REVISION GUIDE

How living things *move*

Muscle and motility

A sarcomere shortens by sliding, a motor neuron wakes a whole unit of fibres at once, and a limb is a lever. From a barnacle's feathery legs to a dolphin's tail, follow the machinery of movement.

12 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility

Contents

01	Everything alive moves, even if it stays put HL	3
02	A muscle fibre is a stack of sarcomeres HL	5
03	Pull, let go, pull again HL	7
04	A spring, and a partner muscle HL	10
05	One neuron, many fibres HL	12
06	Something to pull against HL	15
07	Force against distance HL	17
08	Inside the hip joint HL	19
09	How far, in how many directions HL	21
10	Two layers that pull opposite ways HL	23
11	Why travel at all? HL	26
12	Built for diving HL	27
	Key terms	31
	Dry lab: Range of motion	32
	Check yourself	33
	Answers	34

By the end you can

- [ ] Describe movement in motile and sessile organisms B3.3.1
- [ ] Explain muscle contraction with the sliding filament model B3.3.2
- [ ] Explain the roles of titin and antagonistic muscles in relaxation B3.3.3
- [ ] Describe the structure and function of a motor unit B3.3.4
- [ ] Describe skeletons as anchorage for muscles and as levers B3.3.5
- [ ] Describe movement at a synovial joint, using the hip B3.3.6
- [ ] Compare and measure the range of motion of joints B3.3.7
- [ ] Explain how the intercostal muscles act as antagonists in breathing B3.3.8
- [ ] Give reasons for locomotion, with an example of each B3.3.9
- [ ] Describe adaptations of marine mammals for swimming B3.3.10

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

01

B3.3.1 HL ADAPTATIONS FOR MOVEMENT AS A UNIVERSAL FEATURE OF LIVING ORGANISMS

Everything alive *moves*, even if it stays put

Movement is a feature of all living things. An **motile** organism, such as a salmon, moves its whole body to find food, escape, or breed. A **sessile** organism, such as an acorn barnacle or a plant, stays where it is, but it also moves parts of itself.

A barnacle sweeps its feathery legs through the water to catch food. A Venus flytrap closes its leaf on an insect. A plant bends its shoot toward the light and its roots toward water. Even the larva of a barnacle is a free-swimming animal, which is how the species spreads. Movement lets organisms get food, avoid being eaten, find mates and disperse, and an organism's structure is adapted to the kind of movement it makes: a salmon has muscles and a streamlined body, a barnacle has limbs that can be extended.

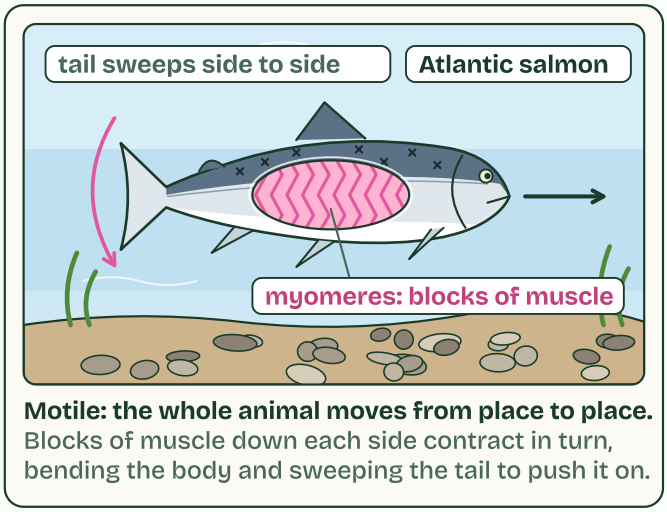
KEY POINTS

- **Motile** organisms move from place to place; **sessile** organisms are fixed in place.
- Sessile organisms still **move parts** of their bodies, to feed or to grow toward resources.
- Movement is used to **find food, escape, find a mate and disperse**.

KEY TERMS

motile
Able to move from place to place under its own power.

sessile
Fixed in one place, usually attached to a surface, for most or all of its life.

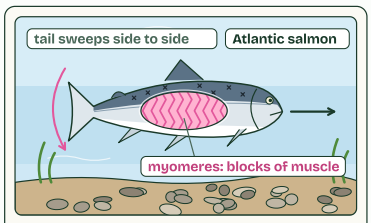


Motile: the whole animal moves from place to place. Blocks of muscle down each side contract in turn, bending the body and sweeping the tail to push it on.

SWITCH IT

3 SETTINGS

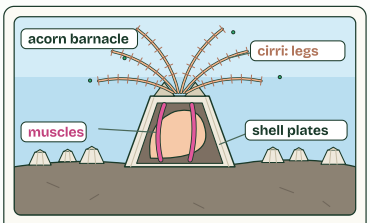
1



Motile: the whole animal moves from place to place.
Blocks of muscle down each side contract in turn, bending the body and sweeping the tail to push it on.

Salmon (motile)

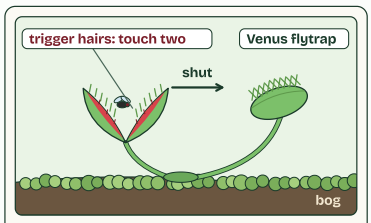
2



Sessile: cemented to the rock for life,
but muscles sweep its feathery legs, the cirri, through the water to catch food.

Barnacle (sessile)

3



Sessile: rooted in the bog, yet a leaf snaps
shut in a fraction of a second. No muscles: water moves in its cells to flip the leaf's shape.

Flytrap (sessile)

PREDICT

A barnacle is glued to a rock for its adult life. Which statement is correct?

(A) It cannot move, so it is not a living organism

(B) It is sessile but moves parts of its body, for feeding

(C) It is motile, because it can move its shell open and shut

(D) Its larva is sessile and its adult is motile

Decide before you look. Answer on page 34.

02 A muscle fibre is a *stack of sarcomeres*

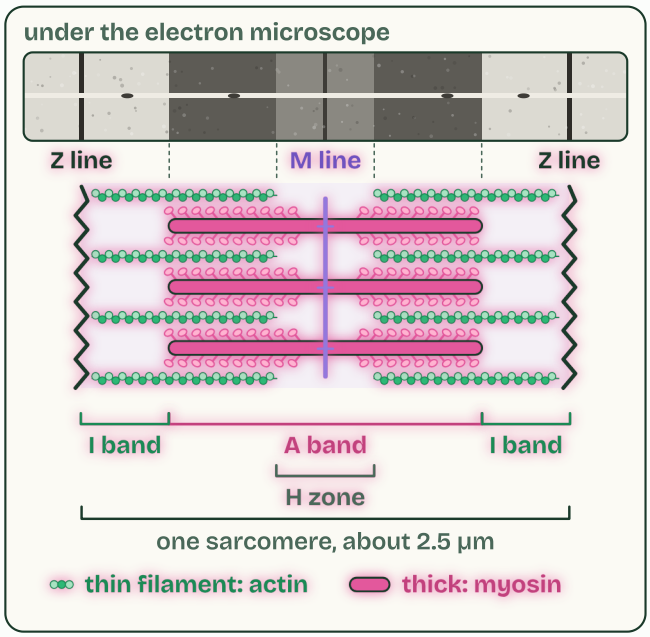
B3.3.2 HL THE STRUCTURE OF A SARCOMERE

A skeletal muscle is made of long cells called muscle fibres. Each fibre is packed with thread-like **myofibrils**, and each myofibril is a chain of repeating units called **sarcomeres**. The sarcomere is the part that shortens, so the muscle shortens when thousands of sarcomeres in a row shorten together.

Look at it under an electron microscope and the filaments make **bands**. Learn where each one is, because the examination asks you to read a micrograph and say what happens to each band in contraction. Tap each part of the diagram to see its name and what it does.

KEY TERMS

sarcomeres
The unit of a myofibril, from one Z line to the next. It contains overlapping thin (actin) and thick (myosin) filaments and is the part that shortens in muscle contraction.



Thin filaments are made mostly of the protein **actin**. One end of each is anchored in a Z line, and they reach in toward the middle of the sarcomere. They do not shorten when a muscle contracts: they slide.

Z lines The mark the two ends of one sarcomere. The thin filaments are anchored to them. In contraction the Z lines are pulled closer together, so the sarcomere gets shorter.

A band The is the whole length of the thick filaments (dark in a micrograph). It stays the **same length** when the muscle contracts, because the thick filaments do not change length.

H zone The is the gap in the middle of the A band with **only thick filaments**, between the tips of the thin ones. It gets **shorter** in contraction, and can vanish.

Thick filaments are made of the protein **myosin**. Each is a bundle of myosin molecules whose **heads** stick out toward the thin filaments. They stay in the middle of the sarcomere, and do not shorten when a muscle contracts.

M line The is the middle of the sarcomere, where the thick filaments are held together. It lies in the centre of the H zone.

I band The is the part with **only thin filaments** (light in a micrograph), between the end of the thick filaments and the Z line. It gets **shorter** in contraction.

READING A MICROGRAPH

Light bands (I) have thin filaments only; dark bands (A) have thick filaments, and the narrow light zone in the middle of the dark band (H) has thick filaments only. Measure from Z line to Z line for the length of one sarcomere.

03 Pull, let go, *pull again*

B3.3.2 HL SLIDING FILAMENT MODEL OF MUSCLE CONTRACTION

The **sliding filament model** says that a sarcomere shortens because the thin filaments slide between the thick ones. The filaments themselves keep their length.

The steps are a cycle that repeats, many times a second, in every sarcomere:

A nerve impulse makes the fibre release **calcium ions**.
Calcium makes **tropomyosin** move, which **uncovers the binding sites** on actin.
The **myosin heads bind** to actin.
The heads **pivot** (the power stroke) and pull the thin filaments toward the centre.
ATP binds to the head, which lets go of actin. The ATP is split, and the head re-cocks, ready to bind again further along.

While calcium is present the cycle goes on and the sarcomere shortens. When calcium is taken back up, the sites are covered and the sarcomere is stretched out again.

KEY POINTS

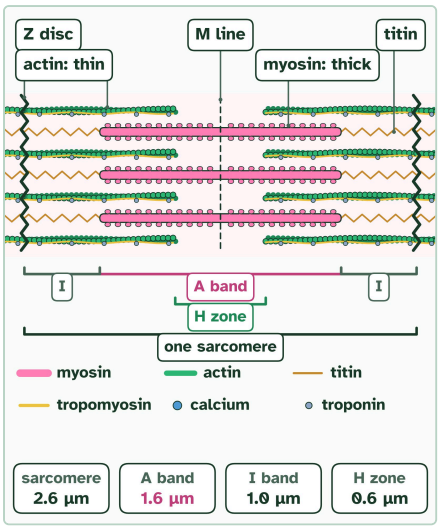
- Thin filaments **slide** between thick filaments, pulled by **myosin heads**. Neither shortens.
- The **I band** and **H zone** shorten. The **A band** does not.
- **Calcium** uncovers the sites; **ATP** lets the heads go.

KEY TERMS

sliding filament model
The explanation of muscle contraction in which thin actin filaments are pulled past thick myosin filaments by the myosin heads, so the sarcomere shortens although neither filament does.

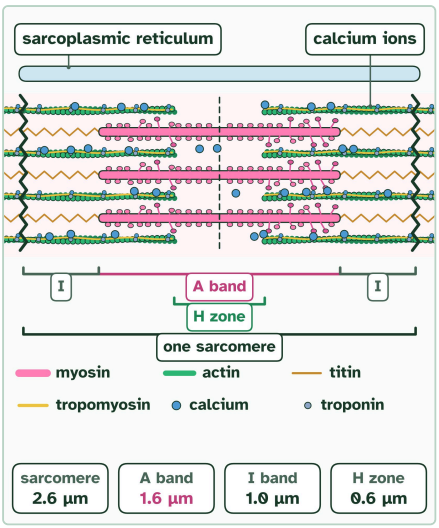
ANIMATION · SLIDING FILAMENTS
9 MOMENTS

1 AT REST



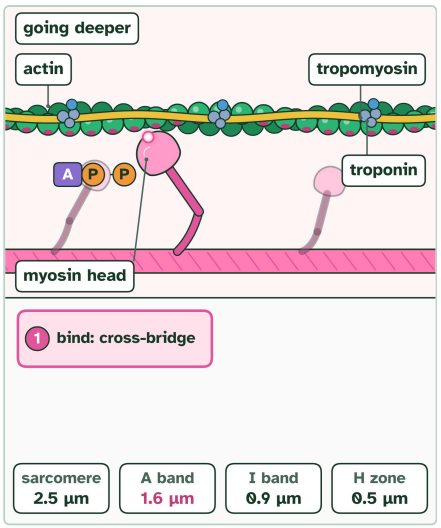
One **sarcomere**, between two **Z discs**. Thin filaments of **actin** hang from each Z disc; thick filaments of **myosin**, bristling with heads, lie between them. Springs of **titin** tie the thick filaments to the Z discs.

2 CALCIUM



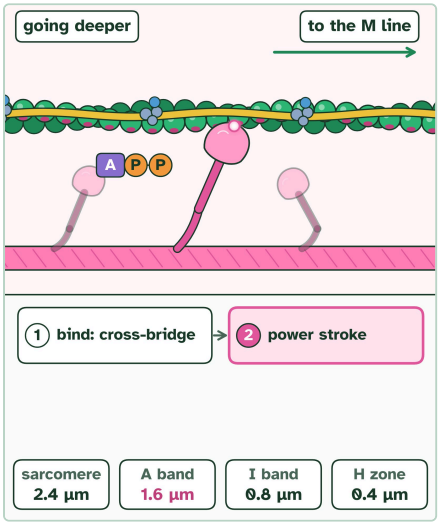
Going deeper: a nerve impulse makes the **sarcoplasmic reticulum** release **calcium ions**. They bind **troponin**, which pulls **tropomyosin** off the binding sites on the actin.

3 1 CROSS-BRIDGE



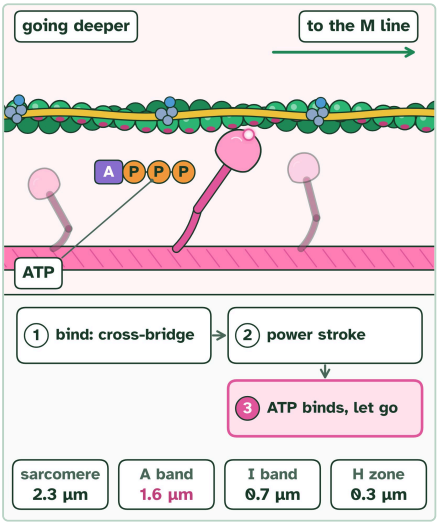
1 Cross-bridge. One myosin head, close up. Cocked and carrying ADP and phosphate, it binds an uncovered site on the actin.

4 2 POWER STROKE



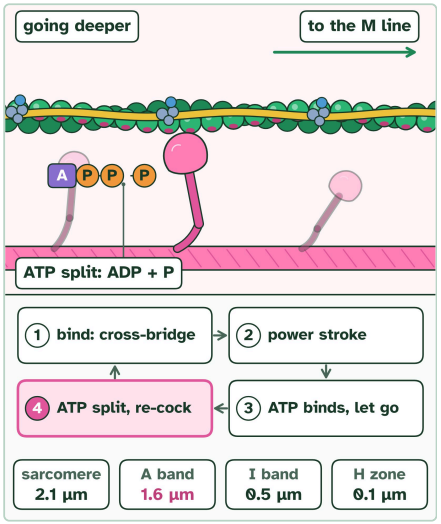
2 Power stroke. The phosphate leaves and the head swings, pulling the actin towards the M line. Then the ADP leaves.

5 3 ATP BINDS



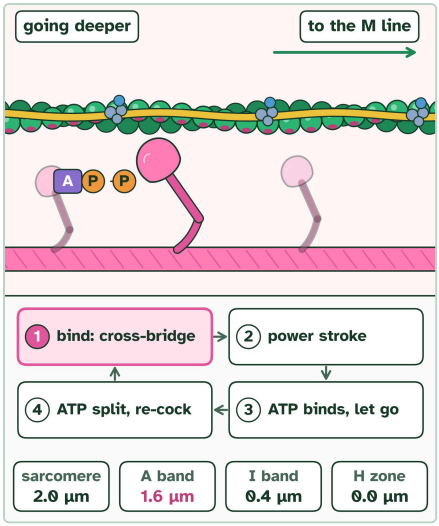
3 ATP binds. A new ATP molecule fits into the head, and the head lets go of the actin: the cross-bridge breaks.

6 4 RE-COCK



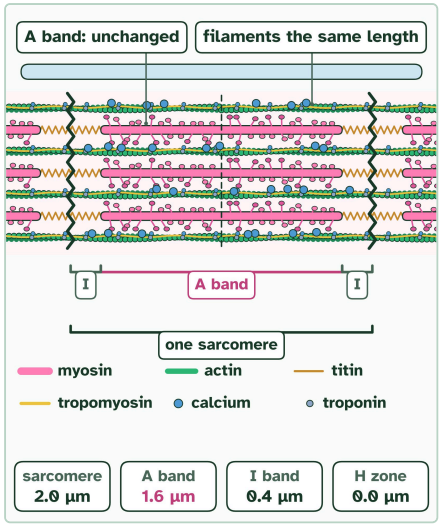
4 Re-cock. The head splits the ATP into ADP and phosphate, and the energy released cocks the head, ready to bind further along.

7 AGAIN AND AGAIN



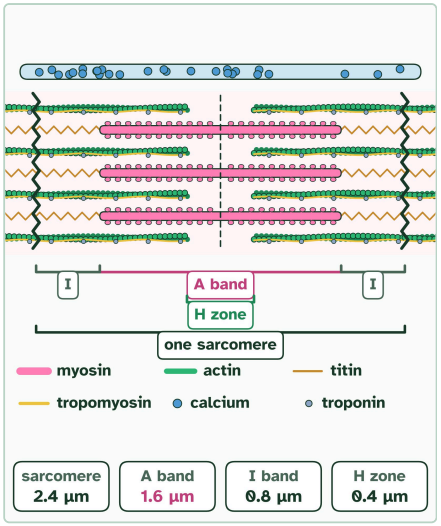
The cycle runs again and again. Thousands of heads cycle out of step, so some always hold on while others reach forward, and the actin never slips back.

8 CONTRACTED



The thin filaments have **slid** towards the M line. The sarcomere, the **I band** and the **H zone** are shorter; the **A band**, the length of the thick filament, has not changed.

9 RELAXING



When the impulses stop, calcium is pumped back, tropomyosin covers the sites and the heads let go. **Titin** and the pull of the antagonistic muscle stretch the sarcomere out again.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#sliding

REMEMBER IT

C U B P A: cats use big paws, always

C	U	B	P	A
C	U	B	P	A
Calcium released by the impulse	**Uncover** tropomyosin moves aside	**Bind** heads latch onto actin	**Pull** the power stroke slides actin	**ATP** head lets go and re-cocks

PREDICT

A muscle fibre is stimulated and its sarcomeres shorten from 2.6 to 2.0 micrometres. What happens to the length of the A band?

(A) It decreases by 0.6 micrometres, like the sarcomere

(B) It does not change, because the thick filaments do not shorten

(C) It increases, because the filaments overlap more

(D) It decreases, because the thin filaments shorten

Decide before you look. Answer on page 34.

IN THE EXAM

Explain the sliding filament model (4 marks): calcium ions released, binding sites on **actin** exposed; **myosin heads bind** to actin; heads pivot and **pull the thin filaments** toward the centre, using **ATP**; filaments **slide**, the **sarcomere shortens**, and the I band and H zone shorten while the A band does not.

04 A spring, and a *partner muscle*

B3.3.3 HL ROLE OF THE PROTEIN TITIN AND ANTAGONISTIC MUSCLES IN MUSCLE RELAXATION

Contraction is an active process, but relaxation is not: muscle fibres have no way of pushing themselves long again. Two things lengthen a relaxed muscle.

One is the protein **titin**, the largest protein in the body. Each molecule links a thick filament to a Z line and is elastic. When a sarcomere shortens, titin is compressed. When contraction stops, the titin **recoils** and helps pull the sarcomere back to its resting length. It also **resists** being stretched too far, which stops the filaments being pulled apart.

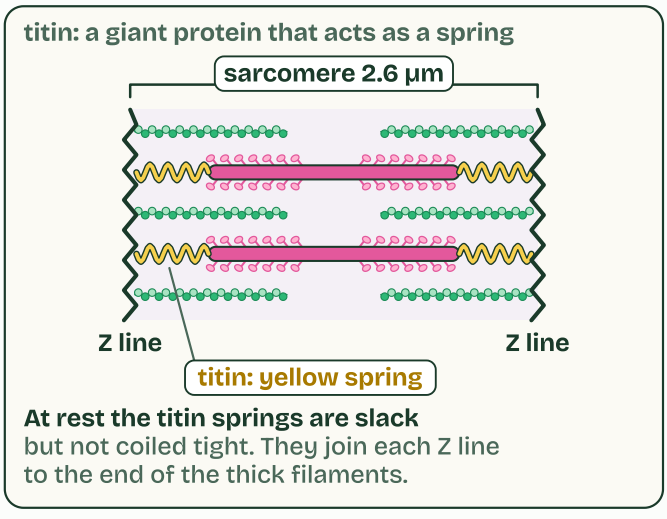
The other is an **antagonistic muscle**. A muscle can only exert force when it **contracts**: it pulls, never pushes. A joint is therefore moved by pairs of muscles that work in opposite directions. In the arm the **biceps** bends the elbow and the **triceps** straightens it. When the biceps contracts, the triceps relaxes and is stretched, and the other way round. You will meet another antagonistic pair, the intercostal muscles, in chapter 9.

KEY POINTS

- **Titin** is an elastic protein: it **recoils** after contraction and **prevents overstretching**.
- A muscle can only **pull**, so joints are moved by **antagonistic pairs**.
- Example: **biceps and triceps**; **external and internal intercostals**.

KEY TERMS

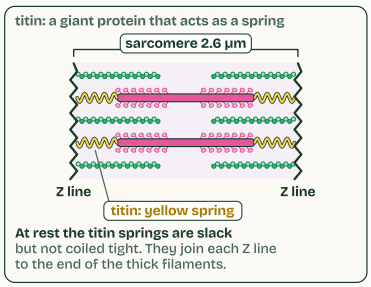
titin
A very large elastic protein that links the thick filament to the Z line in a sarcomere. It acts like a spring.



SWITCH IT

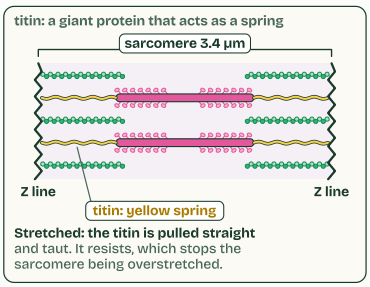
3 SETTINGS

1



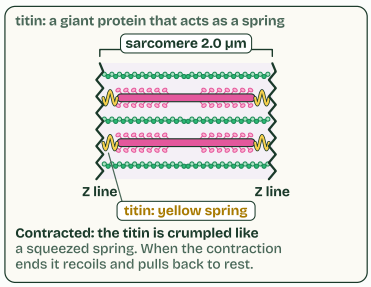
At rest

2



Stretched

3



Contracted

PREDICT

Why can a muscle that has just contracted not simply lengthen itself again?

(A) Because relaxation is the active step that needs ATP, which has run out

(B) Because muscle fibres can only pull when they contract, so something else must stretch them

(C) Because the thick filaments shrink during contraction and must be rebuilt

(D) Because calcium ions are needed to pull the filaments apart

Decide before you look. Answer on page 34.

05 One neuron, *many fibres*

B3.3.4 HL STRUCTURE AND FUNCTION OF MOTOR UNITS IN SKELETAL MUSCLE

A skeletal muscle fibre contracts only when a motor neuron tells it to. Where the axon of the neuron meets the fibre is a **neuromuscular junction**: a synapse that works as you saw in C2.1 and C2.2. A motor neuron branches, and each branch makes a junction with a different fibre.

A **motor unit** is one motor neuron and all the fibres it supplies, which contract together, all or nothing. A muscle contains many motor units, and the force it makes depends on **how many are active**. To make a bigger force the nervous system **recruits** more units, smallest first.

Muscles that need fine control, such as those that move the eye or the fingers, have many **small units**, so force changes in tiny steps. Muscles that need power, such as the thigh, have fewer, **larger units**. Use the tool below to compare them.

KEY POINTS

- A **motor unit** is one **motor neuron** and all the **fibres** it supplies through **neuromuscular junctions**.
- More force comes from **recruiting more units**.
- **Small units** give fine control; **large units** give great force.

KEY TERMS

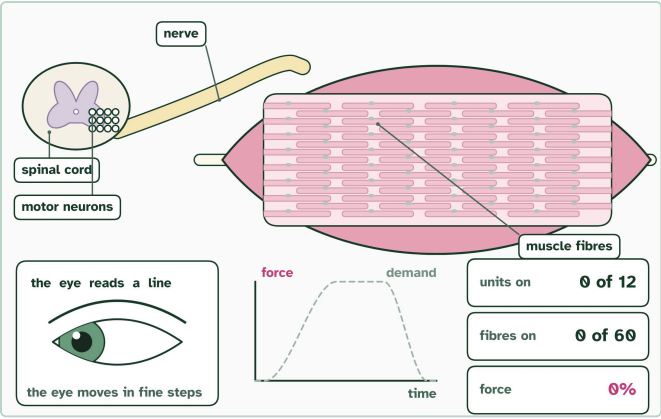
neuromuscular junction
A synapse between a motor neuron and a muscle fibre. The neuron releases acetylcholine, which makes the fibre contract.

motor unit
One motor neuron together with all the muscle fibres it supplies.

ANIMATION · MOTOR UNITS AND RECRUITMENT

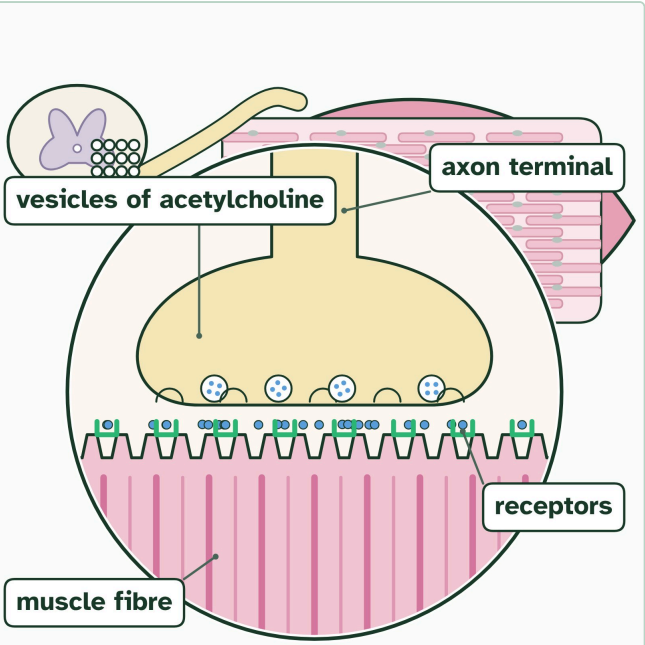
6 MOMENTS

1 A MUSCLE



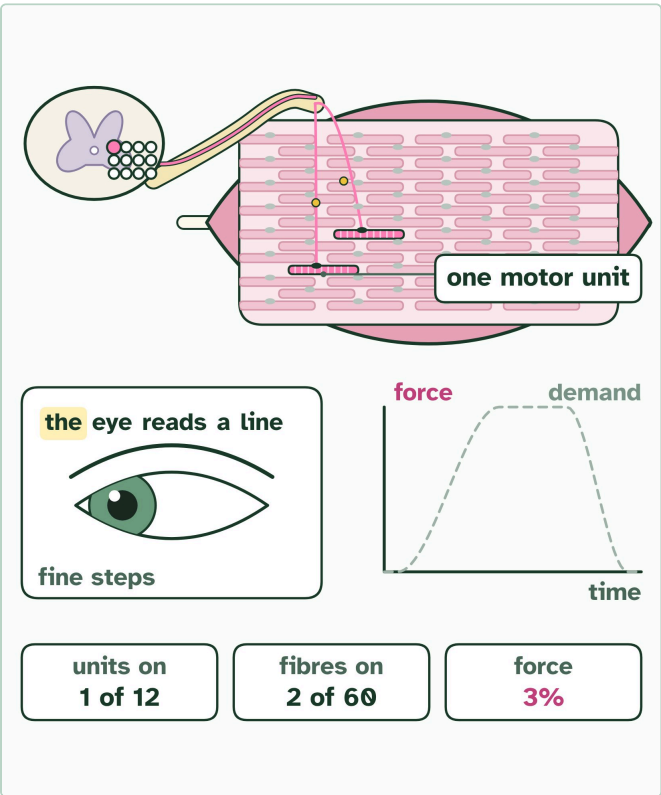
A skeletal muscle is made of many **muscle fibres**. Motor neurons in the spinal cord send their axons out in a nerve to the muscle.

2 THE JUNCTION



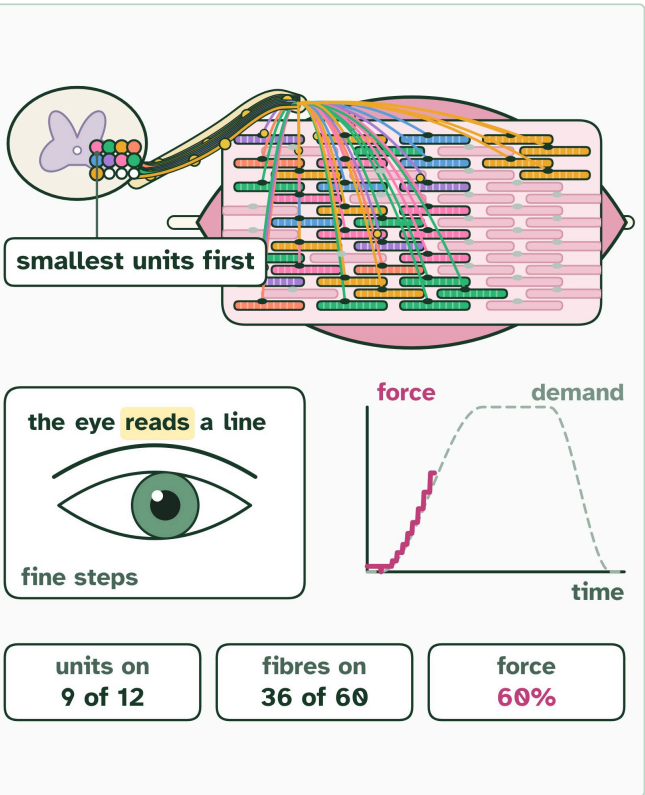
Each axon branch ends on a fibre at a **neuromuscular junction**. An impulse makes it release **acetylcholine**, which crosses the gap and binds to receptors on the fibre: the fibre contracts.

3 ONE MOTOR UNIT



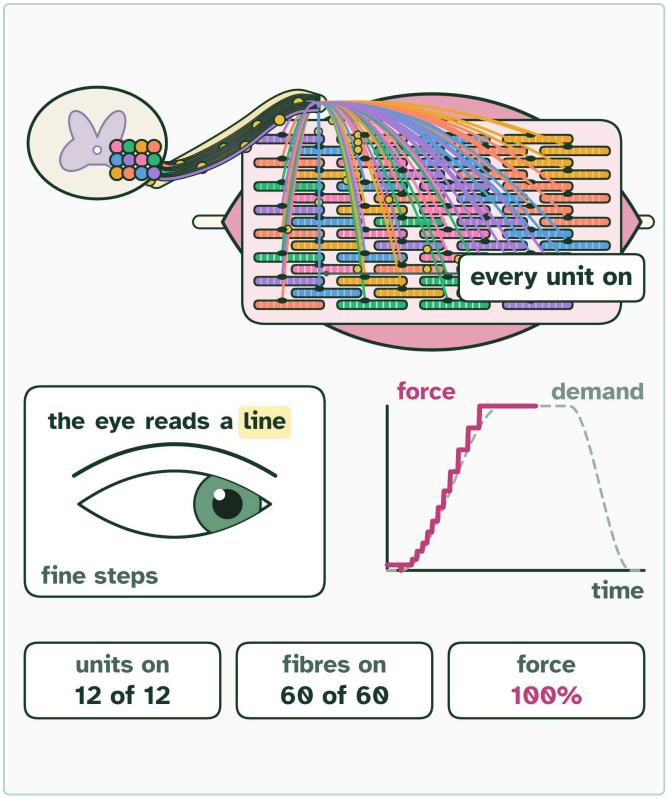
A **motor unit** is one motor neuron and all the fibres it supplies. When the neuron fires, **all its fibres contract together**.

4 RECRUITING



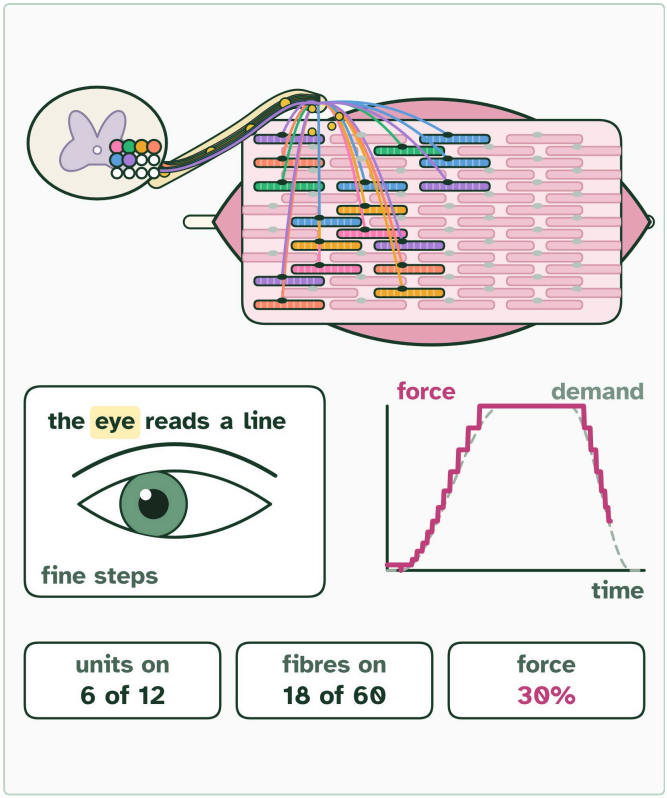
To pull harder, the nervous system **recruits more motor units**, the small ones first. The force goes up in steps, one for each unit.

5 ALL UNITS ON



At the maximum force every unit is recruited. The steps are **small** where the units are small, and **large** where the units are large.

6 UNITS DROP OUT



When the load is put down the units drop out again. Choose the other muscle and compare the size of the steps.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#motor

PREDICT

Which statement is correct about the fibres in one motor unit?

(A) They all contract together when their neuron fires

(B) They contract one after another, in a wave along the muscle

(C) They are the only fibres in the muscle that can contract

(D) They contract more strongly when the neuron fires faster, but never fully

Decide before you look. Answer on page 34.

06 Something to *pull against*

B3.3.5 HL ROLES OF SKELETONS AS ANCHORAGE FOR MUSCLES AND AS LEVERS

A contracting muscle has to pull on something firm, or it would only crumple. The skeleton does this job: it is an **anchorage** for muscles, joined to them by tendons. It also acts as a set of **levers**. A lever turns about a pivot, the joint, when a muscle pulls at one place. Depending on where the muscle pulls, the lever can multiply the force or multiply the distance and speed of the movement, but not both: see the film.

Animals have two kinds of skeleton. **Arthropods**, such as crabs and insects, have an **exoskeleton**: a hard case outside the body with the muscles inside. **Vertebrates** have an **endoskeleton**: bones inside the body with muscles attached outside. In both, muscles come in opposing pairs that pull the segments in opposite directions about a joint.

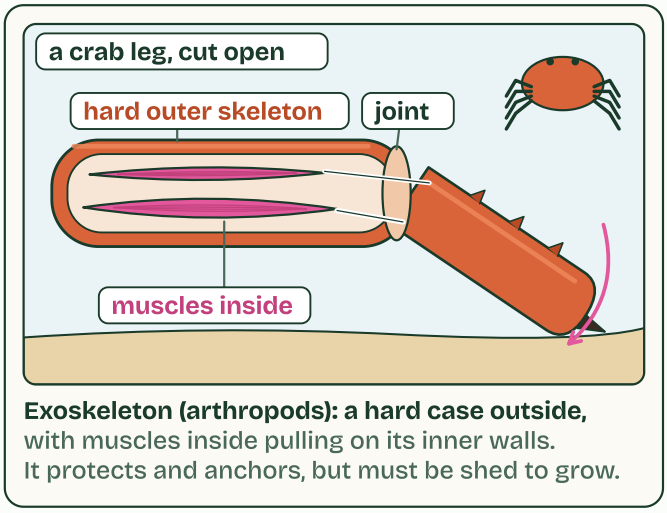
KEY POINTS

- A skeleton gives muscles an **anchorage** and acts as **levers**.
- **Arthropods:** exoskeleton, muscles inside.
- **Vertebrates:** endoskeleton, muscles outside.

KEY TERMS

exoskeleton
A hard skeleton on the outside of the body that protects it and gives anchorage to muscles, which are attached inside it.

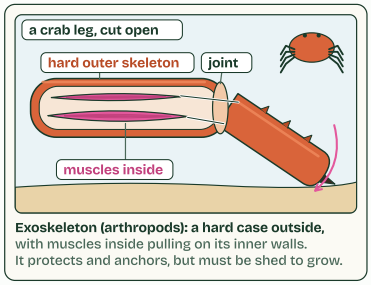
endoskeleton
A skeleton inside the body, of bone or cartilage, to which muscles are attached on the outside.



Exoskeleton (arthropods): a hard case outside, with muscles inside pulling on its inner walls. It protects and anchors, but must be shed to grow.

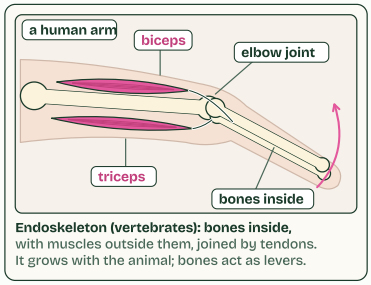
SWITCH IT
2 SETTINGS

1



Exoskeleton (crab)

2



Endoskeleton (person)

PREDICT

A muscle in the arm of a person and one in the leg of a crab are alike in which way?

(A) Each is attached to a skeleton that gives it a firm anchorage to pull against

(B) Each is attached to the inside of a hard external skeleton

(C) Each pushes the skeleton, as well as pulling it

(D) Each works alone, with no partner muscle

Decide before you look. Answer on page 34.

07

B3.3.5 HL SKELETONS AS LEVERS

Force against *distance*

In the forearm the **elbow** is the pivot (the fulcrum), the **biceps** pulls on the forearm only a few centimetres from the elbow (the effort), and the **load** is held in the hand about 30 cm away. Taking moments about the elbow, a muscle that acts close to the pivot must pull with a force several times the weight of the load. The gain is the other way: a small shortening of the muscle moves the hand a long way and fast.

Move the muscle's attachment farther from the elbow in the tool below, and the force needed falls, but so does the distance the hand moves. A lever can trade force for distance and speed. Muscles are mostly attached close to joints, which suits animals that need to move quickly, over a range of movement.

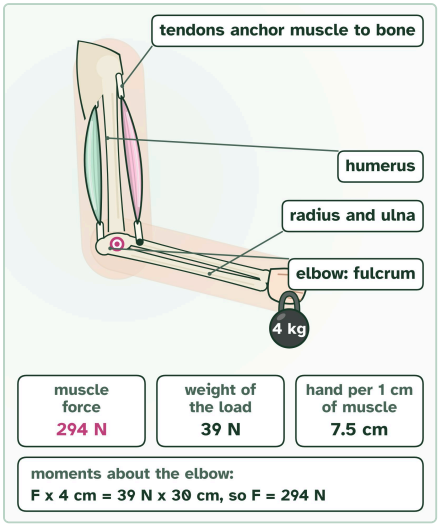
KEY POINTS

- The bones act as **levers**, the joint as the **pivot**, the muscle as the **effort**.
- Close to the pivot: **big force** needed, **big, fast movement**.
- Farther from the pivot: **less force**, **smaller movement**.

ANIMATION · THE ARM AS A LEVER

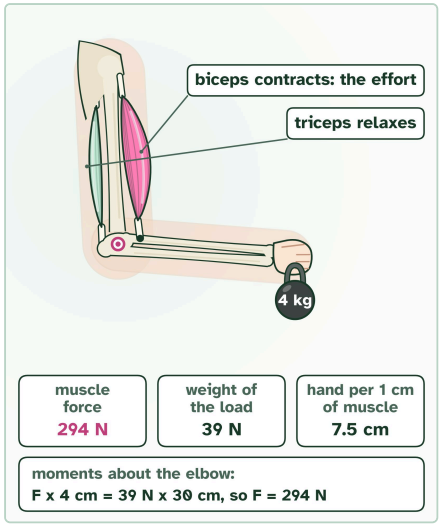
5 MOMENTS

1 294 N TO LIFT 4 KG



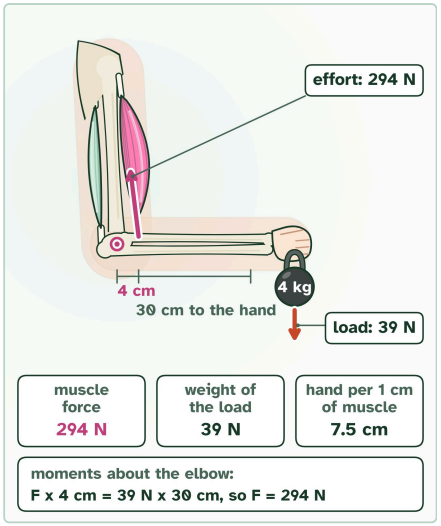
The bones of the arm are a **lever**. The **elbow** is the pivot, or fulcrum. The bones give the muscles something firm to pull on: they are an **anchorage**.

2 294 N TO LIFT 4 KG



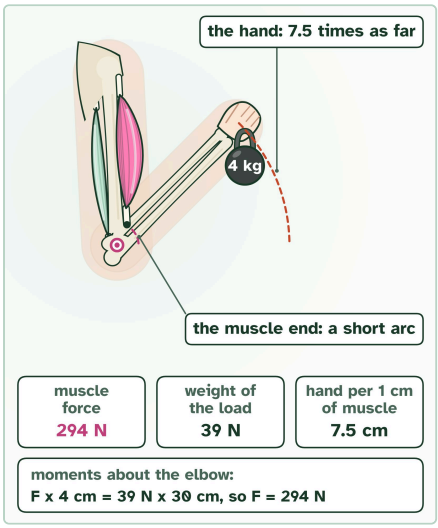
The **biceps** is attached to the forearm very close to the elbow. When it contracts it pulls the forearm up: this pull is the **effort**.

3 294 N TO LIFT 4 KG



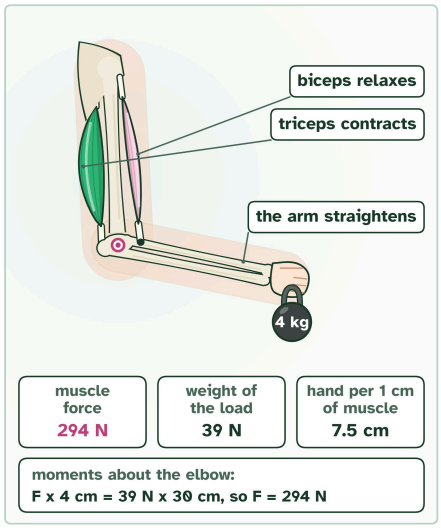
The load is far from the elbow and the muscle is close to it, so the muscle must pull **much harder than the weight** it lifts. Slide the load to see how the force changes.

4 294 N TO LIFT 4 KG



The same short attachment gives a **big movement**: a small shortening of the muscle moves the hand a long way, and quickly. Move the attachment away from the elbow to compare.

5 294 N TO LIFT 4 KG



A muscle can only pull. The **triceps**, on the other side, pulls the arm straight again. Muscles that work in opposite directions are **antagonistic**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#lever

PREDICT

A load of 5 kg is held in the hand 30 cm from the elbow, and the biceps pulls 4 cm from the elbow. What is true of the force in the muscle?

(A) It is smaller than the weight of the load

(B) It equals the weight of the load

(C) It is about 7.5 times the weight of the load

(D) It is the weight of the load divided by 7.5

Decide before you look. Answer on page 34.

08

B3.3.6 HL MOVEMENT AT A SYNOVIAL JOINT

Inside the *hip joint*

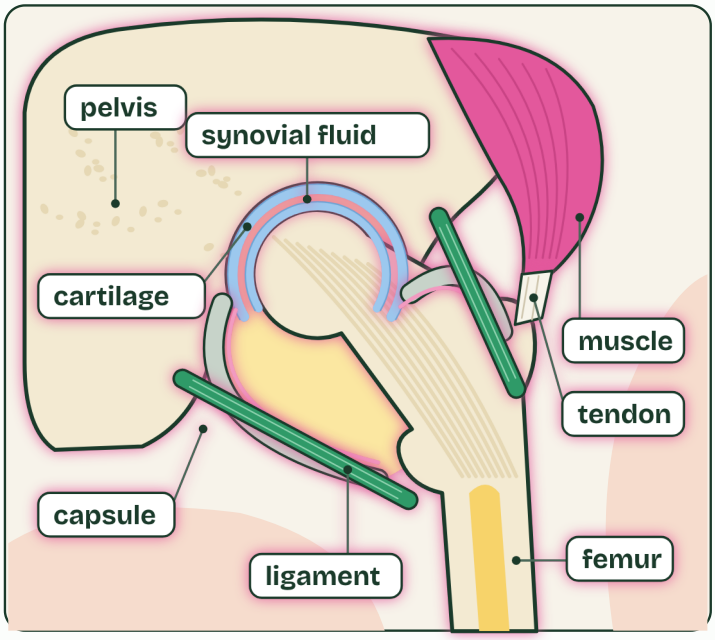
A **synovial joint** is a joint that moves freely. The human **hip** is a ball and socket synovial joint between the **pelvis** and the **femur**. You need to name those two bones, and the parts that make the movement smooth and safe.

The head of the femur is a ball and fits into a socket in the pelvis. The ends of both bones are covered with **cartilage**, which is smooth and absorbs shock. The cavity is filled with **synovial fluid**, which lubricates it and reduces friction. A **capsule** encloses the joint and **ligaments** join bone to bone and hold the joint in place. **Muscles** pull on the bones through **tendons**, which join muscle to bone, and so move the leg. You do not need to name the particular muscles or ligaments.

KEY TERMS

synovial joint
A joint in which the bones are separated by a fluid-filled cavity, with cartilage on the bone ends and a capsule round the outside. It allows free movement.

The right hip, cut open from the front



Synovial fluid fills the joint cavity. It is a slippery lubricant, so the cartilage surfaces slide past each other with very little friction, and it carries nutrients to the cartilage.

femur The is the thigh bone. Its ball-shaped head fits the socket, which lets the leg move in many directions. Its shaft is a lever.

Synovial fluid fills the joint cavity. It is a slippery lubricant, so the cartilage surfaces slide past each other with very little friction, and it carries nutrients to the cartilage.

Ligaments join bone to bone. They hold the joint together and limit movements that would dislocate it.

tendon A joins a muscle to a bone. It is strong and almost does not stretch, so all the pull of the muscle reaches the bone.

pelvis The has a cup-shaped socket, the **acetabulum**, that the head of the femur sits in. Bone is a rigid anchorage for the muscles that move the hip.

Cartilage covers the surfaces of the bones where they meet. It is smooth, slightly springy and absorbs shock, so the bones do not wear.

joint capsule The is a tough sleeve of tissue that surrounds the joint and keeps the synovial fluid in.

muscle A pulls on the bone it is attached to. When it contracts, the femur moves about the hip joint. Muscles come in antagonistic pairs, to move the joint in opposite directions.

IN THE EXAM

Outline the role of each part of the hip joint (4 marks): **cartilage** reduces friction / absorbs shock; **synovial fluid** lubricates the joint; **ligaments** hold the bones together / limit movement; **muscles** contract to move the bone, attached by **tendons**; the **femur** and **pelvis** are levers and provide a socket and ball.

WATCH OUT

Ligaments join **bone to bone**, and tendons join **muscle to bone**. They are often mixed up.

09 How far, in *how many directions*

B3.3.7 HL RANGE OF MOTION OF A JOINT

The **range of motion** of a joint is how far it can move, as an angle, in each direction. Different joints have different ranges. A **hinge** joint such as the knee or elbow moves in **one plane**: it flexes and extends. A **ball and socket** joint such as the hip or shoulder moves in **many dimensions**: it flexes and extends, swings out (abduction) and in (adduction), and rotates. The shape of the bones sets the range, and so do the ligaments and muscles around the joint, which is why ranges vary between people and change with age and training.

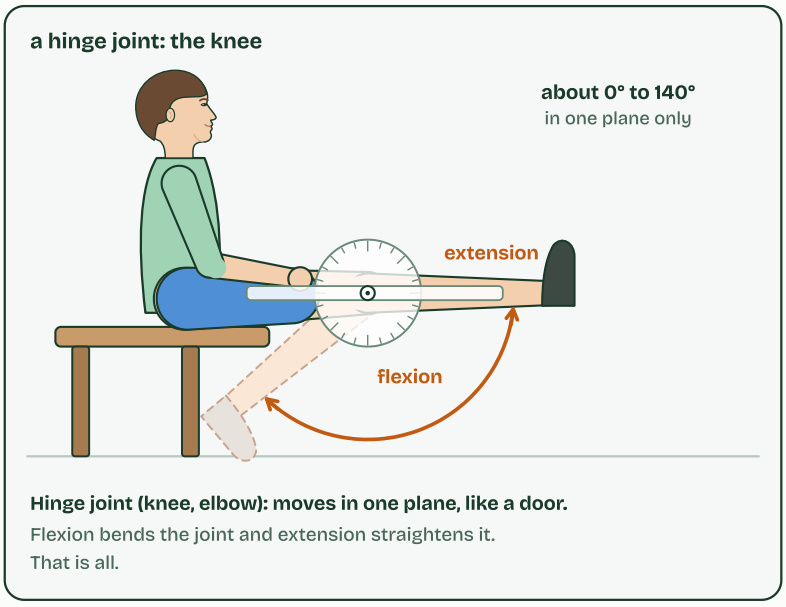
You measure a range with a **goniometer**, which has a fixed arm and a moving arm that you line up with the two bones, or by analysing a photograph or video on a computer. In the dry lab you measure four joints for three people. Repeat a reading to see the random error, and compare the number of dimensions of a hinge and of a ball and socket.

KEY POINTS

- **Range of motion** is the angle a joint moves through, in each dimension.
- **Hinge:** one plane. **Ball and socket:** many.
- Measured with a **goniometer** or from images.

KEY TERMS

range of motion
The angle through which a joint can move, in each direction in which it can move.

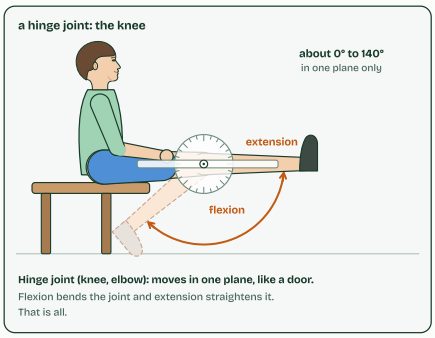


Hinge joint (knee, elbow): moves in one plane, like a door.
Flexion bends the joint and extension straightens it.
That is all.

SWITCH IT

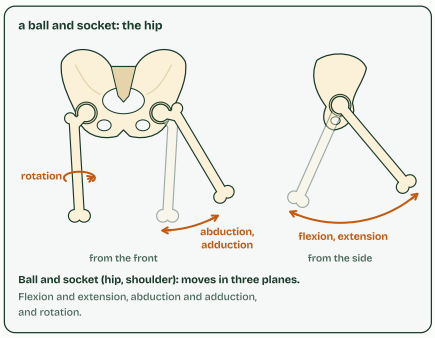
2 SETTINGS

1



Hinge (knee)

2



Ball and socket (hip)

PREDICT

Why can the hip move in more directions than the knee?

(A) The hip has more muscles attached, which pull in more directions

(B) The hip is a ball and socket joint, and the knee is a hinge that moves in one plane

(C) The hip has synovial fluid, and the knee has none

(D) The hip bones are lighter, so they move more easily

Decide before you look. Answer on page 34.

GO TO THE LAB

Measure range of motion: choose a joint, a movement and a person, and compare the bars.

10 Two layers that *pull opposite ways*

B3.3.8 HL INTERNAL AND EXTERNAL INTERCOSTAL MUSCLES AS ANTAGONISTIC MUSCLE ACTION

Between every pair of ribs there are two layers of **intercostal muscle**. The **external intercostals** have fibres that run **down and forward**. The **internal intercostals** lie beneath them with fibres at **right angles**, running down and back. Because their fibres run in different directions, the two layers move the ribcage in **opposite directions**: they are antagonistic muscles. When one layer contracts it **stretches the other**.

To **breathe in**, the external intercostals contract and raise the ribs up and out, so the volume of the thorax increases, the pressure falls, and air flows in. **Quiet breathing out** is passive: the muscles relax, and the ribs fall back by elastic recoil. In **forced breathing out**, as in running or blowing up a balloon, the internal intercostals contract and pull the ribs down and in, and the abdominal muscles also help. The diaphragm works with these muscles, as you saw in B3.1.

KEY POINTS

- **External** layer: contracts to **breathe in**, raising the ribs.
- **Internal** layer: contracts for **forced breathing out**, lowering them.
- They are **antagonistic**: fibres run in different directions, and one stretches the other.

KEY TERMS

intercostal muscle
Muscle between the ribs. The external layer raises the ribs for breathing in; the internal layer lowers them in forced breathing out.

ANIMATION · INTERCOSTAL MUSCLES AT WORK

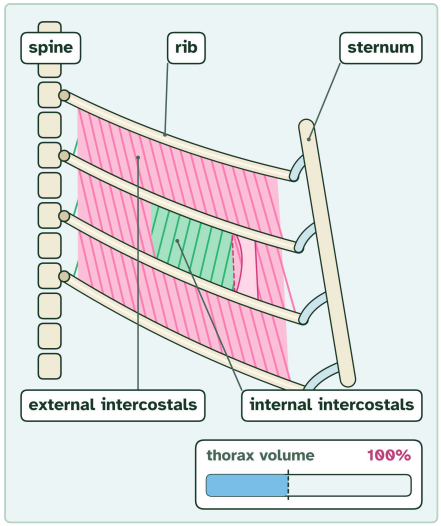
7 MOMENTS

1 BREATHING



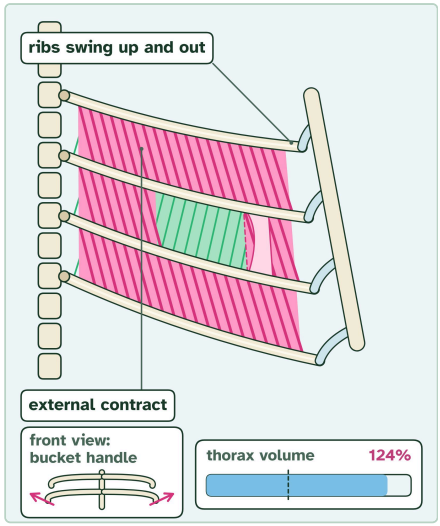
Breathing in and out. The ribs move with every breath, and two layers of muscle between them do the moving.

2 TWO LAYERS



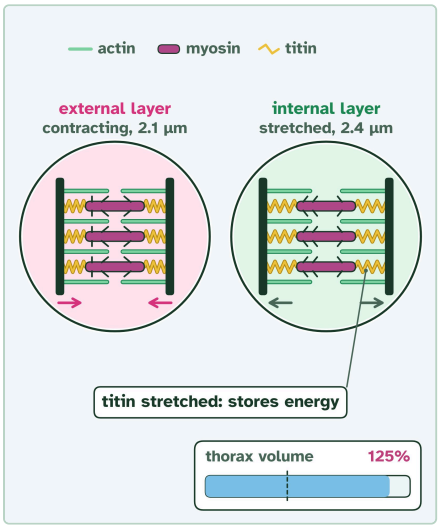
Between each pair of ribs lie two layers of **intercostal muscle**. The **external** fibres run down and forward; the **internal** fibres, peeled into view here, run at right angles to them.

3 BREATHING IN



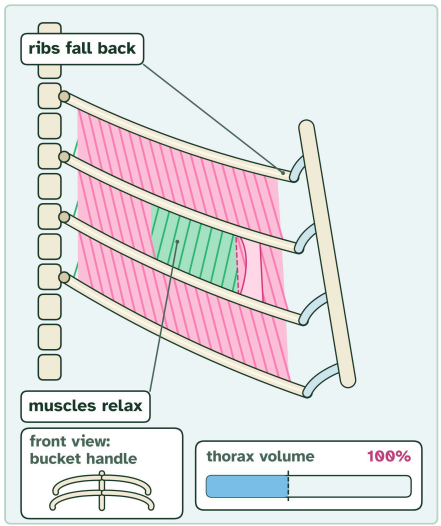
To breathe in, the **external intercostals contract**. The ribs swing **up and out** and the sternum moves forward. The thorax gets bigger, its pressure falls and air flows in.

4 TITIN STRETCHED



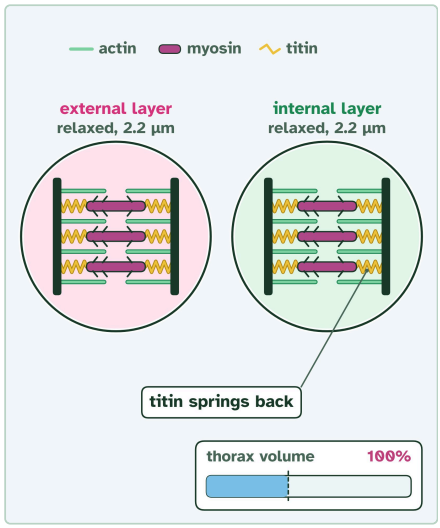
Inside the fibres: the **external** sarcomeres shorten, which **stretches** the internal layer. Its giant protein **titin** is pulled out like a spring and stores **elastic potential energy**.

5 QUIET OUT



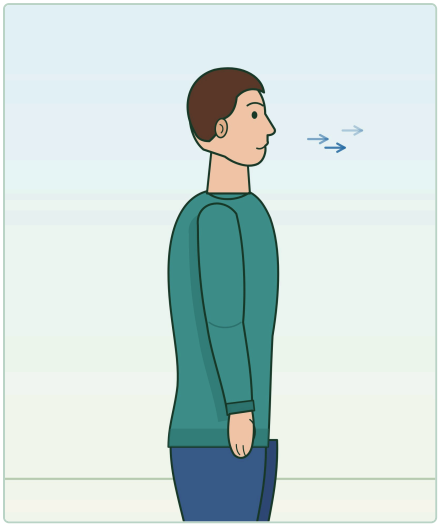
Breathing out. In **quiet** breathing no muscle contracts: the ribs fall back by elastic recoil. In **forced** breathing the **internal intercostals contract** and pull the ribs down and in.

6 SPRINGING BACK



Now the roles swap. The layer that was stretched recoils, or contracts, and stretches the other. A muscle can only pull, so it needs an **antagonist** to reset it.

7 ANTAGONISTS



Two layers pulling in opposite directions: **antagonistic muscles**, with titin helping each one spring back. Switch between Quiet and Forced to compare.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#intercostals

PREDICT

The internal intercostal muscles contract, and the external ones are stretched. What happens?

(A) The ribs are raised and the thorax gets bigger

(B) The ribs are pulled down and in, and air is forced out of the lungs

(C) The ribs stay still, because the forces cancel out

(D) The diaphragm moves up and the ribs move out

Decide before you look. Answer on page 34.

IN THE EXAM

Explain how the intercostal muscles cause ventilation (3 marks): **external** intercostals contract, raising the ribs, so volume increases, pressure falls and air enters; **internal** intercostals contract in forced exhalation, lowering the ribs, so volume decreases, pressure rises and air leaves; they are **antagonistic**, as one contracts it stretches the other.

REMEMBER IT

IEEI: Inhale External, Exhale Internal

I I E	E E I
Inhale: External the external intercostals lift the ribs up and out	**Exhale: Internal** the internal intercostals pull the ribs down and in (forced breathing out only)

11

B3.3.9 HL REASONS FOR LOCOMOTION

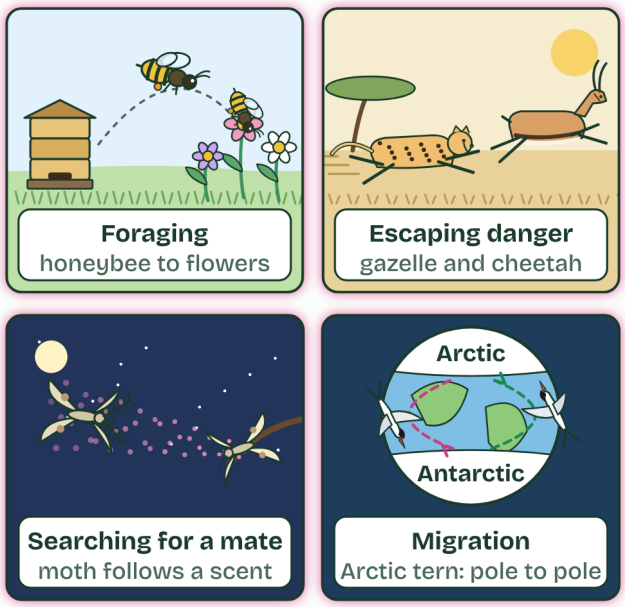
Why *travel* at all?

Locomotion costs energy and carries risks, so it has to pay for itself. Animals move for four main reasons, and you need at least one example of each.

Foraging for food. Food is spread out and changes with time, so animals move to find it. Example: honeybees flying to flowers.
Escaping from danger. Prey that can move away survives to breed. Example: a Thomson's gazelle running from a cheetah.
Searching for a mate. A mate can be far away, and many animals move toward it, following scent, sound or sight. Example: male silk moths following a pheromone plume.
Migration. Some animals travel regularly between places, usually as the seasons change, to reach better food or places to breed. Example: Arctic terns.

The reasons are linked: an Arctic tern migrates to find food, a bee that forages is also looking for a place to nest, and a gazelle that flees is also staying alive to breed. Tap each tile to read an example.

Four reasons for locomotion



Foraging for food. A honeybee (*Apis mellifera*) flies from the hive to flowers, sometimes several kilometres, collecting nectar and pollen. Moving lets an animal find food that is spread out, and in the right place at the right time.

Searching for a mate. A male silk moth (*Bombyx mori*) detects a few molecules of the female's pheromone with his large feathery antennae, and flies up the scent plume to her. Moving finds a mate when mates are scattered.

Escaping from danger. A Thomson's gazelle (*Eudorcas thomsonii*) can outrun a cheetah (*Acinonyx jubatus*) over a long chase, because the cheetah tires first. Locomotion lets prey escape predators.

Migration. The Arctic tern (*Sterna paradisaea*) breeds in the Arctic and spends the northern winter around Antarctica, a round trip of tens of thousands of kilometres. Migration takes animals to better food and breeding places as the seasons change.

12 Built for *diving*

B3.3.10 HL ADAPTATIONS FOR SWIMMING IN MARINE MAMMALS

Whales, dolphins and seals are mammals that live in the sea, so they must swim well and still come to the surface to breathe air. Their bodies show several adaptations.

Streamlining. The body is smooth and tapered with a thick layer of blubber under the skin, and few projections. Water flows past with little drag, so less energy is used.
Limbs as flippers. The forelimbs are short, flat flippers (the bones are still there, in the arm and fingers). They are used to steer and brake. The hindlimbs have been lost or are tiny.
A tail with a fluke. The tail ends in a flat fluke that beats **up and down**, driven by strong muscles of the back. (A fish's tail beats from side to side. A mammal's spine bends up and down, as it does when a cheetah runs.)
Changes to the airways. The nostrils have moved to the top of the head as a **blowhole** that is closed during a dive. The animal breathes **periodically**: it holds its breath on a dive, then at the surface it swaps most of the air in its lungs in a fraction of a second, which refills the oxygen store quickly.

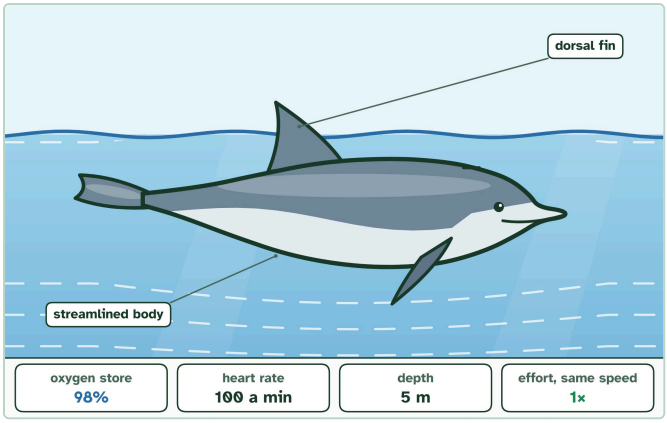
KEY POINTS

- **Streamlined** body, **flippers**, and a tail with a **fluke** that beats **up and down**.
- A **blowhole** that can be closed: the animal **holds its breath** and breathes **periodically**.
- Each adaptation saves **energy** or **oxygen**.

ANIMATION · A DOLPHIN SWIMMING AND DIVING

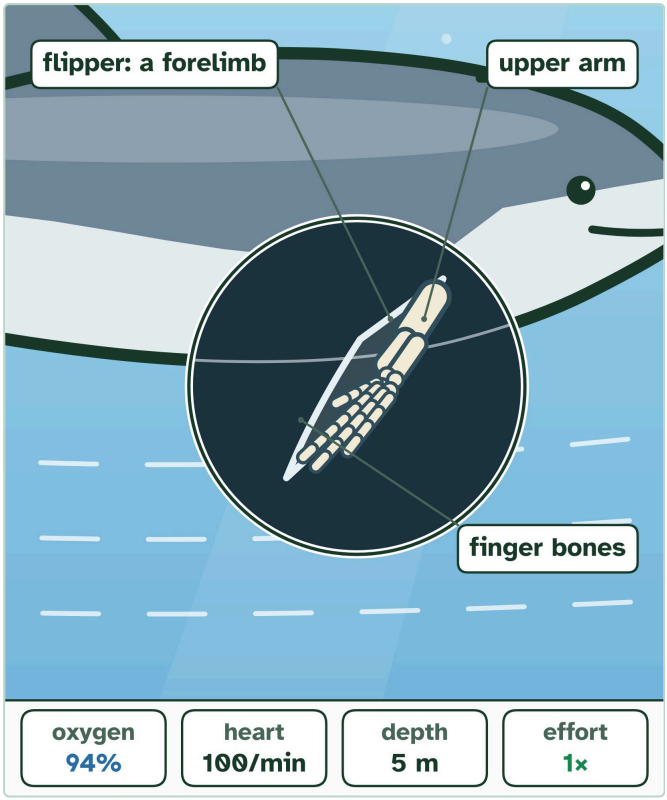
8 MOMENTS

1 CRUISING



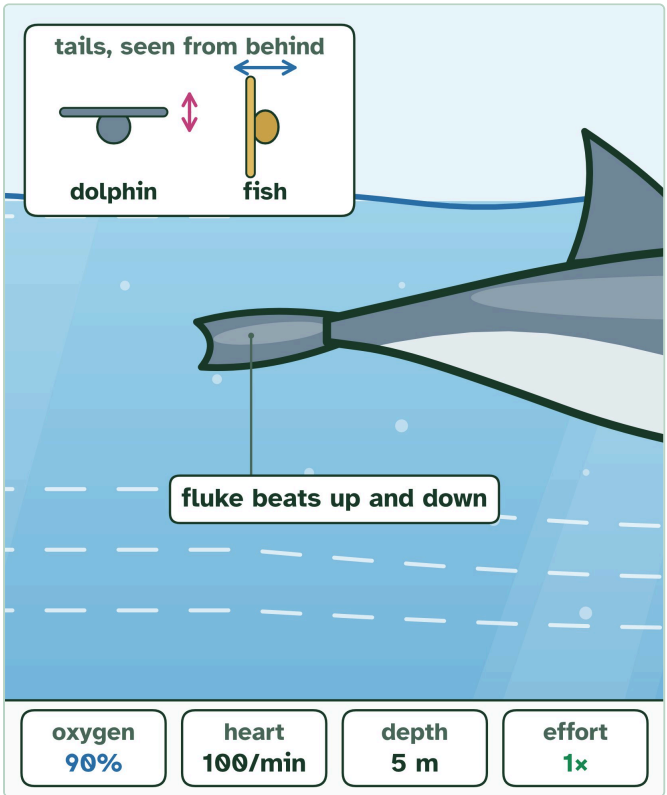
A bottlenose dolphin cruising just under the surface. Its **streamlined** body, smooth and tapered at both ends, lets the water slide past with little drag.

2 THE FLIPPER



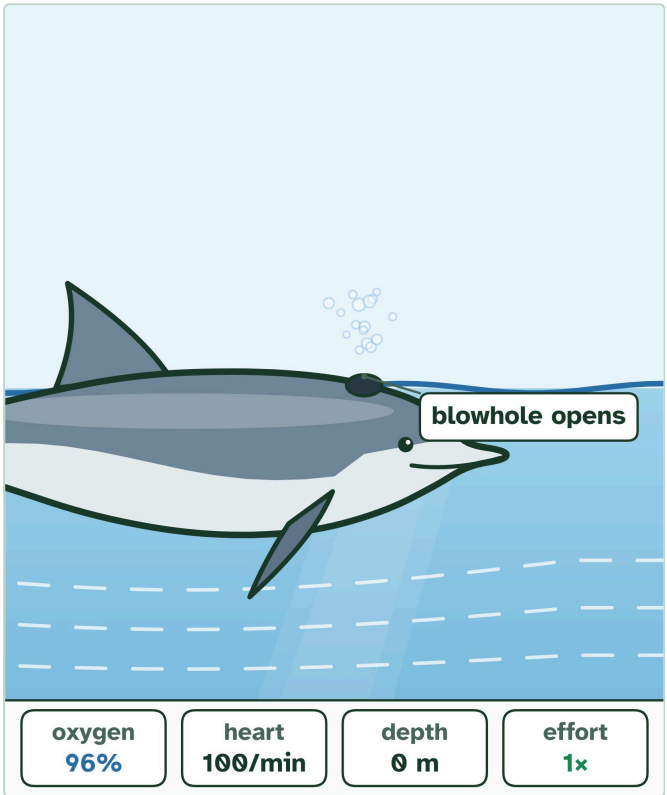
The **forelimbs are flippers**. Inside are the bones of an arm and hand: a short upper arm and forearm and long finger bones, bound into one stiff paddle to steer and brake.

3 THE FLUKE



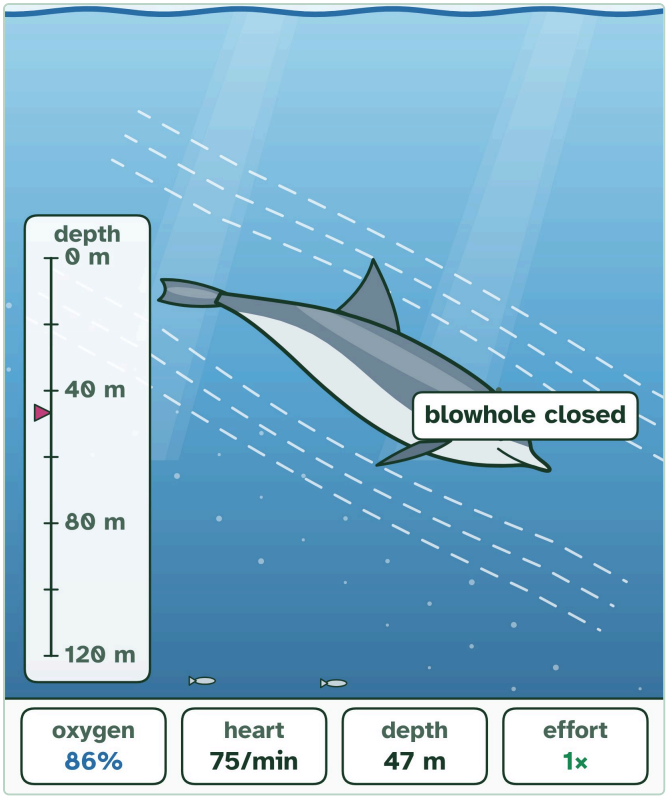
The tail ends in a **fluke**: flat, horizontal and beaten **up and down** to drive the dolphin forward. A fish's tail fin is upright and beats from side to side.

4 A BREATH



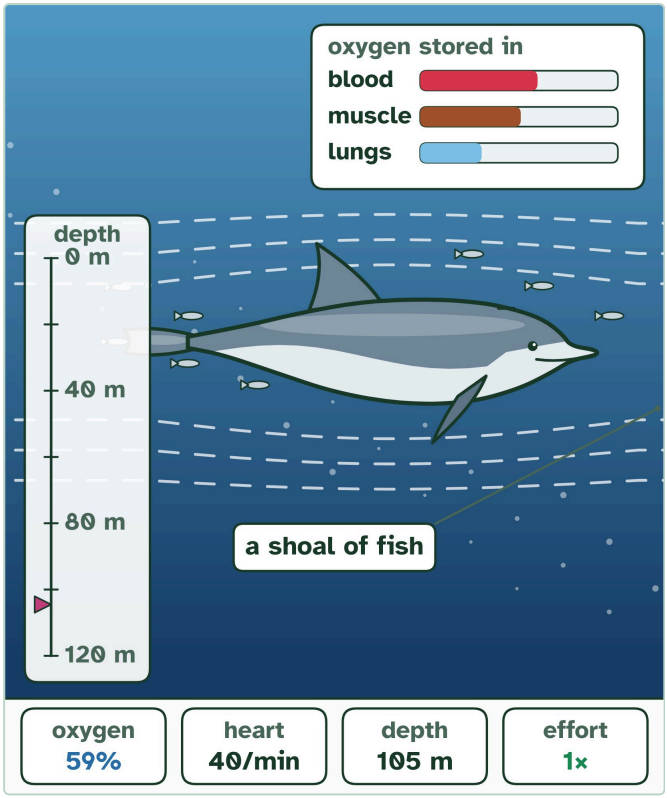
At the surface the **blowhole**, a nostril on top of the head, opens. The dolphin breathes out and in in well under a second, swapping most of the air in its lungs.

5 DIVING



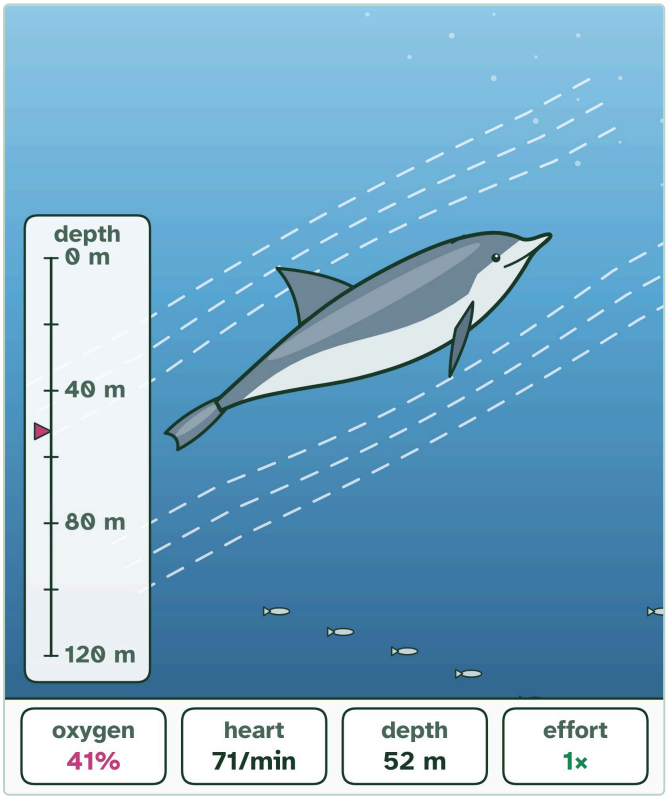
It dives with the blowhole **closed**. Its airway is separate from its throat, so it can open its mouth under water. It will not breathe until it surfaces: **periodic breathing**.

6 AT DEPTH



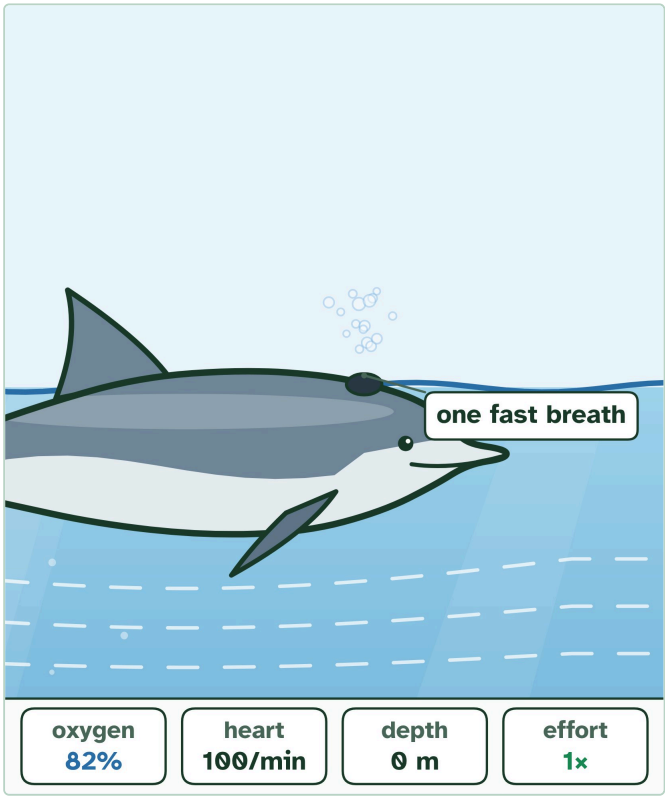
At depth it runs on stored oxygen, more in its blood (**haemoglobin**) and muscles (**myoglobin**) than in its lungs. Its **heart slows**, so the store lasts longer.

7 COMING UP



It swims back up as the oxygen store runs low.

8 A BREATH



At the surface again: blowhole open, one fast breath, and the store is full. Switch the body to Boxy to see what streamlining saves.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#swimming

PREDICT

Why does a dolphin breathe out explosively through its blowhole when it surfaces?

(A) To swap most of the air in its lungs in a very short time, so it can dive again soon

(B) To blow water out of its stomach, where it has swallowed it

(C) To make a sound that other dolphins can hear

(D) To cool itself, as it cannot sweat

Decide before you look. Answer on page 35.

IN THE EXAM

Describe adaptations of marine mammals for swimming (3 marks): **streamlined** body reduces drag; limbs modified into **flippers** to steer; tail with a **fluke** that moves up and down to propel; airway changes, such as a **blowhole** that closes, allowing **periodic breathing** between dives.

Key terms

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

endoskeleton 06
A skeleton inside the body, of bone or cartilage, to which muscles are attached on the outside.

exoskeleton 06
A hard skeleton on the outside of the body that protects it and gives anchorage to muscles, which are attached inside it.

intercostal muscle 10
Muscle between the ribs. The external layer raises the ribs for breathing in; the internal layer lowers them in forced breathing out.

motile 01
Able to move from place to place under its own power.

motor unit 05
One motor neuron together with all the muscle fibres it supplies.

neuromuscular junction 05
A synapse between a motor neuron and a muscle fibre. The neuron releases acetylcholine, which makes the fibre contract.

range of motion 09
The angle through which a joint can move, in each direction in which it can move.

sarcomeres 02
The unit of a myofibril, from one Z line to the next. It contains overlapping thin (actin) and thick (myosin) filaments and is the part that shortens in muscle contraction.

sessile 01
Fixed in one place, usually attached to a surface, for most or all of its life.

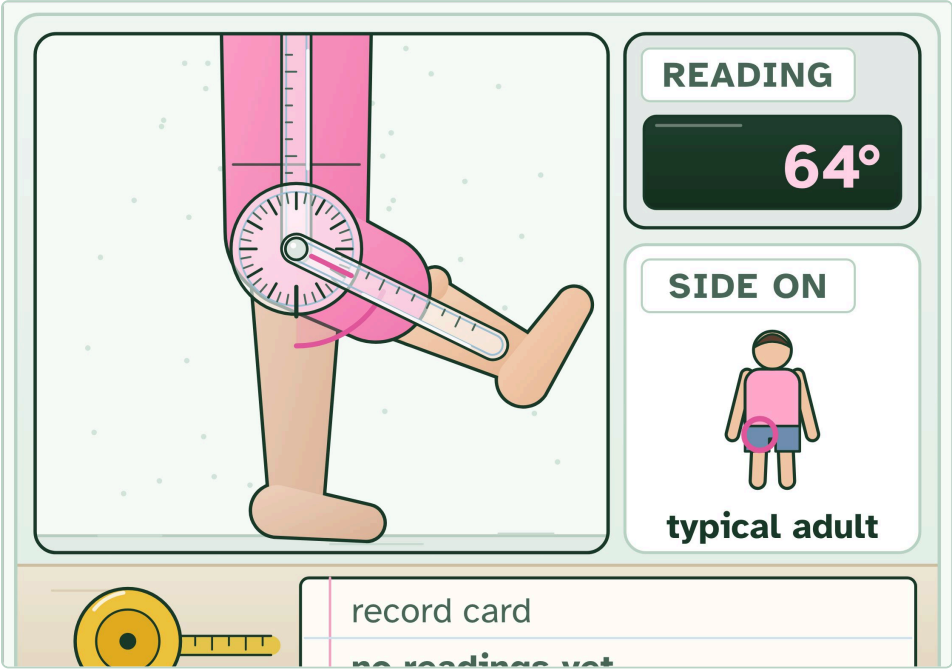
sliding filament model 03
The explanation of muscle contraction in which thin actin filaments are pulled past thick myosin filaments by the myosin heads, so the sarcomere shortens although neither filament does.

synovial joint 08
A joint in which the bones are separated by a fluid-filled cavity, with cartilage on the bone ends and a capsule round the outside. It allows free movement.

titin 04
A very large elastic protein that links the thick filament to the Z line in a sarcomere. It acts like a spring.

Dry lab: *Range of motion*

Use a goniometer on the hip, shoulder, knee and elbow, for a typical adult, a trained gymnast and an older adult, and see how many dimensions each joint moves in and how far.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-b3-3-muscle-and-motility#lab`

Your question

How many dimensions can each joint move in, and how does the range of motion differ between joints and people?

What you can change

The joint (hip, shoulder, knee or elbow), the movement (such as flexion or rotation) and the person (typical adult, gymnast or older adult).

What to record

For each movement, the angle on the goniometer. Repeat a reading to see the random error and take a mean. Count the movements of a hinge and of a ball and socket joint. Download the CSV to plot your own graph.

Find out

- **How many ways can a hinge move?** Choose the knee and press Measure every movement. How many bars do you get? Do the same for the elbow.
- **How many ways can a ball and socket move?** Do the same for the hip and the shoulder. Compare the number of bars with the knee.
- **Which movement goes furthest?** Rank the movements of the shoulder by mean angle. What do the largest and the smallest have in common?
- **Does the person matter?** Repeat the hip for the gymnast and the older adult. Which movements change most?
- **Back to biology.** Use your results to explain how the structure of the hip lets it move in more dimensions than the knee.

Record

- For each test: the joint, the movement, the person, and the goniometer reading.
- A repeat of one movement three times, and the mean, to see how much a reading wobbles.
- The number of movements (dimensions) for each joint, and the largest range of each.
- Download the CSV to plot your own graph.

Your question How many dimensions can each joint move in, and how does the range of motion differ between joints and people?**What you can change**The joint (hip, shoulder, knee or elbow), the movement (such as flexion or rotation) and the person (typical adult, gymnast or older adult).**What to record**For each movement, the angle on the goniometer. Repeat a reading to see the random error and take a mean. Count the movements of a hinge and of a ball and socket joint. Download the CSV to plot your own graph.

Back to biology

Use your results to explain how the structure of the hip lets it move in more dimensions than the knee.

QUESTIONS ON THE LAB

QUESTION 1

You measure every movement of the knee and of the hip for the same person. How do the two sets of results compare?

(A) The knee has more movements, because it is a bigger joint and carries more weight

(B) The hip has more movements, because a ball and socket joint moves in more than one plane

(C) Both have the same number, because every synovial joint has the same structure

Answer on page 35.

QUESTION 2

You take the same reading of hip flexion three times and get 118, 121 and 119 degrees. What does the spread tell you?

(A) That the person's range really changes by a few degrees each time they move

(B) That a reading has a random error of a few degrees, so the mean of several is a better value

(C) That the goniometer is broken and the experiment must be started again

Answer on page 35.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on B3.3 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=B3.3&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 A barnacle is glued to a rock for its adult life. Which statement is correct?

B **It is sessile but moves parts of its body, for feeding**

Sessile means fixed in one place, not unable to move. The adult barnacle moves its cirri to feed, and its larva swims, which spreads the species. Movement is a universal feature of life.

03 A muscle fibre is stimulated and its sarcomeres shorten from 2.6 to 2.0 micrometres. What happens to the length of the A band?

B **It does not change, because the thick filaments do not shorten**

The A band is the length of the thick filaments, which stay the same. The I band and the H zone are the parts that shorten. Run the film and read the numbers.

04 Why can a muscle that has just contracted not simply lengthen itself again?

B **Because muscle fibres can only pull when they contract, so something else must stretch them**

A muscle only pulls. It is stretched back to length by the elastic recoil of titin and by an antagonistic muscle, which contracts and pulls the joint the other way.

05 Which statement is correct about the fibres in one motor unit?

A **They all contract together when their neuron fires**

One motor neuron supplies all the fibres of its unit. When it fires, all contract together, fully. A bigger force comes from recruiting more units, not from a stronger signal to one fibre.

06 A muscle in the arm of a person and one in the leg of a crab are alike in which way?

A **Each is attached to a skeleton that gives it a firm anchorage to pull against**

Both skeletons give muscles an anchorage and act as levers. The crab has an exoskeleton with muscles inside it, and the person has an endoskeleton with muscles outside it. In both, muscles only pull and work in pairs.

07 A load of 5 kg is held in the hand 30 cm from the elbow, and the biceps pulls 4 cm from the elbow. What is true of the force in the muscle?

C **It is about 7.5 times the weight of the load**

Force x 4 cm = load x 30 cm, so the muscle force is 7.5 times the weight. The same attachment lets the hand move 7.5 cm for each centimetre that the muscle shortens.

09 Why can the hip move in more directions than the knee?

B **The hip is a ball and socket joint, and the knee is a hinge that moves in one plane**

The shape of the joint sets the planes of movement. A ball in a socket can move in three planes, and a hinge moves in only one. Both are synovial joints with cartilage and fluid.

10 The internal intercostal muscles contract, and the external ones are stretched. What happens?

B **The ribs are pulled down and in, and air is forced out of the lungs**

The internal layer pulls the ribs down and in, reducing the volume of the thorax and raising the pressure, so air is forced out. The external layer is stretched, ready to raise the ribs for the next breath.

12 Why does a dolphin breathe out explosively through its blowhole when it surfaces?

A **To swap most of the air in its lungs in a very short time, so it can dive again soon**

Time at the surface is time in danger and time not feeding. A fast breath replaces most of the air in the lungs, so the oxygen store is filled again quickly. Humans swap only a small part of the air in each breath.

QUESTIONS ON THE DRY LAB

Q1 You measure every movement of the knee and of the hip for the same person. How do the two sets of results compare?

B **The hip has more movements, because a ball and socket joint moves in more than one plane**

The knee is a hinge and flexes and extends, in one plane. The hip is a ball and socket joint, which flexes and extends, swings out and in, and rotates. More dimensions means more bars on the chart.

Q2 You take the same reading of hip flexion three times and get 118, 121 and 119 degrees. What does the spread tell you?

B **That a reading has a random error of a few degrees, so the mean of several is a better value**

Small differences between repeats are random error, from reading the scale and placing the arms. Averaging several readings reduces its effect, and the spread tells you how precise the method is.

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.