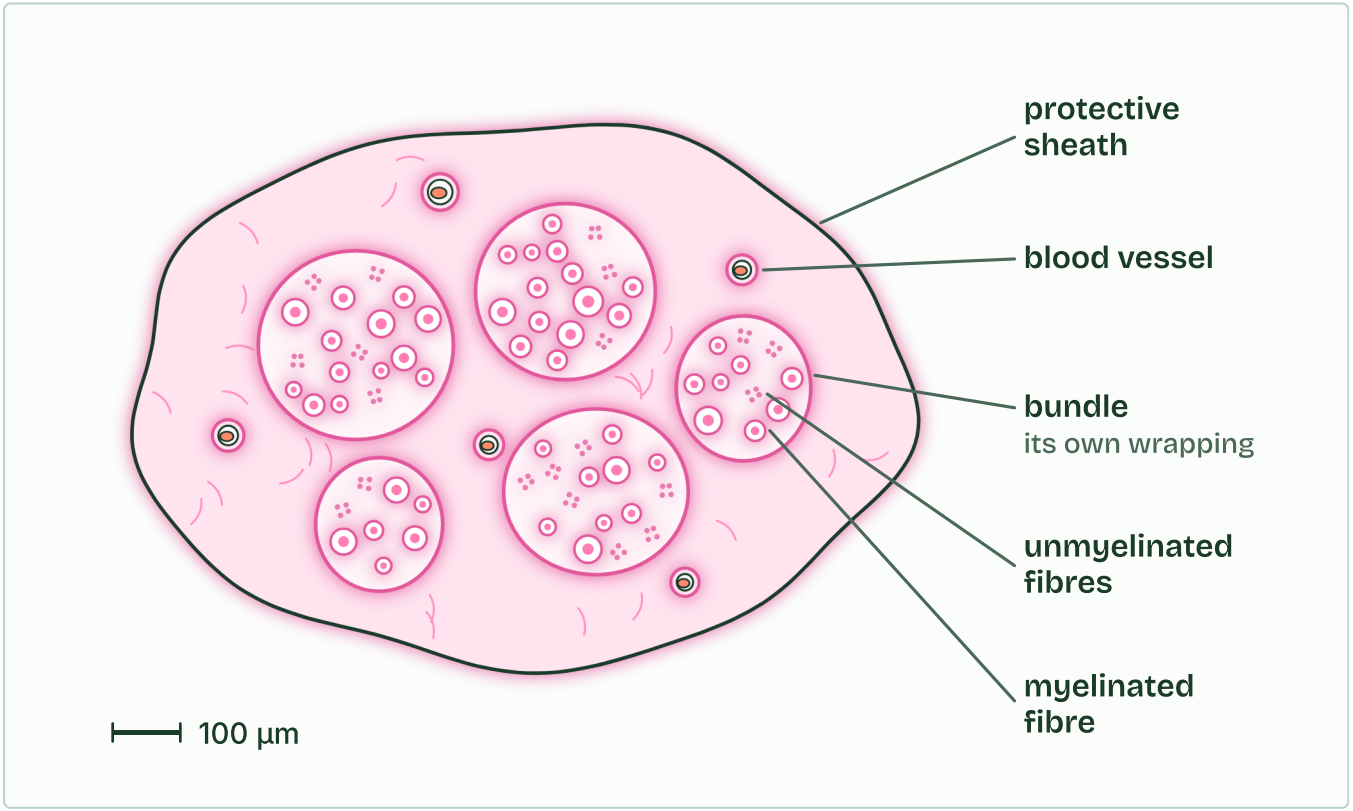
- A nerve is a bundle of nerve fibres in a protective sheath, not one cell.
- Most nerves hold both sensory and motor fibres.
- Some fibres are myelinated (a ring round the axon), some unmyelinated.

KEY TERMS

nerve
A bundle of many nerve fibres, the long axons of neurons, wrapped in a protective sheath of connective tissue.

nerve fibres
The long axon of a neuron, which carries impulses.

myelinated
Wrapped in myelin, layers of fatty membrane laid down by Schwann cells, which insulate the fibre and make impulses travel much faster.



Protective sheath Tough connective tissue round the whole nerve, with small blood vessels in it. It protects the fibres and holds the bundles together.

Blood vessel A small artery or vein in the sheath, with a red cell inside: the nerve's own supply of oxygen and glucose.

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PREDICT

One nerve in a person's arm is cut. They lose all feeling in part of the hand and cannot move some of the fingers. What does that show about the nerve?

(A) It held both sensory and motor fibres, bundled in the one sheath

(B) It held a single neuron that did both jobs, carrying both ways

(C) It held only sensory fibres, and the movement was lost from shock

(D) Feeling and movement both run in the spinal cord, not in the nerve

Decide before you look. Answer on page 80.

WATCH OUT

"A nerve is a neuron." It is a bundle of the fibres of many neurons. "A nerve carries one kind of message." Most carry sensory and motor messages, in opposite directions. "Every fibre is myelinated." Many thin ones are not. And "a nerve fibre is a whole neuron." It is one neuron's axon; the cell body lies elsewhere, in or near the CNS.

C3.1.9 PAIN REFLEX ARCS AS AN EXAMPLE OF INVOLUNTARY RESPONSES WITH SKELETAL MUSCLE AS THE EFFECTOR

15 The pain *reflex*

Back to the blink at the dust: who decided? Nobody. A **reflex** is a fast response to a stimulus that does not wait for a decision. It is **involuntary**. The route it takes is a **reflex arc**.

The IB's example is pulling the hand away from something that hurts, neuron by neuron. A **free nerve ending** of a sensory neuron in the skin of the hand is the pain receptor. The **sensory neuron** carries impulses up the arm into the spinal cord. In the **grey matter** the message crosses to a single **interneuron**, which passes it to a **motor neuron**. The motor neuron carries impulses out to a skeletal muscle, the **effector**: the biceps in the upper arm, which contracts and bends the elbow, pulling the hand away. Each handover between neurons is a synapse (C2.2).

A reflex is quick because the path is short, with only two synapses in the cord, and nothing has to be thought about. And it protects you: the hand moves before you know there is danger. The brain is still told, a moment later.

KEY POINTS

- Pain reflex arc: free nerve ending, sensory neuron, interneuron in the grey matter, motor neuron, skeletal muscle.
- It is involuntary and fast, and protects before the brain is aware.

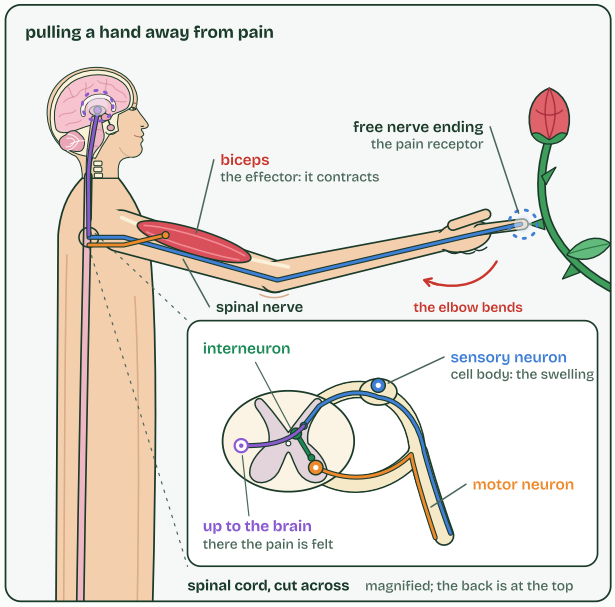
KEY TERMS

reflex
A rapid, involuntary response to a stimulus, carried out through a reflex arc without a decision by the brain.

involuntary
Not under conscious control: it happens whether or not we choose.

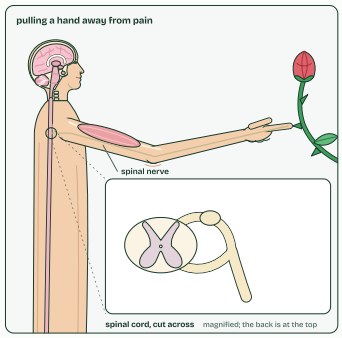
reflex arc
The pathway of a reflex: receptor, sensory neuron, interneuron in the CNS, motor neuron and effector.

free nerve ending
The bare, branching end of a sensory neuron in the skin, with no special receptor cell; many detect damaging heat or pressure and act as pain receptors.



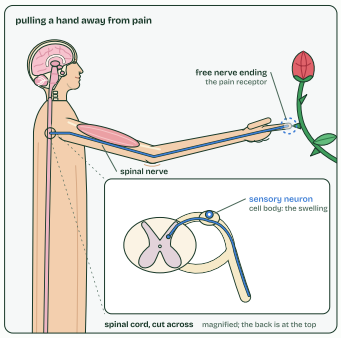
STEP BY STEP
5 STEPS

1



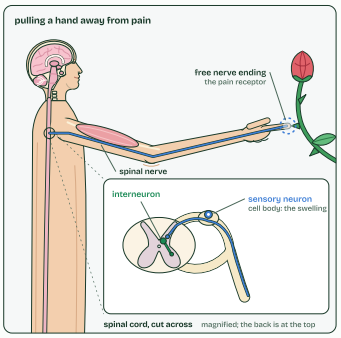
A fingertip touches a rose thorn. The arm is joined to the **spinal cord** by a spinal nerve; the cord, cut across, is drawn magnified. Predict: which neurons carry the message, and where does it turn round?

2



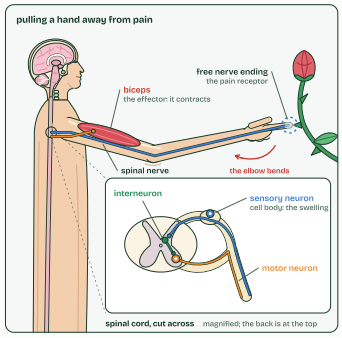
A **free nerve ending** in the skin, the pain receptor, starts impulses. The **sensory neuron** carries them up the arm and in at the back of the cord.

3



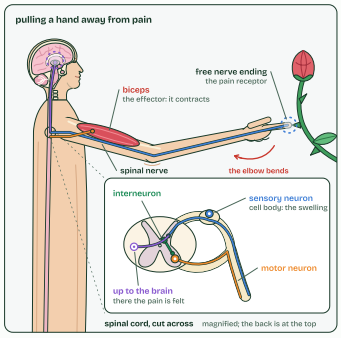
In the grey matter the message crosses a synapse to one **interneuron**.

4



Across a second synapse a **motor neuron** carries impulses out to the **biceps**, the effector, which contracts: the elbow bends and the hand pulls away.

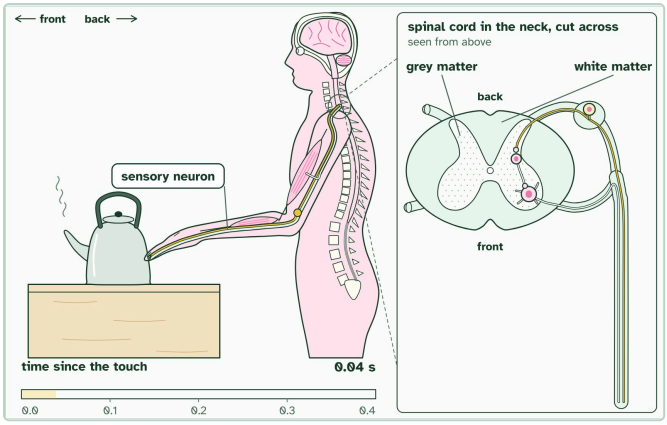
5



The sensory neuron also passes the message to a fibre that climbs the cord to the **brain**. Only when it arrives is the pain felt, after the hand has moved.

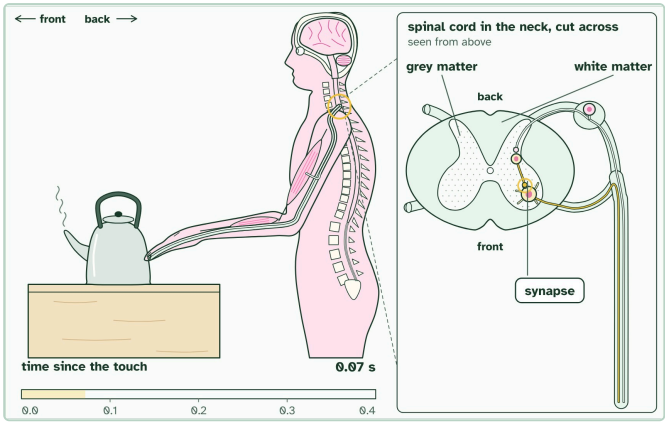
ANIMATION · THE PAIN REFLEX
4 MOMENTS

1 0.04 S



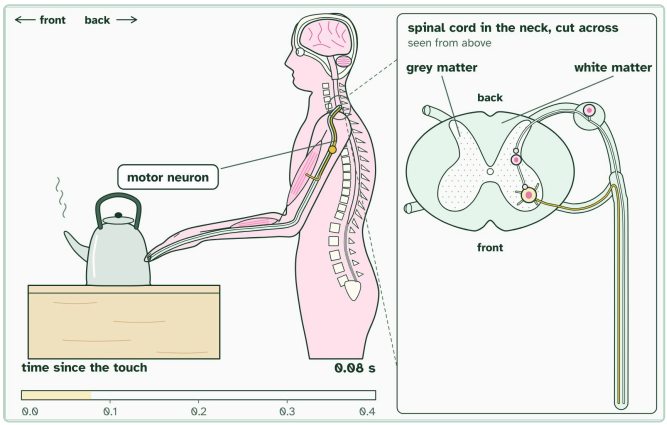
The fingertip touches the hot metal. A **pain receptor** in the skin, the free nerve ending of a **sensory neuron**, starts impulses that travel up the arm to the spinal cord.

2 0.07 S



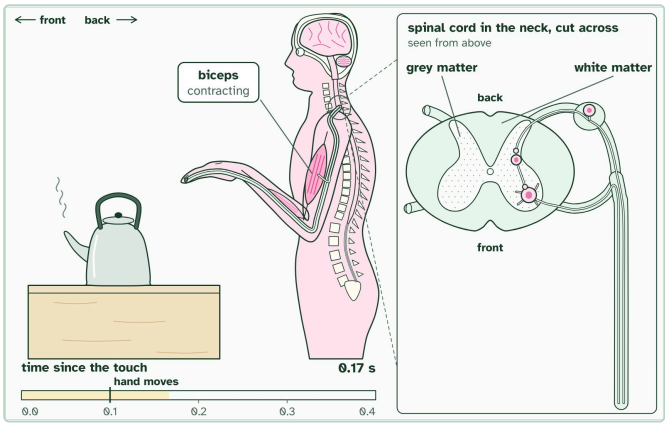
In the **grey matter** of the spinal cord the impulse crosses a **synapse** to an **interneuron**, which passes it across a second synapse to a **motor neuron**.

3 0.08 S



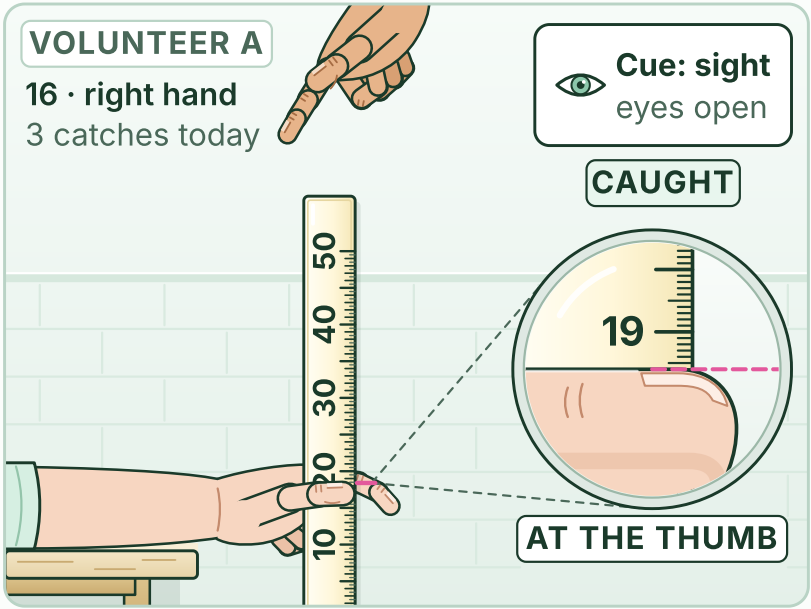
The motor neuron carries impulses out of the cord and down the arm to the **biceps**, the **effector**.

4 0.17 S



The biceps contracts and bends the elbow, pulling the hand away. Nobody decided to: this is a **reflex**, fast and **involuntary**.

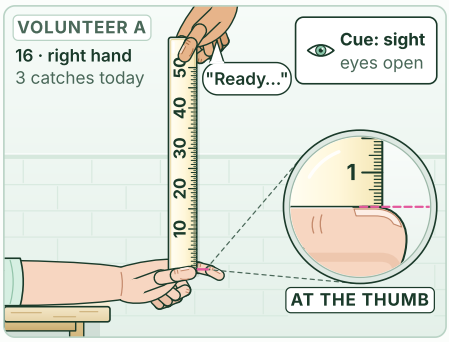
Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#reflex



Run it on the page: choose a volunteer and a cue, press Drop, read where the ruler was caught, and the table and graph fill in.

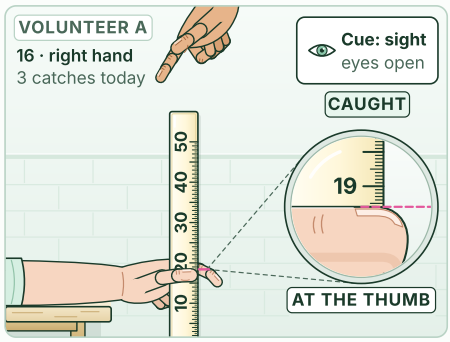
STEP BY STEP
2 STEPS

1



Set up: the volunteer's forearm rests on the table, finger and thumb open either side of the ruler, its zero level with the top of the thumb. The partner holds the top.

2



Caught: the partner let go without warning and the volunteer pinched the ruler as soon as they could. The distance it fell, read at the top of the thumb, gives the reaction time: $t = \sqrt{(2d \div g)}$.

PREDICT

A person pulls a hand away from a hot object. When do they feel the pain?

(A) Before the hand moves, since the brain must feel it to order the move

(B) At the same moment, since the two messages travel together at one speed

(C) After the hand has moved, since the reflex is done in the spinal cord

(D) Never at all, since reflexes are unconscious and so are never felt

Decide before you look. Answer on page 80.

WATCH OUT

"The brain makes a reflex happen." The spinal cord completes it. "A reflex is a very quick decision." Nothing is decided. "The sensory neuron runs straight to the muscle." It meets an interneuron in the cord. And "the pain is in the hand." The receptor is in the hand; the pain is made in the brain.

BEYOND THE GUIDE

As the biceps contracts, the triceps behind the upper arm is made to relax, so it does not pull against it. The real circuit has more interneurons than the IB's one.

C3.1.11 MODULATION OF SLEEP PATTERNS BY MELATONIN SECRETION AS A PART OF CIRCADIAN RHYTHMS

16 Dark, light and *sleep*

Your body runs on a cycle of about 24 hours, a **circadian rhythm**: sleep and waking, body temperature and many hormones rise and fall with it. A clock in the hypothalamus keeps the time (the suprachiasmatic nucleus, a name you do not need), and light reaching the eyes resets it each day.

The clock controls the **pineal gland**, a small gland deep in the brain, which secretes the hormone **melatonin**. Its secretion is **diurnal**, following day and night: low through the day, rising in the evening about two hours before you usually fall asleep, highest in the middle of the night, and falling before you wake.

Light on the retina, through the clock, switches the pineal gland off, so melatonin is high only in the dark. Melatonin carries the message "it is night" round the body in the blood. It makes you sleepy and lowers your body temperature a little, and it helps keep the cycle of sleeping and waking in step with the day. That explains several things. Bright screens late in the evening, especially blue-rich light, can hold melatonin back and delay sleep. A night-shift worker sleeping by day has a rhythm that keeps drifting. A traveller across several time zones sleeps badly for days (jet lag), because their clock and melatonin still follow the old day and night. In many teenagers the evening rise of melatonin tends to come later than it did in childhood, so they feel sleepy later. Melatonin tablets are sold for jet lag and may help some people to fall asleep, though the evidence is mixed.

KEY POINTS

- The pineal gland secretes melatonin in a diurnal pattern: high at night, low by day.
- Light on the retina, through the body clock in the hypothalamus, switches it off.
- Melatonin prepares the body for sleep and helps set the cycle of sleeping and waking.

KEY TERMS

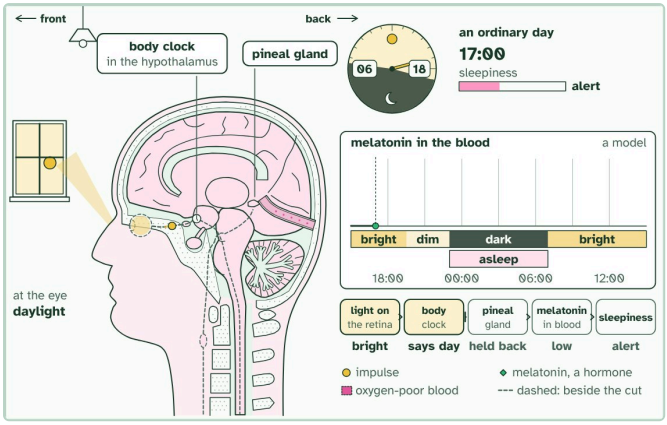
circadian rhythm
A cycle in the body's activity of roughly 24 hours, such as sleeping and waking, kept in step with day and night by light.

pineal gland
A small gland deep in the brain that secretes melatonin, mostly at night.

melatonin
A hormone secreted by the pineal gland in the dark; its rise at night prepares the body for sleep.

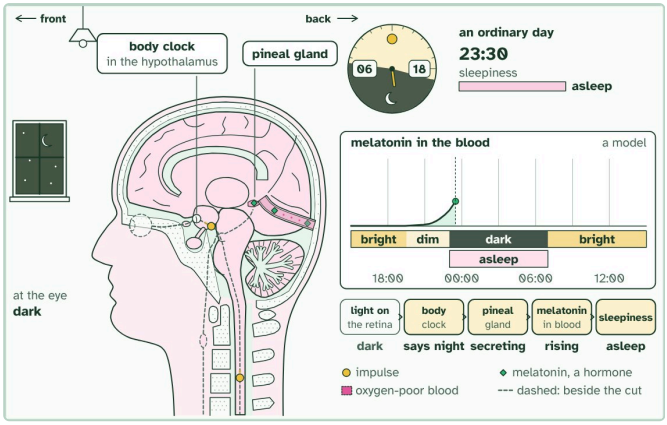
ANIMATION · DARK, LIGHT AND SLEEP 4 MOMENTS

1 17:00



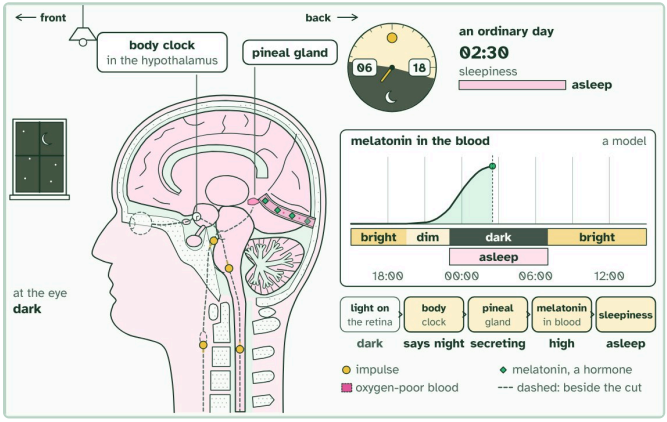
An ordinary day. Daylight on the **retina** sends impulses to the **body clock** in the hypothalamus, and the **pineal gland** is held back: almost no **melatonin**.

2 23:30



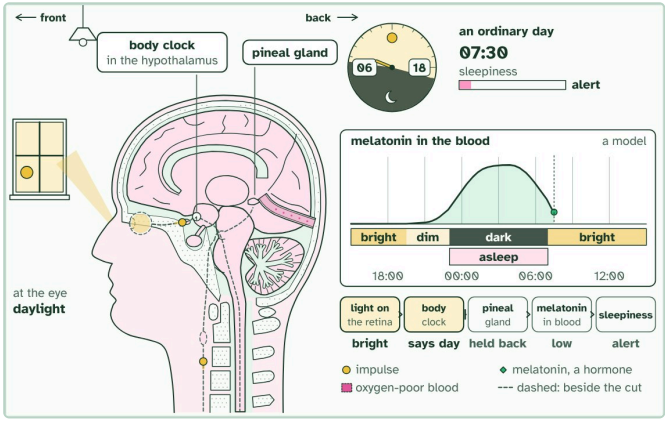
Lights out. In the dark nothing holds the pineal gland back: melatonin climbs, and the body gets ready for sleep.

3 02:30



Melatonin is highest in the middle of the night.

4 07:30



Morning light on the retina stops what is left. Melatonin stays low all day: a **diurnal** pattern, set by the clock and kept in step by light.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#melatonin

PREDICT

A person lives in a room with no windows, lit by a bright lamp for 20 hours a day. What happens to their night-time melatonin?

(A) It stays low while the lamp is on, so its night-time rise is cut short

(B) It still rises each night on time, since the pineal gland ignores all light

(C) It rises higher, since the body makes more of it when there is more light

(D) It stays high all day, since the cells of the eye itself are making it

Decide before you look. Answer on page 80.

WATCH OUT

"Light raises melatonin." Light lowers it; darkness lets it rise. "Melatonin is a sleeping pill." It signals that it is night and makes sleep more likely; it does not knock you out. "The pineal gland makes you sleep." It tells the body it is dark. And "the body clock is the heart." It is in the hypothalamus.

C3.1.12 EPINEPHRINE (ADRENALINE) SECRETION BY THE ADRENAL GLANDS TO PREPARE THE BODY FOR VIGOROUS ACTIVITY

17 Ready to *run*

A dog runs at you, barking. Within seconds your heart is pounding. Part of that is **epinephrine** (adrenaline), the hormone of "fight or flight". In danger or excitement, the hypothalamus sends impulses down the spinal cord and out along nerves to the **adrenal glands**, which sit on top of the kidneys. Their inner part, the adrenal medulla, secretes epinephrine into the blood, with a little norepinephrine.

The blood carries epinephrine to cells all over the body, and each organ with receptors for it responds in a way that helps the muscles contract hard:

KEY POINTS

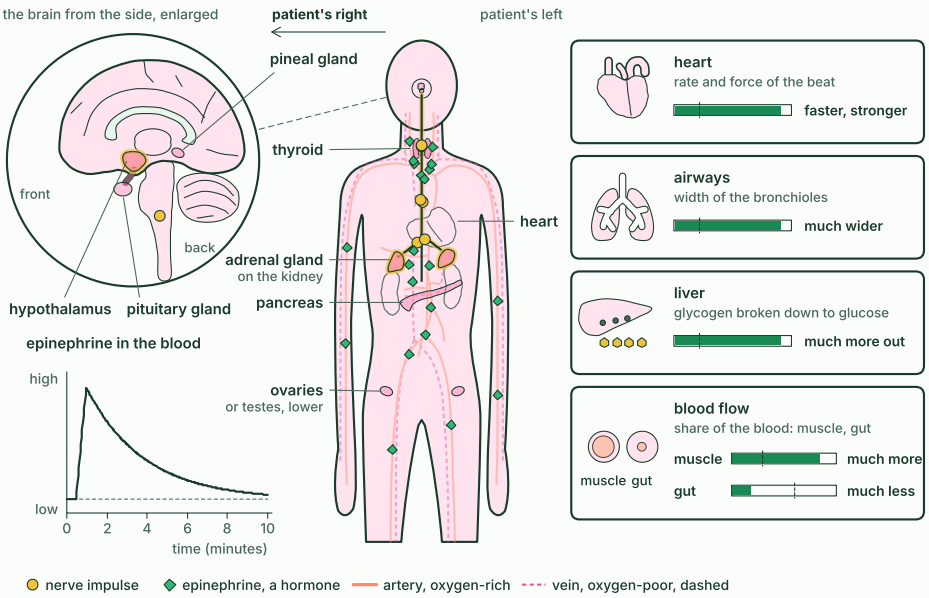
- the **heart** beats faster and more strongly, pumping more blood each minute;
- the **airways** in the lungs widen, so air moves in and out more easily (the faster breathing of exercise comes mostly from the carbon dioxide loop, chapter 20);
- the **liver** breaks down glycogen to glucose, raising the blood glucose that muscles use as fuel;
- the **arterioles** to skeletal muscle widen while those to the gut and skin narrow, sending the blood to the muscles;
- the **pupils** widen, letting more light into the eyes.

Together these deliver more oxygen and glucose to the muscles and carry away more carbon dioxide and heat: the body is prepared for vigorous activity. The effect starts within seconds and fades within minutes, because the hormone is quickly broken down. It joins the nerves that speed the heart (chapter 19; the heart's own pacemaker is in B3.2), and works on the arterioles you met in B3.2. How a hormone acts inside a target cell is part of C2.1.

KEY TERMS

epinephrine
A hormone, also called adrenaline, secreted by the adrenal glands in danger or excitement; it prepares the body for vigorous activity.

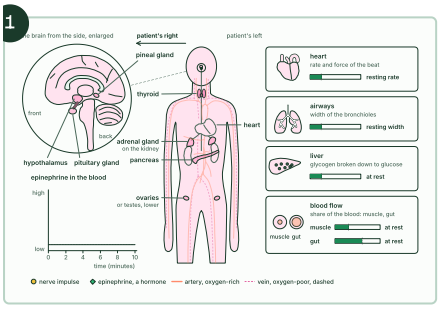
adrenal glands
Two endocrine glands, one on top of each kidney; their inner part, the adrenal medulla, secretes epinephrine.



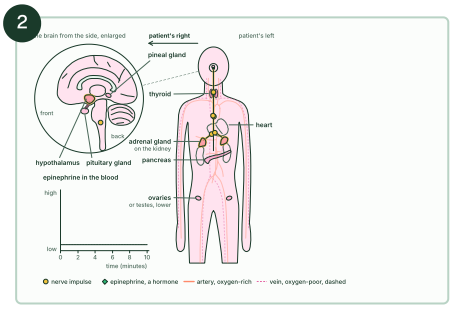
A body with its glands and blood vessels. Answer the question first, then set Stress to startled or sprinting and follow the hormone to the heart, airways, liver and arterioles.

STEP BY STEP

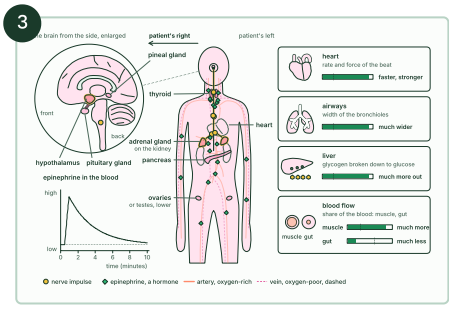
3 STEPS



A person at rest. The hypothalamus, at the base of the brain, and the adrenal glands on the kidneys; four of the hormone's targets, at rest.



Danger, or a sprint: the hypothalamus sends nerve impulses down the spinal cord to the adrenal glands.



The adrenal glands secrete epinephrine into the blood, which carries it everywhere: the heart beats faster and harder, the airways widen, the liver releases glucose, and more blood goes to the muscles and less to the gut.

PREDICT

A person is startled and runs. Compared with rest, what happens to the blood flow to the gut and to the leg muscles?

(A) Both rise together, because the heart is pumping harder to both of them at once

(B) Less goes to the gut and more to the leg muscles, as arterioles change width

(C) Both fall together, because the blood pressure drops in a sudden fright or shock

(D) Neither changes, because the flow to each organ is fixed for life by its size

Decide before you look. Answer on page 80.

WATCH OUT

"Adrenaline only speeds up the heart." It acts on the airways, the liver, the arterioles and the eyes too. "It makes you stronger without any fuel." It makes more fuel and oxygen available. "It is a nerve signal." It is a hormone in the blood, though nerves trigger its release. And "its effects last for hours." Minutes.

C3.1.13 CONTROL OF THE ENDOCRINE SYSTEM BY THE HYPOTHALAMUS AND PITUITARY GLAND

18 The hypothalamus and the *pituitary*

The **hypothalamus**, at the base of the brain, is where the nervous system and the endocrine system meet. It receives nerve messages about the body and the world outside, and it monitors the blood flowing through it. It controls the **pituitary gland**, a gland the size of a pea that hangs just beneath it on a short stalk.

The pituitary secretes hormones into the blood. Some act directly on tissues; others travel to other endocrine glands and make them secrete their own hormones. Because so many glands answer to it, the pituitary is often called the "master gland", but it takes its orders from the hypothalamus. So the hypothalamus and pituitary together control much of the endocrine system. One chain, as an example: the hypothalamus signals the pituitary, the pituitary's hormone travels in the blood to the thyroid gland in the neck, and the thyroid secretes thyroid hormone, which raises the rate of metabolism in cells all over the body.

The chain controls itself. As thyroid hormone rises, it is detected by the hypothalamus and the pituitary, which then secrete less. Less pituitary hormone means less thyroid hormone, and the level settles. A response that reverses the change that caused it is **negative feedback**.

KEY POINTS

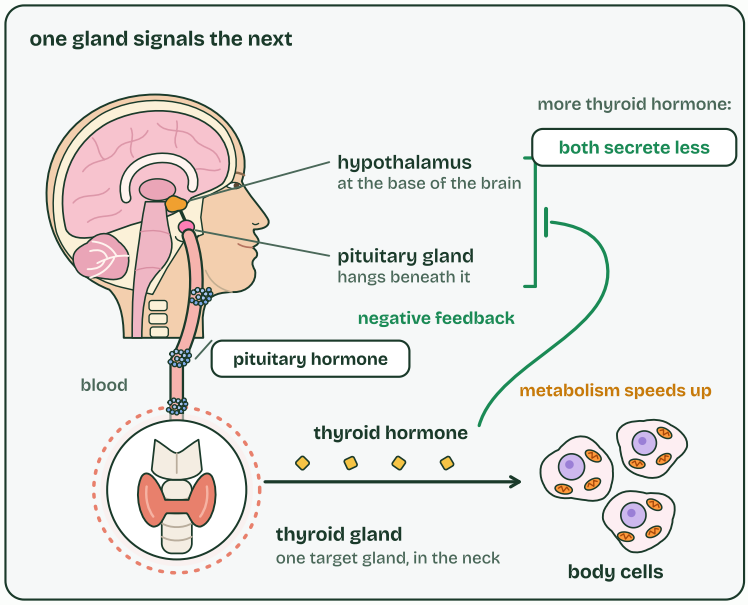
- The hypothalamus links the nervous and endocrine systems and controls the pituitary gland.
- Pituitary hormones control other endocrine glands, and some tissues directly.
- The glands' own hormones feed back to the hypothalamus and pituitary: negative feedback.

KEY TERMS

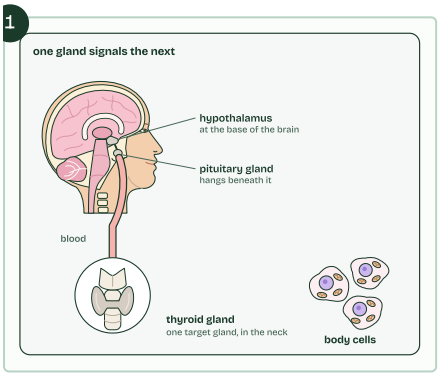
hypothalamus
A small region at the base of the brain that links the nervous system to the endocrine system: it monitors the body and controls the pituitary gland.

pituitary gland
A pea-sized gland hanging just below the hypothalamus; its hormones control several other endocrine glands and some tissues directly.

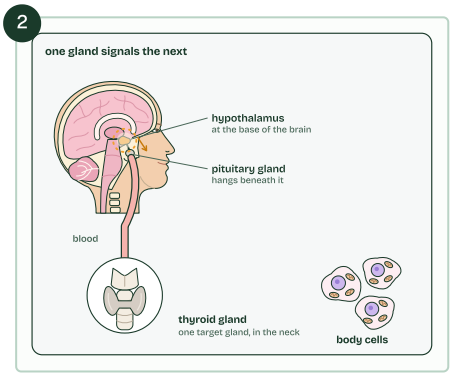
negative feedback
A loop in which a change sets off a response that reverses it, bringing a value back towards its set point.



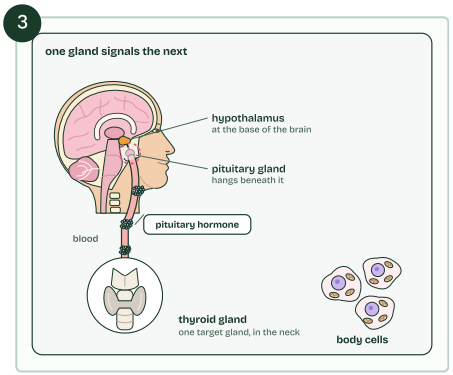
STEP BY STEP 5 STEPS



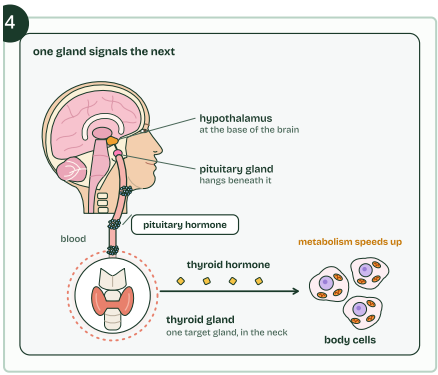
The head cut down the middle: the **hypothalamus** at the base of the brain, and the **pituitary gland** hanging beneath it.



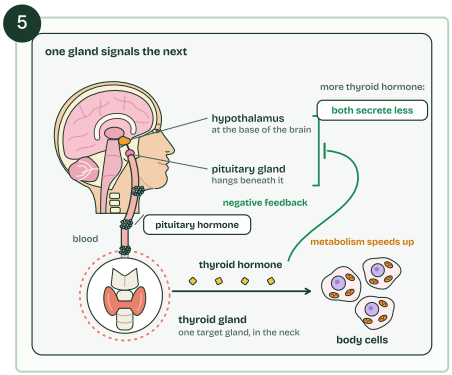
The hypothalamus **signals** the pituitary to secrete its hormone.



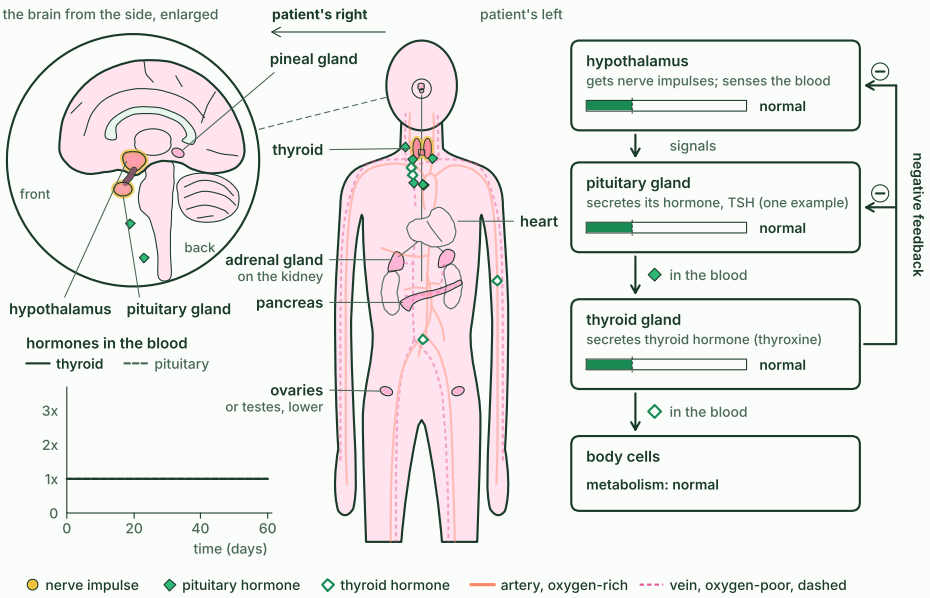
The pituitary's hormone leaves in the **blood**, which carries it all round the body.



It reaches a **target gland**, here the thyroid (one example), which secretes its own hormone into the blood; that hormone speeds up metabolism in cells all over the body.



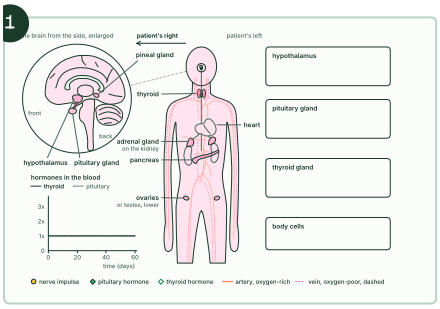
As the thyroid's hormone rises, the hypothalamus and the pituitary **secrete less**: negative feedback holds the level steady.



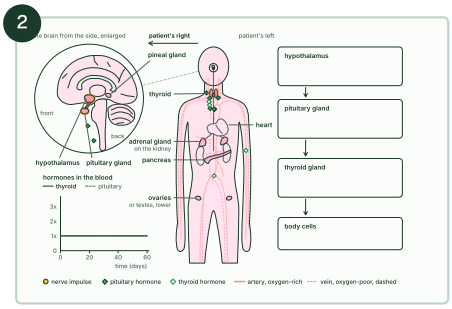
The hypothalamus, the pituitary and the thyroid as the one example, with a trace of their hormones. Answer the question first, then switch the feedback off.

STEP BY STEP

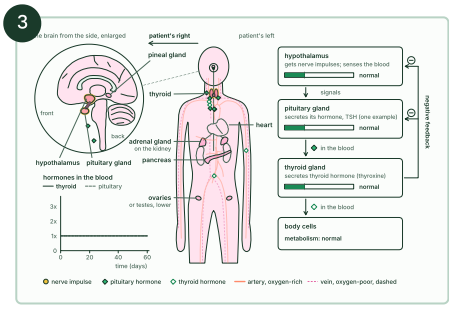
3 STEPS



The hypothalamus at the base of the brain, the pituitary gland just beneath it, and other glands of the body; the thyroid is the example here.



The hypothalamus signals the pituitary; the pituitary's hormone (TSH) travels in the blood to the thyroid, which secretes its own hormone, thyroxine, to the body's cells.



As thyroxine rises, it makes the hypothalamus and the pituitary secrete less: negative feedback keeps its level near normal.

PREDICT

A drug blocks the receptors on a target gland that respond to a pituitary hormone. What happens to the pituitary's output of that hormone?

(A) It falls, since the pituitary senses that nothing is arriving at the gland

(B) It stays the same, since only the hypothalamus can change the pituitary

(C) It rises, since the blocked gland sends nerve impulses up to the pituitary

(D) It rises, since less of the gland's hormone means weaker feedback

Decide before you look. Answer on page 80.

WATCH OUT

"The pituitary is the boss of the body." The hypothalamus controls it. "The hypothalamus is part of the pituitary." It is part of the brain, above it. "Every pituitary hormone acts on a gland." Some act on tissues directly. And "the pituitary is in the neck." It is under the brain, behind the eyes.

BEYOND THE GUIDE

Pituitary hormones you will meet again: FSH and LH (the ovaries and testes, D3.1), ADH (the kidneys, D3.3) and oxytocin (contractions in labour). The pituitary has two parts that work in different ways; the IB does not ask for the difference.

C3.1.14 FEEDBACK CONTROL OF HEART RATE FOLLOWING SENSORY INPUT FROM BARORECEPTORS AND CHEMORECEPTORS

19 Keeping the beat *right*

Your heart sets its own beat: the SA node in its wall starts each one (B3.2). The brain changes the rate to suit what the body is doing, using a feedback loop. A loop has a **receptor** that detects a change, a **control centre** that decides, and an **effector** that acts. In negative feedback the action reverses the change, so the value comes back towards its set point.

The receptors for heart rate are in the walls of the arteries. **Baroreceptors** in the aortic arch and the carotid arteries of the neck sense how much the wall is stretched, so they monitor blood pressure. Sensory neurons carry their impulses to the control centre, the **medulla oblongata** of the brainstem. The medulla coordinates a response and sends impulses along nerves to the heart, changing the **heart rate** and the **stroke volume**.

Pressure is not all the medulla is told about. **Chemoreceptors**, in small bodies in the walls of the same arteries and in the brainstem itself, monitor the blood's pH and its concentrations of oxygen and carbon dioxide.

Two cases. **Exercise**: working muscles make more carbon dioxide, and in hard exercise lactic acid too, both lowering the pH, so in the IB's model the heart speeds up, as above. In a real body the brain also speeds the heart from the first stride, before the blood has changed, and signals from the working muscles help. **Blood pressure**: stand up quickly and blood pools in your legs for a moment, so the pressure in the arteries falls; the baroreceptors are stretched less, and the medulla speeds the heart and raises the pressure again. If the pressure rises too high, they are stretched more, and the medulla slows the heart.

KEY POINTS

- Baroreceptors (blood pressure) and chemoreceptors (pH, carbon dioxide, oxygen) in the aortic arch and carotid arteries; chemoreceptors in the brainstem too.
- The medulla coordinates and sends impulses to the heart, changing heart rate and stroke volume.
- The response reverses the change: negative feedback.

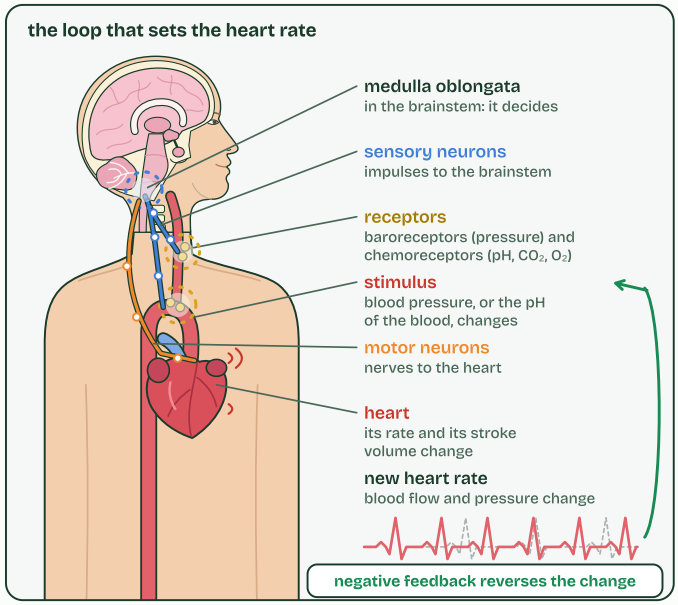
KEY TERMS

baroreceptors
Stretch receptors in the walls of the aortic arch and the carotid arteries that monitor blood pressure.

medulla oblongata
The lowest part of the brainstem, joined to the spinal cord; it coordinates the control of heart rate, breathing and swallowing.

stroke volume
The volume of blood the left ventricle pumps out in one beat.

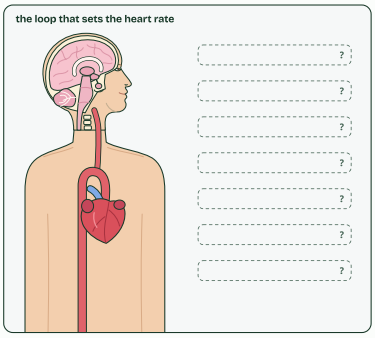
chemoreceptors
Receptors that monitor the chemistry of the blood: its pH and its concentrations of carbon dioxide and oxygen.



STEP BY STEP

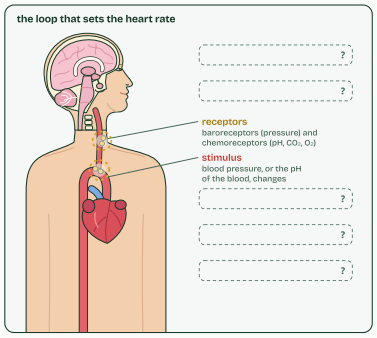
6 STEPS

1



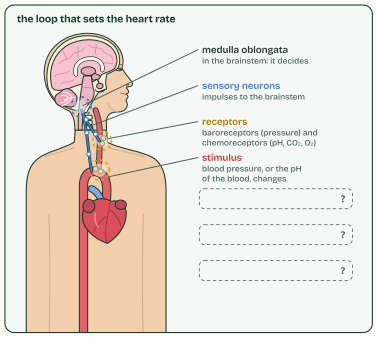
The loop that sets the heart rate, as empty boxes. Predict before you step on: what starts it?

2



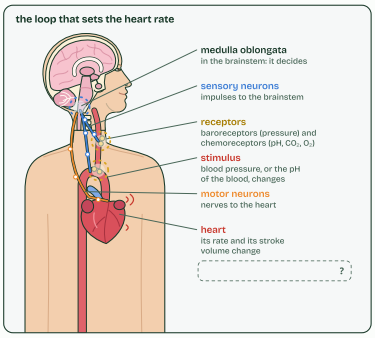
A **stimulus**: the blood pressure, or the pH of the blood, changes. **Baroreceptors** (pressure) and **chemoreceptors** (pH, carbon dioxide, oxygen) in the aortic arch and carotid arteries detect it.

3



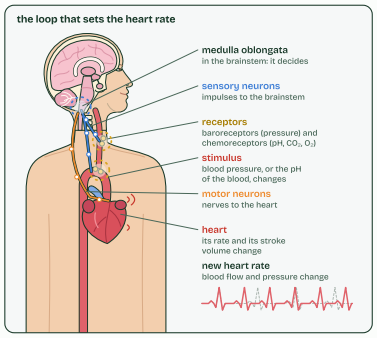
Sensory neurons carry impulses to the control centre, the **medulla oblongata**, which coordinates a response.

4



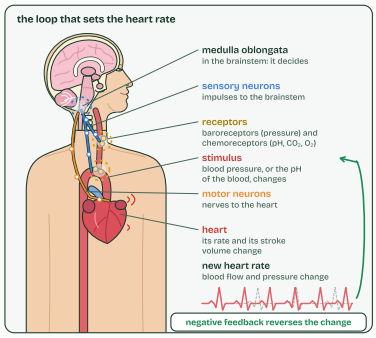
The medulla sends impulses along **motor neurons** to the **heart**, changing its rate and its stroke volume.

5



The **new heart rate** changes the blood flow and the pressure.

6

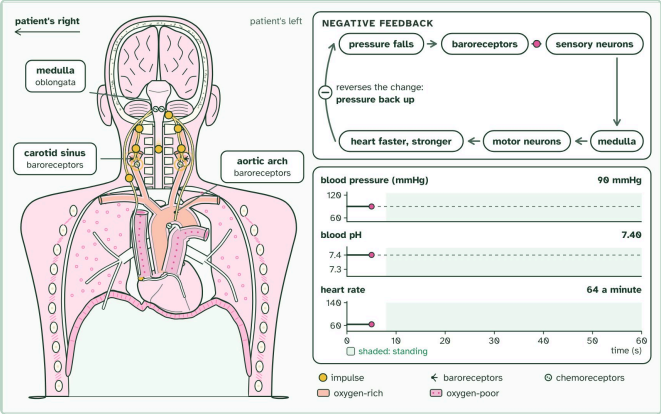


The change is reversed: the pressure or the pH goes back towards normal. That is **negative feedback**.

ANIMATION · HEART RATE UNDER CONTROL

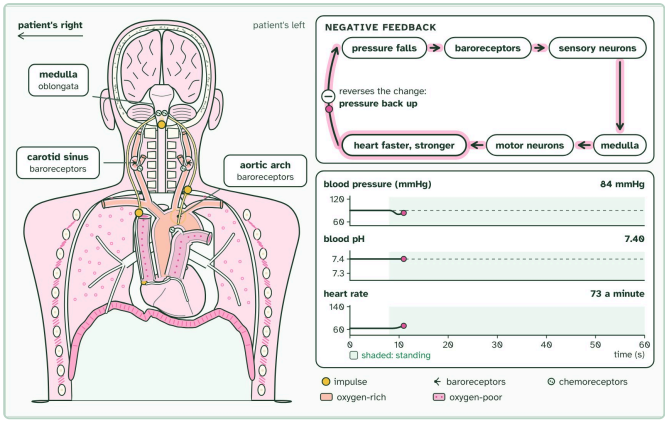
3 MOMENTS

1 64 BEATS A MINUTE



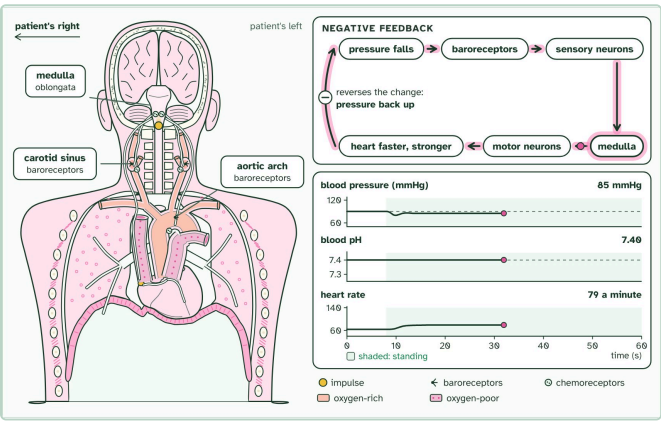
They send a steady stream of impulses along sensory neurons to the **medulla oblongata**, which holds the heart rate steady.

2 73 BEATS A MINUTE



The person **stands up quickly**. Blood pools in the legs, less returns to the heart, and the stroke volume and the blood pressure fall.

3 79 BEATS A MINUTE



The blood pressure rises back towards normal: the response **reverses the change** that started it. This is **negative feedback**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#heartrate

PREDICT

During hard exercise the blood leaving the working muscles carries more carbon dioxide. What happens to the heart rate?

(A) It falls, since baroreceptors sense the high pressure and slow the heart

(B) It stays the same, since the SA node alone sets the rate of the heart

(C) It rises, since chemoreceptors report the fall in pH to the medulla

(D) It rises, since the SA node senses the carbon dioxide in its own wall

Decide before you look. Answer on page 80.

REMEMBER IT

The parts of every feedback loop, in order

R Rabbits	C Can	E Escape
Receptor detects the change	**Control centre** the medulla decides	**Effector** the heart responds

WATCH OUT

"Baroreceptors detect oxygen." They detect stretch, so pressure. "The heart is started by a nerve." The SA node starts each beat; nerves change the rate. "The medulla is part of the heart." It is in the brainstem. And "negative feedback is bad." Negative means the response reverses the change.

BEYOND THE GUIDE

Two sets of nerves run from the medulla to the heart: sympathetic nerves speed it up, and the vagus nerve slows it down. Epinephrine (chapter 17) adds to the sympathetic nerves. See the heart's own beat in B3.2, and measure a pulse rising and recovering on B3.2's pulse bench.

C3.1.15 FEEDBACK CONTROL OF VENTILATION RATE FOLLOWING SENSORY INPUT FROM CHEMORECEPTORS

20 Breathing to *order*

Every cell that respires makes carbon dioxide (C1.2), and the more it works, the more it makes. Breathing has to keep pace, and it is set by the brainstem, not by the lungs.

Every cell that respires makes carbon dioxide (C1.2), and the more it works, the more it makes. Carbon dioxide dissolves in the blood and reacts with water to form carbonic acid, which releases hydrogen ions: so **more carbon dioxide means a lower pH**. That is the cause of most changes in the pH of the blood; in hard exercise, lactic acid from anaerobic respiration lowers it too.

Chemoreceptors in the brainstem monitor the pH of the blood and of the fluid round the brain; chemoreceptors in the aorta and carotid arteries add their own reports. When the pH falls, the medulla sends impulses more often along the nerves to the **diaphragm** and the **intercostal muscles**, which contract more often and more strongly. The **ventilation rate** rises, and breaths get deeper (B3.1). More carbon dioxide is breathed out, so the pH rises back: negative feedback. When carbon dioxide falls, breathing slows.

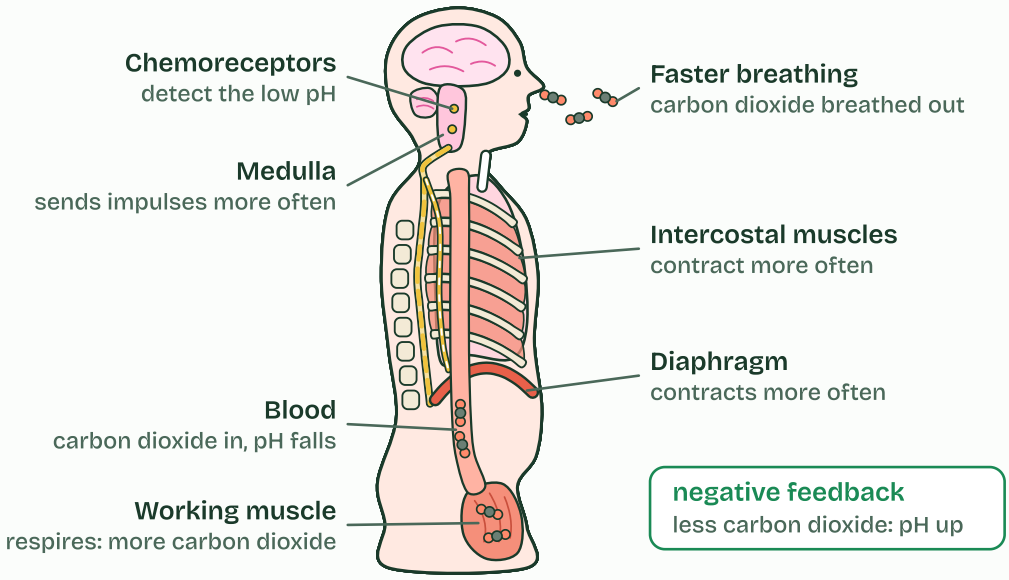
It is carbon dioxide, through its effect on pH, that normally drives breathing. A low oxygen level matters only when it falls a long way, as at high altitude. In the IB's model, ventilation and heart rate rise together in exercise because the same chemoreceptors report to the same medulla. In moderate exercise the carbon dioxide in arterial blood barely changes, though: signals from the brain's movement areas and from the working muscles drive much of the rise.

KEY POINTS

- More carbon dioxide in the blood lowers its pH.
- Chemoreceptors in the brainstem monitor the pH; the medulla sends impulses to the diaphragm and intercostal muscles.
- Breathing faster removes carbon dioxide and the pH recovers: negative feedback.

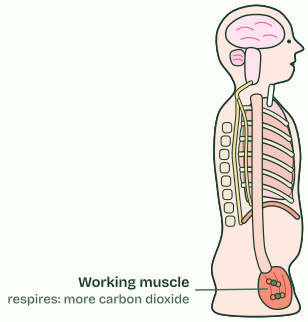
KEY TERMS

ventilation rate
The number of breaths taken per minute.


Chemoreceptors
detect the low pH
Medulla
sends impulses more often
Blood
carbon dioxide in, pH falls
Working muscle
respires: more carbon dioxide
Faster breathing
carbon dioxide breathed out
Intercostal muscles
contract more often
Diaphragm
contracts more often
negative feedback
less carbon dioxide: pH up

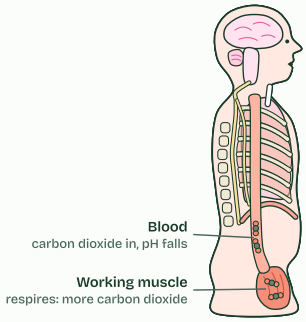
STEP BY STEP
5 STEPS

1



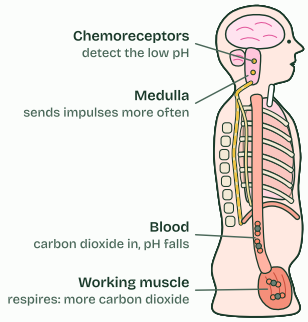
Working muscle respires faster and makes more **carbon dioxide**. Predict: what happens to the blood?

2



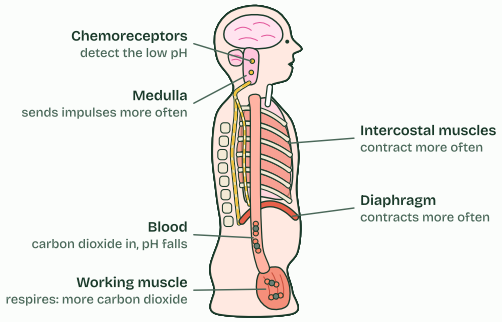
Carbon dioxide dissolves in the blood and forms carbonic acid, so the blood's **pH falls**.

3



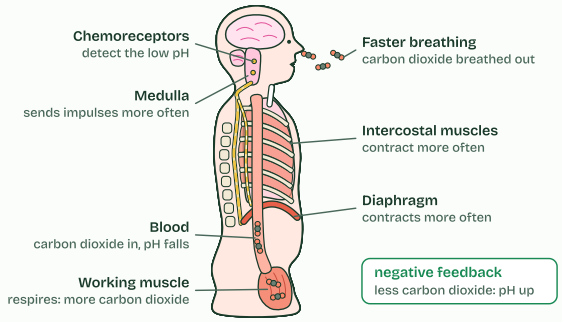
Chemoreceptors in the brainstem detect the lower pH, and the **medulla** sends impulses more often.

4



The impulses reach the **diaphragm** and the **intercostal muscles**, which contract more often and more strongly.

5

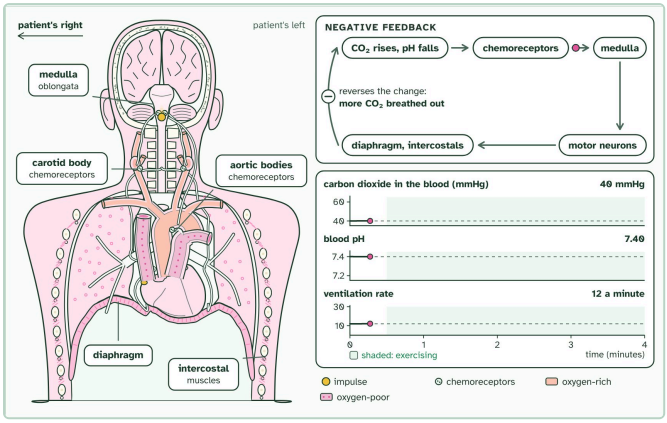


The **ventilation rate** rises, more carbon dioxide is breathed out, and the pH comes back up: **negative feedback**.

ANIMATION · BREATHING UNDER CONTROL

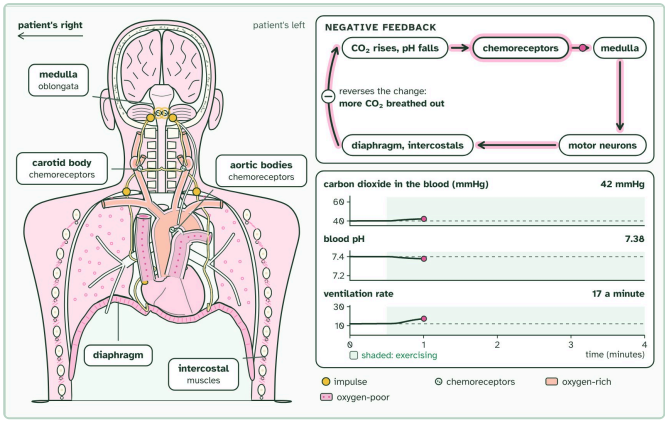
3 MOMENTS

1 12 BREATHS A MINUTE



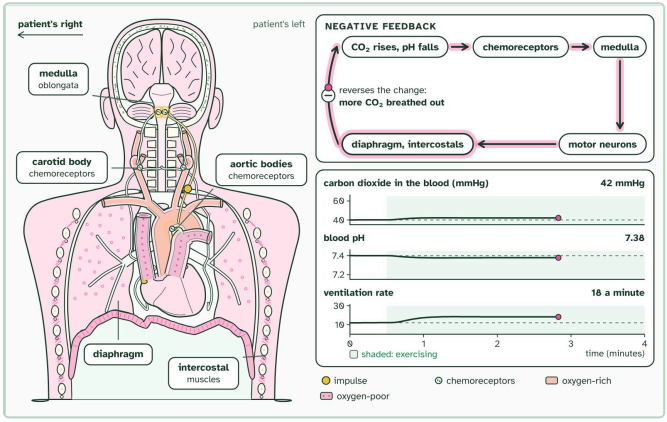
Chemoreceptors in the medulla monitor the pH of the blood and of the fluid round the brain; those in the carotid and aortic bodies add to the signal.

2 17 BREATHS A MINUTE



Exercise starts. The muscles give off more carbon dioxide. It reacts with water in the blood to form carbonic acid, and the **pH falls**.

3 18 BREATHS A MINUTE



The pH stays close to normal while the exercise goes on: **negative feedback**. It is carbon dioxide, through pH, that drives the breathing, not a shortage of oxygen.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#ventilation

PREDICT

A person finishes a hard sprint and stands still, but their breathing stays fast for another minute. What keeps it fast?

(A) The chest muscles are tired out and so cannot slow down again yet

(B) The blood is short of oxygen, and the brain is calling for more of it

(C) The heart is still beating fast, and drags the breathing along with it

(D) The blood still has extra carbon dioxide, so its pH is still lower

Decide before you look. Answer on page 80.

WATCH OUT

"Low oxygen is what makes us breathe faster." Normally it is rising carbon dioxide and falling pH. "The lungs control breathing themselves." The medulla does, through the muscles. "Holding your breath is safe, as the urge to breathe always comes in time." Rising carbon dioxide does force a breath, but breathing hard first lowers the carbon dioxide, so the urge comes late, and swimmers have blacked out underwater that way. And "the diaphragm moves on its own." It contracts when nerve impulses reach it.

SEE IT

The muscles that breathe, in B3.1; measure ventilation after exercise on B3.1's spirometer bench; and where the carbon dioxide comes from, in C1.2.

C3.1.16 CONTROL OF PERISTALSIS IN THE DIGESTIVE SYSTEM BY THE CENTRAL NERVOUS SYSTEM AND ENTERIC NERVOUS SYSTEM

21 A gut with a mind of its *own*

Food is moved along the gut by **peristalsis**: a wave of contraction in the muscle of the gut wall, the muscle just behind a mass of food (a **bolus**) contracting while the muscle in front of it relaxes. Who controls it depends on where the food is.

The **central nervous system** controls the two ends, voluntarily. You decide when to start swallowing, and you decide when to egest faeces, by relaxing the ring of muscle at the anus (the external sphincter). Between those points, from the oesophagus through the stomach and the small and large intestines, peristalsis is involuntary, controlled by the **enteric nervous system** (ENS): a net of hundreds of millions of neurons in the gut wall. Its neurons sense the stretch of the wall round a bolus and coordinate the muscle behind it to contract and the muscle in front to relax, in the right order and the right place, so material passes along the gut in a coordinated way. The brain can adjust the ENS, speeding or slowing the gut, but the ENS can run peristalsis even when the nerves from the brain are cut.

Egestion is the IB's word for getting rid of undigested material as faeces; it is not excretion, which removes waste made by the body's own metabolism.

KEY POINTS

- The CNS controls the start (swallowing) and the end (egestion), voluntarily.
- Between them, the ENS in the gut wall controls peristalsis, involuntarily, and coordinates the passage of material.

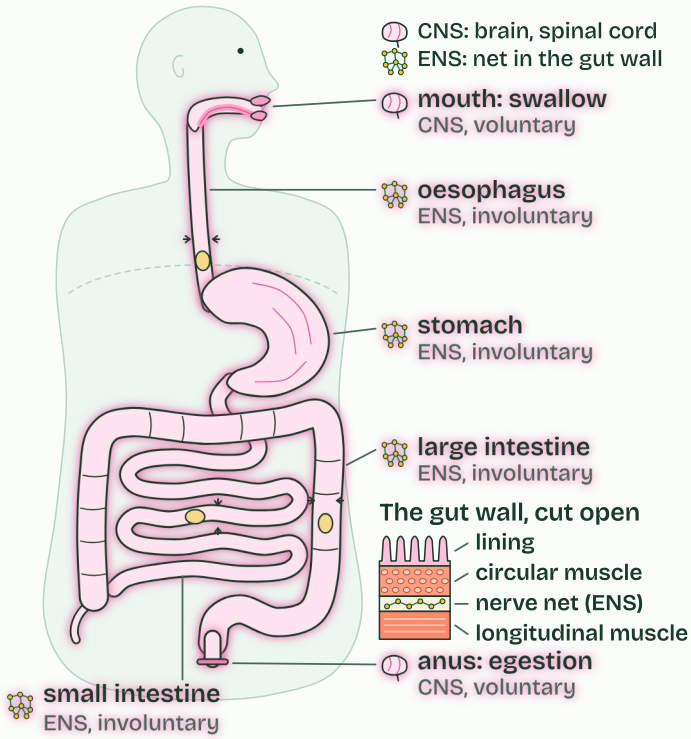
KEY TERMS

peristalsis
A wave of muscle contraction in the wall of the gut that pushes food along: the muscle behind the food contracts while the muscle in front relaxes.

bolus
A soft ball of chewed food, mixed with saliva, that is swallowed and moved along the gut.

enteric nervous system
The network of neurons in the wall of the gut, from the oesophagus to the anus, that controls peristalsis without needing the brain.

egestion
Getting rid of undigested food, as faeces, from the anus. It is not excretion: excretion removes waste made by the body's own metabolism.



Small intestine About 6 m long. The enteric nervous system senses the stretch of the wall round each bolus and squeezes behind it: involuntary.

Anus: egestion You choose when to relax the outer ring of muscle (the external sphincter) and egest the faeces: the central nervous system, voluntary.

Stomach Waves of contraction mix the food and push it on, coordinated by the enteric nervous system in its wall: involuntary.

Mouth: swallowing starts You choose when to swallow: the central nervous system, voluntary. Once the bolus is in the throat, the rest of the swallow runs by itself.

Stomach Waves of contraction mix the food and push it on, coordinated by the enteric nervous system in its wall: involuntary.

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Large intestine Slower waves move the remains on and water is absorbed; still the enteric nervous system, involuntary.

Oesophagus Waves of peristalsis carry each bolus down to the stomach, under involuntary control (the IB puts all the gut between the two ends under the ENS).

Mouth: swallowing starts You choose when to swallow: the central nervous system, voluntary. Once the bolus is in the throat, the rest of the swallow runs by itself.

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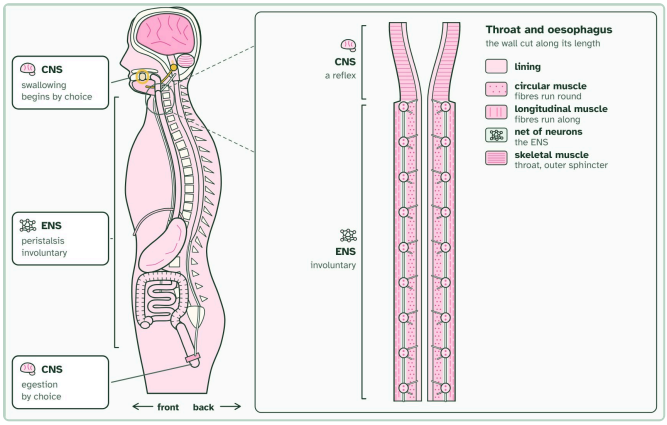
Anus: egestion You choose when to relax the outer ring of muscle (the external sphincter) and egest the faeces: the central nervous system, voluntary.

Small intestine About 6 m long. The enteric nervous system senses the stretch of the wall round each bolus and squeezes behind it: involuntary.

ANIMATION · A BOLUS DOWN THE GUT

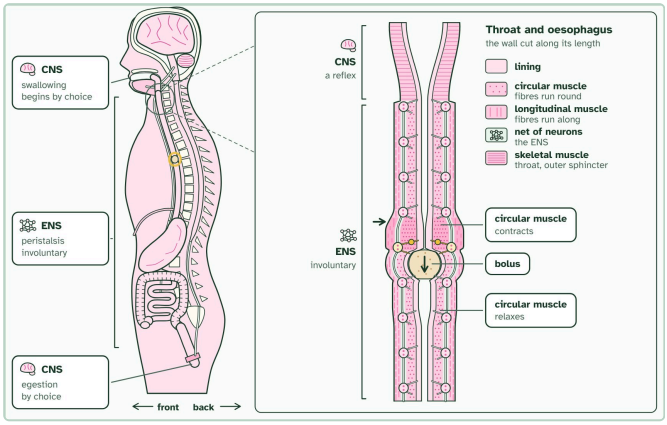
4 MOMENTS

1 MOUTH



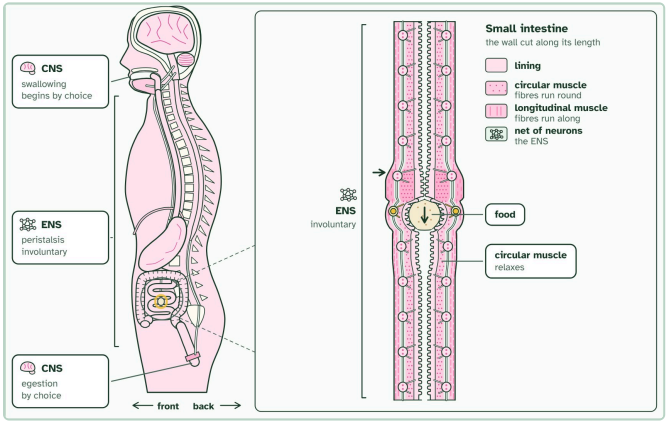
Swallowing starts when the person chooses to: the brain sends impulses to the tongue, which pushes the bolus back. This start is **voluntary**, under the **central nervous system** (CNS).

2 OESOPHAGUS



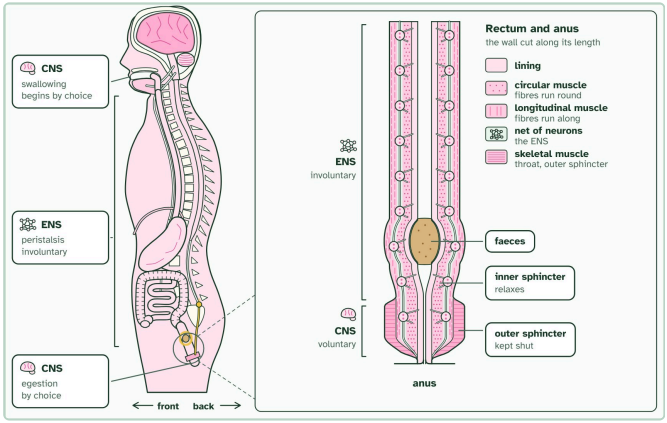
Behind the bolus the ENS makes the circular muscle **contract** and squeeze; in front of it the muscle **relaxes**. The squeeze moves on: **peristalsis**.

3 SMALL INTESTINE



Nerves link the brain to the gut, but they only adjust the pace. Between swallowing and egestion, every wave is run by the ENS.

4 RECTUM



The outer sphincter is skeletal muscle, kept shut by impulses from the spinal cord. It opens only when the person decides.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#peristalsis

PREDICT

A student swallows a mouthful of bread. By the time it reaches the small intestine, what controls the squeezing of the gut wall?

(A) The nerve net in the gut wall itself, without the student choosing

(B) The brain, which orders each squeeze by choice through the spinal cord

(C) The cerebellum, which times the gut's contractions as it does the limbs

(D) The gut muscles alone, which contract by themselves with no nerves

Decide before you look. Answer on page 80.

WATCH OUT

"Peristalsis moves blood in the veins." Only the gut has peristalsis. "The brain must keep telling the gut to work." The ENS runs it. "The gut has no neurons of its own." It has hundreds of millions. And "food falls down the gut by gravity." Astronauts swallow and digest in orbit, and you can swallow standing on your head.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

accuracy 01
How close a measurement is to the true value.

active transport 04
Moving a substance across membranes using energy from ATP. It can move a substance towards where it is already more concentrated.

adrenal glands 17
Two endocrine glands, one on top of each kidney; their inner part, the adrenal medulla, secretes epinephrine.

angle of curvature 01
The angle between the vertical, the way the shoot grew before, and the line the tip of the shoot now points along.

apical dominance 06
The main shoot tip holding back the growth of the side buds below it, by the auxin it sends down the stem.

apoplast 04
The cell walls and the spaces between plant cells: everything outside the cells' membranes.

auxin efflux carriers 04
Proteins in a plant cell's membrane that move auxin out of the cell. A cell can place them on one side only, so auxin leaves through that side.

baroreceptors 19
Stretch receptors in the walls of the aortic arch and the carotid arteries that monitor blood pressure.

body system 08
A group of organs that work together, such as the nervous system or the blood system.

bolus 21
A soft ball of chewed food, mixed with saliva, that is swallowed and moved along the gut.

cell elongation 05
Growth of a plant cell by getting longer, as its loosened wall is stretched by the pressure of the water inside.

central nervous system 13
The brain and the spinal cord.

cerebellum 11
The part of the brain under the back of the cerebral hemispheres that coordinates the timing and force of skeletal muscle contractions, and keeps balance.

cerebral hemispheres 10
The two halves of the cerebrum, the large folded upper part of the brain: thought, memory, voluntary movement and the meaning of what the senses send.

chemoreceptors 19
Receptors that monitor the chemistry of the blood: its pH and its concentrations of carbon dioxide and oxygen.

circadian rhythm 16
A cycle in the body's activity of roughly 24 hours, such as sleeping and waking, kept in step with day and night by light.

coleoptile 02
The pointed sheath that covers the young shoot of a grass seedling as it grows up through the soil.

concentration gradient 04
A difference in concentration between two places, such as more auxin at one end of a tissue than at the other.

conscious 12
Processes we are aware of and can control by choice, such as speaking or throwing a ball; the cerebral hemispheres deal with them.

cross-links 05
Links between the cellulose fibres of a plant cell wall, made by other carbohydrates bonded to them. Loosening them lets the wall stretch.

cytokinin 06
A phytohormone that makes plant cells divide. Made mainly in root tips, it travels up to the shoots in the xylem sap.

effector 13
A muscle or gland that responds to impulses from a motor neuron.

egestion 21
Getting rid of undigested food, as faeces, from the anus. It is not excretion: excretion removes waste made by the body's own metabolism.

emergent property 08
A property of a whole system that none of its parts has alone, and that arises from how the parts interact.

endocrine system 09
The glands that secrete hormones into the blood, and the hormones themselves.

enteric nervous system 21
The network of neurons in the wall of the gut, from the oesophagus to the anus, that controls peristalsis without needing the brain.

epinephrine 17
A hormone, also called adrenaline, secreted by the adrenal glands in danger or excitement; it prepares the body for vigorous activity.

free nerve ending 15
The bare, branching end of a sensory neuron in the skin, with no special receptor cell; many detect damaging heat or pressure and act as pain receptors.

grey matter 12
Nervous tissue made mostly of cell bodies, dendrites and the interneurons that connect neurons; it forms the inner butterfly of the spinal cord.

hormones 09
A chemical messenger secreted by an endocrine gland into the blood, which carries it to every part of the body; it acts only on target cells with the right receptor.

hypothalamus 18
A small region at the base of the brain that links the nervous system to the endocrine system: it monitors the body and controls the pituitary gland.

integration 08
Coordinating the parts of a system so that together they carry out an overall function that none of them could do alone.

interneurons 12
A neuron inside the brain or spinal cord that passes impulses from one neuron to another.

involuntary 15
Not under conscious control: it happens whether or not we choose.

medulla oblongata 19
The lowest part of the brainstem, joined to the spinal cord; it coordinates the control of heart rate, breathing and swallowing.

melatonin 16
A hormone secreted by the pineal gland in the dark; its rise at night prepares the body for sleep.

motor neurons 13
A neuron that carries impulses from the central nervous system to an effector, a muscle or a gland.

myelinated 14
Wrapped in myelin, layers of fatty membrane laid down by Schwann cells, which insulate the fibre and make impulses travel much faster.

negative feedback 07
A loop in which a change sets off a response that reverses it, bringing a value back towards its set point.

negative tropism 01
Growth away from the stimulus.

nerve 14
A bundle of many nerve fibres, the long axons of neurons, wrapped in a protective sheath of connective tissue.

nerve fibres 14
The long axon of a neuron, which carries impulses.

nervous system 09
The brain, spinal cord and nerves: neurons that carry electrical impulses to particular targets.

organ 08
A structure made of several tissues that carries out a particular job, such as the heart or a leg muscle.

peristalsis 21
A wave of muscle contraction in the wall of the gut that pushes food along: the muscle behind the food contracts while the muscle in front relaxes.

phytohormones 03
Signalling chemicals that plants make in small amounts to control their growth, their development and their responses to stimuli. Also called plant hormones.

pineal gland 16
A small gland deep in the brain that secretes melatonin, mostly at night.

pituitary gland 18
A pea-sized gland hanging just below the hypothalamus; its hormones control several other endocrine glands and some tissues directly.

positive feedback 07
A loop in which a change sets off a response that pushes the change further, so it speeds up until something stops it.

positive phototropism 02
Growth of a shoot towards light that comes from one side: a positive tropism.

positive tropism 01
Growth towards the stimulus: a shoot growing towards light from one side, for example.

precision 01
How finely a measurement is made, and how closely repeated measurements agree with each other.

proton pumps 05
Proteins in the plasma membrane that use energy from ATP to pump hydrogen ions (protons) out of the cell.

qualitative 01
Observations that describe, in words or pictures, without measuring: the shape of a shoot, its colour, which way it bends.

quantitative 01
Observations recorded as numbers, measured with an instrument and given a unit: an angle in degrees, a length in millimetres.

receptor cells 13
A cell or nerve ending that detects a stimulus, such as light, pressure or heat, and starts impulses in a sensory neuron.

reflex 15
A rapid, involuntary response to a stimulus, carried out through a reflex arc without a decision by the brain.

reflex arc 15
The pathway of a reflex: receptor, sensory neuron, interneuron in the CNS, motor neuron and effector.

reliable 01
How far a result can be trusted to come out the same when the experiment is repeated.

ripening 07
The changes that make a fruit ready to eat: its colour, sweetness, softness and scent.

sensory neurons 13
A neuron that carries impulses from receptor cells to the central nervous system.

spinal cord 12
The column of nervous tissue that runs from the brain down the back inside the vertebrae; it integrates reflexes and carries messages between the brain and the body.

stroke volume 19
The volume of blood the left ventricle pumps out in one beat.

systematic error 01
An error that shifts every reading the same way, such as a camera at a slant. Repeating the measurement does not remove it.

target cell 09
A cell with a receptor that a particular hormone binds to, so it responds to that hormone.

tissue 08
A group of similar cells that work together to carry out one function, such as muscle tissue.

tropism 01
A growth response whose direction is set by the direction a stimulus comes from, such as light from one side.

unconscious 12
Processes that go on without our awareness, such as reflexes, digestion and the heartbeat.

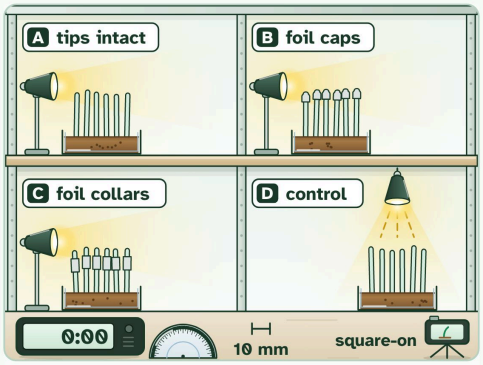
ventilation rate 20
The number of breaths taken per minute.

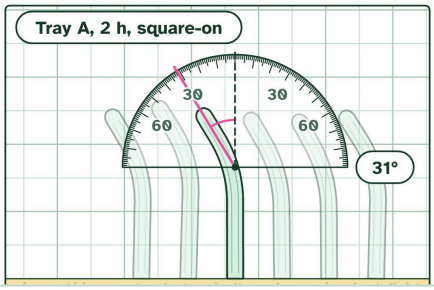
white matter 12

Nervous tissue made mostly of myelinated nerve fibres; it surrounds the grey matter of the spinal cord and carries messages up and down it.

Dry lab: *Seedlings and light*

Four trays of oat seedlings, each under its own lamp. Cap their tips, cut them off or change the light, then record what happens two ways: a drawing with notes, and photographs in which you measure every seedling's angle of curvature with an on-screen protractor.





Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-c3-1-integration-of-body-systems#lab`

Your question

How do oat seedlings respond to light from one side, and how well can you measure it? Pick one thing to investigate, the tip, the light or the lamp's distance, and set each tray to one value of it. Keep one tray as the control, lit evenly from above.

What you can change

The tip (intact, under a foil cap, with a foil collar just below it, or cut off), the light (from one side, darkness, or a slow turntable that turns every side to the lamp in turn), the lamp's distance (20 to 100 cm) and how many seedlings each tray holds. Change one thing across the trays and keep the rest the same.

What to record

The clock stops at 0, 1, 2, 4, 6, 24 and 48 hours. At each stop you can draw the trays with short notes, your qualitative record, and photograph them from the side to measure every seedling's angle of curvature, your quantitative record. Change the camera or the protractor's scale to test what limits your precision and accuracy. The coach under the bench helps you plan, process and evaluate.

Find out

- **Does the tip matter?** Trays lit from one side with the tips intact, under foil caps and with foil collars just below the tips, beside a control tray lit evenly from above. Then run it again with the tips cut off in one tray. Record at 0, 1, 2, 4 and 6 hours, then again at 24.
- **Does the light have to come from one side?** Light from one side, darkness, and a slow turntable that turns every side of the tray to the lamp in turn, beside a control tray lit evenly from above.
- **Does a closer lamp give a bigger bend, or a faster one?** The lamp at three or more distances from 20 to 100 cm, every tip intact. Compare the angles at 2 hours and at 24.
- **How good are your measurements?** Photograph one tray square-on, then with the camera turned and with it raised, and read the angles to 1 degree and to 5. Compare each set of readings with the square-on ones.

Record

- For every tray: what you changed, its value, and what you kept the same (the seedlings' age, the lamp, the temperature, the time).
- A drawing of the trays at each time you choose, with up to three short notes on each: your qualitative record.
- A side-on photograph at each time, and every seedling's angle of curvature: one arm of the protractor along the vertical, the other along the top 5 mm of the shoot. After three by hand, Measure the rest for me reads the others the same way every time.
- Angles towards the lamp count as positive. The mean and standard deviation of each tray at each time; the table and the graph fill in as you go, or download the CSV and plot your own. When you are done, the IA coach below the dry lab helps you write it up as an investigation.

Your question How do oat seedlings respond to light from one side, and how well can you measure it? Pick one thing to investigate, the tip, the light or the lamp's distance, and set each tray to one value of it. Keep one tray as the control, lit evenly from above.**What you can change**The tip (intact, under a foil cap, with a foil collar just below it, or cut off), the light (from one side, darkness, or a slow turntable that turns every side to the lamp in turn), the lamp's distance (20 to 100 cm) and how many seedlings each tray holds. Change one thing across the trays and keep the rest the same.**What to record**The clock stops at 0, 1, 2, 4, 6, 24 and 48 hours. At each stop you can draw the trays with short notes, your qualitative record, and photograph them from the side to measure every seedling's angle of curvature, your quantitative record. Change the camera or the protractor's scale to test what limits your precision and accuracy. The coach under the bench helps you plan, process and evaluate.

Back to biology

Use your results to explain why seedlings lit from one side bend towards the lamp, and why those with foil caps do not.

QUESTIONS ON THE LAB

QUESTION 1

On the bench, seedlings with their tips cut off stay straight for the first two hours of light from one side, but by 24 hours they have bent a little. Why?

(A) Light now reaches the growing region through the open, cut end

(B) The stump grows a new tip, which starts making auxin again

(C) The shoots are injured, and an injured shoot leans to the light

(D) Auxin made in the roots climbs the shoot to the lit side instead

Answer on page 81.

QUESTION 2

A tray on a slow turntable sits beside a lamp, so each side of every seedling faces the lamp in turn. How do the seedlings grow?

(A) Towards the lamp, because at every moment one side of it is lit

(B) In a spiral, following the lamp round as the tray turns

(C) Straight up, as every side gets the same light in the end

(D) Not at all, because the light keeps changing direction

Answer on page 81.

QUESTION 3

A camera is raised above the tray and looks down at the seedlings, instead of facing them square-on. How do the angles read from its photographs compare with the true ones?

(A) Every bend looks smaller than it really is, so the angles read too small

(B) Some read too big and some too small, so the mean stays the same

(C) They are unchanged, because the seedlings themselves have not moved

(D) Every bend looks larger than it really is, so the angles read too big

Answer on page 81.

WRITE IT UP AS AN INVESTIGATION

Your results from this dry lab can be written up the way an IB scientific investigation is: four criteria, each worth 6 marks. Tick each line as your write-up does it. The coach on the page checks these as you go; it never gives a mark.

1 Research design

A focused question set in its biology; your choices of what to measure, how, over what range and how often, explained rather than listed; what you kept the same and how; safety, ethics and the environment; a method someone else could follow and repeat.

- [ ] My question names what I changed.
- [ ] It gives the range I used, with units.
- [ ] It names what I measured and how.
- [ ] It names the organism or system.
- [ ] My background explains, with the biology, why the two should be linked.
- [ ] I cite my sources, and each reference can be traced.
- [ ] If I give a hypothesis, it predicts and explains.
- [ ] Every variable has its How, Why and Units.
- [ ] For each thing kept the same, I say how I kept it so.
- [ ] I list at least three things I kept the same.
- [ ] I name the apparatus that set what I changed, and the instrument that measured.
- [ ] I test enough values.
- [ ] My values spread wide enough.
- [ ] I run at least three trials at every value.
- [ ] I run a control.
- [ ] I explain why these values, this many and this often.
- [ ] Someone else could repeat my method.
- [ ] I deal with safety, ethics and the environment.

2 Data analysis

Raw data recorded clearly, with titles, units, uncertainties and the same decimal places down a column; what you saw as well as what you measured; processing that suits the question, shown with a worked example; the spread shown; a graph a reader can trust.

- [ ] Each table has a numbered title that says what it shows.
- [ ] Every heading has its quantity and its unit.
- [ ] Every raw data heading has its uncertainty.
- [ ] Each uncertainty is realistic for the instrument.
- [ ] Each uncertainty has the same decimal places as its readings.
- [ ] I record what I saw as well as what I measured.
- [ ] I show one worked example of my processing, and it is right.
- [ ] I say why I left out any trial.
- [ ] My error bars show a spread my repeats can support.
- [ ] My graph has a numbered title and labelled axes with units.
- [ ] I say what the error bars show.
- [ ] A straight line, if I draw one, has its R^2.
- [ ] A statistical test, if I run one, has its hypotheses and suits the data.

3 Conclusion

Your question answered from the processed data, with numbers quoted and the spread taken into account; the biology that explains the pattern; a comparison with published work; no claim bigger than the data.

- [ ] I answer my question in a sentence, naming both variables.
- [ ] I quote my processed numbers.
- [ ] I say how sure the spread lets me be.
- [ ] I say whether my hypothesis is supported.
- [ ] I explain the pattern with biology.
- [ ] I compare my result with published work, and cite it.
- [ ] I claim no more than my data show.

4 Evaluation

Weaknesses and limitations of this method (not slips in carrying it out), with evidence from your own data, the effect each had on the results, which mattered most and why, and a realistic improvement for each.

- [ ] I give at least three weaknesses or limitations.
- [ ] Every row is filled in.
- [ ] No slips in carrying it out: weaknesses of the method itself.
- [ ] Each improvement is specific: which instrument, how many, what changes.
- [ ] Each effect says what it did to my data.
- [ ] At least two rows point to evidence in my own data.
- [ ] At least one limitation: what this experiment cannot tell me.
- [ ] I say which mattered most, and why.
- [ ] I deal with what stands out in my data.
- [ ] My improvements improve this investigation, not a new one.

Variables

Variable	How?	Why?	Units
Independent: treatment of the tip			
Dependent: mean rate of curvature			
Kept the same: direction of the light (from one side)			
Kept the same: distance from the lamp			
Kept the same: the lamp (the same bulb and power)			
Kept the same: the seedlings (one batch of oat grains, the same age)			
Kept the same: height of the seedlings when the lamp goes on			
Kept the same: temperature of the room			
Kept the same: other light in the room			
Kept the same: water given to the compost			
Kept the same: how the angle is measured (the camera's place and the protractor)			

Evaluation

Weakness or limitation	Which?	Evidence in my data	Effect on my results	Improvement

Data generated with the seedlings dry lab, biologybybradford.com (a simulation; the values are illustrative). These checks catch what is missing. They cannot judge how good it is: that is what your teacher does.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on C3.1 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=C3.1&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Two students measure the same seedling's angle of curvature. One photographs it square-on from the side; the other from above and to one side. Whose angle is more accurate?

C The square-on one, as at a slant a bend looks smaller or larger

The square-on photograph. Seen at a slant, a bend is squashed in one direction: with the camera turned to one side the angle looks smaller, and from above it looks larger. That is a systematic error, and no protractor fixes it, because the picture itself is wrong. A finer scale only makes the reading more precise. In the Dry lab you can photograph the same tray with the camera square-on, turned or raised, and compare the angles.

02 The tip of a grass seedling is covered with a foil cap, and the seedling is lit from one side. What happens?

B It grows straight up: the part that senses light is in the dark

It grows straight up. The growing region below the cap is still lit from one side, but it does not sense light: the tip does, and the tip is in the dark. With no signal from the tip that the light is uneven, both sides grow at the same rate. A collar of foil just below the tip does not stop the bend, because the tip still sees the light. Try the cap and the collar with the film's Tip control, below.

03 Abscisic acid is sprayed on the leaves of a well-watered plant in bright light. What happens to its rate of photosynthesis over the next hour?

D It falls, because its stomata close and less carbon dioxide gets in

Its rate of photosynthesis falls. The stomata close: abscisic acid is the signal a plant makes when it is short of water, and when it reaches the guard cells they close the stomata, even though this plant has plenty of water. So the leaves lose less water, but less carbon dioxide gets in, and photosynthesis slows, just as if the plant were short of water. You can watch abscisic acid close a stoma in the stomata film in B3.1.

04 In a row of five cells, every cell has its auxin efflux carriers on its left side, but the middle cell's carriers are blocked by a chemical. Auxin is added to the right-hand cell. Where does it build up?

C In the middle cell, which takes the auxin in but cannot pass it on

In the middle cell. Auxin is passed left, cell by cell, as far as the middle cell. It takes it in, but with its carriers blocked it cannot send it out again, so the auxin piles up there and none reaches the cells on the left. Point the pumps, below, lets you try your own pattern.

05 Short pieces of shoot, with their tips cut off, are floated in an acidic buffer instead of an auxin solution. What happens?

A They grow longer, as if given auxin: the acid loosens the walls

They grow longer, as if they had been given auxin, at least for the first hour or two. The acid in the buffer does what the pumped hydrogen ions do: it loosens the walls, and water stretches them. This is some of the evidence for the chain: an acidic buffer makes coleoptile pieces grow fast, and a neutral buffer, which stops the walls turning acidic, blocks the quick effect of auxin on their growth. They do not bend, because the acid reaches every side equally.

06 A gardener pinches out the growing tip of a basil plant. What happens over the next two weeks?

D Side buds lower down grow into new shoots: it gets bushier

Buds lower down grow into new side shoots, and the plant gets bushier. The tip was the main source of the auxin that held those buds back. With it gone, the buds are released, and cytokinin from the roots helps them grow. Gardeners pinch out basil for exactly this: more shoots, so more leaves to pick. Less auxin now reaches the roots, not more, and cytokinin comes from the roots, not the tip.

07 A box of green bananas is stored with a sachet that absorbs ethylene from the air. What happens?

B **They ripen later and less together, as the gas is taken up first**

They ripen later, and less together. Each banana can still start to ripen in its own time, but the sachet takes up much of the ethylene the first ones give off before it reaches the rest, so the loop spreads from fruit to fruit far more slowly. Shippers keep green bananas cool, and taking the ethylene out of the air keeps them green for longer. Try the absorber in the film below.

08 A cheetah's legs, lungs, heart and brain are each healthy, but none of them is connected to the others. Can it sprint?

D **No, as a sprint needs the parts to work together, and belongs to the whole**

No. A sprint needs the legs moved in time by the nervous system, oxygen brought by the lungs, heart and blood, fuel released from stores, and a brain steering the chase, all at once. The sprint is a property of the whole integrated animal and of none of its parts. Take any one connection away and it fails.

09 A hot pan burns a fingertip. A hormone, released at the same moment from a gland in the head, must reach the same fingertip. Which message arrives first?

C **The nerve message, because it runs along a neuron the whole way there**

The nerve message. An impulse travels along a neuron at up to about 100 metres a second, so it covers the length of an arm in a few hundredths of a second. A hormone must be secreted, carried round in the blood (a full lap of the body takes about a minute at rest) and picked up by receptors: seconds to minutes. Try both in the tool below.

10 A patient can hold a phone number in mind for half a minute and gets faster each day at a new drawing task, but cannot remember meeting you an hour ago. What does this show?

B **Different kinds of memory and learning depend on different parts of the brain**

Memory is not one thing in one place. Holding a number for a few seconds, learning a skill and storing facts and events for good depend on different parts of the brain, and only one of them was lost. This is the real case of a patient known for decades as H.M.: step through the figure below.

11 A person whose cerebellum is damaged is asked to throw a ball at a target. What is most likely?

D **The throws scatter, as the arm's muscles are no longer timed and measured**

The throws scatter. The person can still aim and can still move: the cerebral hemispheres start the throw. But without the cerebellum the arm's muscles fire a little early or late and a little too hard or too soft, so the ball lands all over the place. Set the cerebellum to damaged in the tool and watch the landings spread.

12 A person's spinal cord was cut across in the middle of the back months ago. A pin touches the sole of their foot. What happens?

C **The foot pulls away by reflex, but the person does not feel the pin**

The foot pulls away by reflex, but nothing is felt. The reflex arc runs through the cord below the cut, and it is intact. But the message cannot climb past the cut to the brain, so the person is not aware of the pin. (Just after an injury, reflexes below it are lost for a while, called spinal shock: that is why the question says months ago.)

13 A person watches a ball fall and catches it. Put these in order: motor neuron, receptor cells in the eye, cerebral hemispheres, arm muscle, sensory neuron. Which comes third?

B **The cerebral hemispheres, between the neurons that bring and send it**

The cerebral hemispheres. Receptor cells in the eye, then sensory neurons to the brain, then the cerebral hemispheres, which decide, then motor neurons out (down the spinal cord), then the arm muscles contract. In by sensory, out by motor, with the decision in between. Play the film below.

14 One nerve in a person's arm is cut. They lose all feeling in part of the hand and cannot move some of the fingers. What does that show about the nerve?

A **It held both sensory and motor fibres, bundled in the one sheath**

It held both sensory and motor fibres. Cutting the sensory fibres stops messages from the skin reaching the CNS, so feeling is lost; cutting the motor fibres stops messages reaching the finger muscles, so they cannot contract. One cut, two losses: a mixed nerve carries messages in both directions at once.

15 A person pulls a hand away from a hot object. When do they feel the pain?

C **After the hand has moved, since the reflex is done in the spinal cord**

After the hand has moved. The reflex arc is complete inside the spinal cord, so the hand is already moving about a tenth of a second after the touch. A second message climbs the cord to the brain, which takes longer to build the feeling: the pain arrives after the hand is safe. Step through the figure.

16 A person lives in a room with no windows, lit by a bright lamp for 20 hours a day. What happens to their night-time melatonin?

A **It stays low while the lamp is on, so its night-time rise is cut short**

It stays low while the lamp is on, so the rise is delayed and cut short. Light on the retina reaches the clock, which keeps the pineal gland from secreting melatonin. With only four hours of dark there are only four hours of high melatonin. Set the light to Bright lamp all day in the film.

17 A person is startled and runs. Compared with rest, what happens to the blood flow to the gut and to the leg muscles?

B **Less goes to the gut and more to the leg muscles, as arterioles change width**

Less to the gut and more to the leg muscles. Epinephrine narrows the arterioles that supply the gut and the skin and widens those in the skeletal muscles, so more of the blood the heart pumps goes where oxygen and glucose are needed now. Digestion can wait. Set Stress to startled in the tool and compare the muscle and gut bars.

18 A drug blocks the receptors on a target gland that respond to a pituitary hormone. What happens to the pituitary's output of that hormone?

D **It rises, since less of the gland's hormone means weaker feedback**

It rises. The gland cannot respond, so it secretes less of its own hormone. The hypothalamus and pituitary detect too little of it, so the negative feedback that held them back is weaker, and they secrete more. Switch Feedback off in the tool to see what the loop does.

19 During hard exercise the blood leaving the working muscles carries more carbon dioxide. What happens to the heart rate?

C **It rises, since chemoreceptors report the fall in pH to the medulla**

It rises. Carbon dioxide makes the blood more acidic. Chemoreceptors detect the fall in pH and send impulses to the medulla, which sends impulses to the heart to beat faster and more strongly. More blood flows through the lungs and the muscles, carbon dioxide is removed faster, and the pH comes back: negative feedback.

20 A person finishes a hard sprint and stands still, but their breathing stays fast for another minute. What keeps it fast?

D **The blood still has extra carbon dioxide, so its pH is still lower**

The extra carbon dioxide, and lactic acid. The muscles made a lot of carbon dioxide during the sprint, and lactic acid from anaerobic respiration, and it takes time to breathe the carbon dioxide out and clear the acid. Until the pH is back to normal, chemoreceptors keep reporting it to the medulla, and the medulla keeps the breathing fast. Step through the figure.

21 A student swallows a mouthful of bread. By the time it reaches the small intestine, what controls the squeezing of the gut wall?

A **The nerve net in the gut wall itself, without the student choosing**

The nerve net in its own wall, the enteric nervous system, involuntarily. The student chose only to swallow. From the lower oesophagus to the rectum the wave runs by itself. The figure below marks who controls each part.

QUESTIONS ON THE DRY LAB

Q1 On the bench, seedlings with their tips cut off stay straight for the first two hours of light from one side, but by 24 hours they have bent a little. Why?

B The stump grows a new tip, which starts making auxin again

The stump grows a new tip. Within a few hours of the cut, the cells at the top of the stump start to sense the light and to make auxin again, as the old tip did, so the stump can bend, though less. That is why the tip experiments are read in the first hours. Light through the cut end is not it, and auxin does not climb from the roots: shoot tips make it.

Q2 A tray on a slow turntable sits beside a lamp, so each side of every seedling faces the lamp in turn. How do the seedlings grow?

C Straight up, as every side gets the same light in the end

Straight up. As the tray turns, each side of a shoot faces the lamp for the same time, so over a turn the light is even, as it is from above. No side gets more auxin than the others for long, so no side grows faster, and the seedlings grow as upright as the control tray. They still grow longer, as the control does.

Q3 A camera is raised above the tray and looks down at the seedlings, instead of facing them square-on. How do the angles read from its photographs compare with the true ones?

D Every bend looks larger than it really is, so the angles read too big

Every bend looks larger. Looking down at a seedling shortens how tall it looks, but not how far it leans, so the line along the tip is tipped further from the vertical than it really is, and every angle reads too big in the same direction. That is a systematic error: more seedlings, repeat readings or a finer protractor scale will not remove it, and neither will taking the mean. Only putting the camera square-on does. Try it on the bench: photograph one tray square-on, then with the camera 40 degrees from above, and compare.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.