Muscle and motility

B3.3 · HL only

Movement is wider than locomotion

B3.3: Higher Level only

Trace a mechanism from cell proteins to a moving joint, then explain why an organism moves.

This unit covers all B3.3 understandings: movement, sliding filaments, titin, motor units, skeletons, hip, measurements, intercostals, locomotion and marine mammal adaptations.

Numerical examples and data are invented teaching models.

Compare a swimming protist and a rooted tree

Organism	**Movement and mechanism**
Paramecium caudatum	Coordinated cilia propel the whole cell through water: locomotion
English oak (Quercus robur)	Shoots can change direction during growth; materials also move inside cells
Distinction	Movement can occur within or among parts without relocating the whole organism
Explanation	Name what moves and how; not every movement uses muscle

Movement at every scale

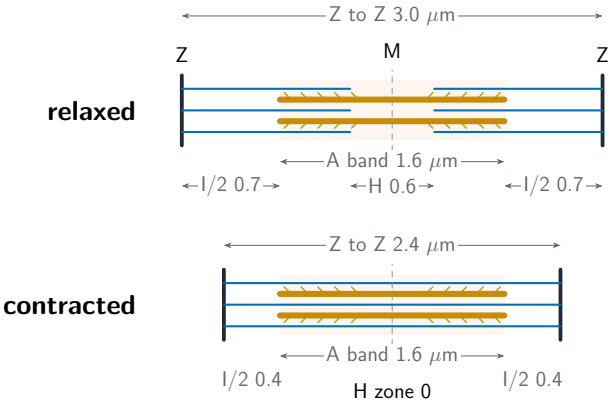
sessile oak
rooted, no locomotion
shoots bend to light
materials move in cells

motile *Paramecium*
locomotion: cilia push against water

every cell
chromosomes move,
vesicles travel:
no muscle needed

Inside every cell, chromosomes and vesicles move

Follow the Z lines and filament ends separately



actin (thin), 1.2 μm from each Z

myosin (thick), 1.6 μm

both lengths unchanged:
filaments slide, overlap rises;
I/2 marks half an I band

Actin and myosin keep their lengths; I/2 marks half an I band.

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Interpret bands without shrinking the filaments

Structure	Sliding-model prediction
Sarcomere	Z line to Z line; shortens when the lines approach
A band	Thick-filament length remains approximately constant
I band	Straddles a Z line; each end of one sarcomere contains half the band
H zone	Central thick-only zone narrows and may disappear

Percentage shortening depends on the measured structure

1. **Invented comparison. Sarcomere**: 3.0 $\rightarrow$ 2.4 μm. Thick filament: 1.6 $\rightarrow$ 1.6 μm.
2. **Calculate.** Sarcomere: $(3.0 - 2.4)/3.0 \times 100 = 20\%$. Thick filament: 0%.
3. **Evidence.** Compare calibrated equal scales and identify boundaries. A static image does not directly reveal the biochemical cycle. Tension can occur without whole-muscle shortening.

Calcium permits access; it is not the energy source

1. **Resting fibre.** Regulatory proteins restrict access to actin sites.
2. **Excitation.** Calcium is released from the sarcoplasmic reticulum and binds troponin, changing tropomyosin position.
3. **Consequence.** Myosin can interact with exposed actin sites. Calcium is not incorporated into actin as fuel.

Separate ATP binding from hydrolysis

1. **Attach and generate force.** An energized head carrying ADP/phosphate attaches. Strong binding and phosphate release accompany the power stroke; ADP is released.
2. **Detach.** Fresh ATP binds myosin and permits release from actin.
3. **Prepare again.** ATP hydrolysis re-energizes/repositions the head for another cycle if sites remain available.

Relaxation still involves energy-dependent processes

Many heads cycle asynchronously

Calcium is transported back into the sarcoplasmic reticulum; regulatory blocking is restored.

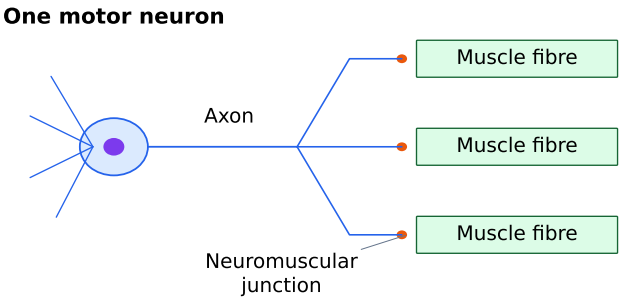
ATP binding is also necessary for cross-bridge detachment. Loss of a signal does not instantly remove calcium.

Load, filament geometry and recruitment influence tension; not all heads occupy one stage together.

Passive recoil and active opposing pull differ

Component	Mechanism and limit
Titin	Elastic **sarcomere** protein stabilizes thick filaments and resists excessive stretch
Antagonist	An opposing muscle group actively pulls the joint in another direction
Relaxation	Loss of active tension does not by itself restore the original joint angle
Real movement	Load, elastic recoil and co-contraction affect position; muscles pull rather than push

Trace one axon to all of its muscle fibres



One motor neuron and its innervated fibres form one motor unit; other units are omitted.

Recruitment changes whole-muscle force

Do not confuse a unit with a fibre or sarcomere

A branched motor axon forms neuromuscular junctions. Acetylcholine acts at muscle membrane receptors, leading to excitation and calcium release.

Recruiting additional units can increase force. Stimulation frequency changes twitch overlap and tension.

Smaller units allow finer force increments, other conditions equal; real fibre properties also matter.

Count cumulative force and additional increments

1. **Equal-force teaching model.** Units A, B and C contain 4, 9 and 16 fibres.
2. **Recruitment.** A alone: 4 units. A + B: 13. All three: 29. Successive additions: 4, 9 and 16.
3. **Limit.** Fibre properties, activation frequency and loading differ in real muscles. Recruitment does not require greater percentage shortening of each fibre.

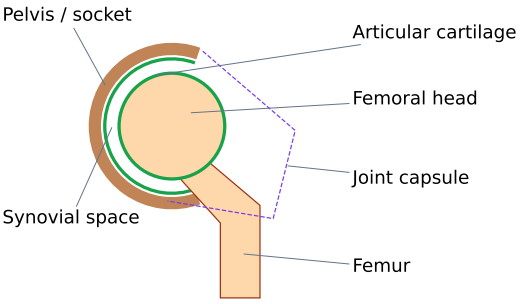
Trace the force to its skeletal attachment

Structure	Function
Endoskeleton	Internal vertebrate skeleton provides anchorage and levers
Exoskeleton	External arthropod skeleton also provides muscle anchorage
Tendon	Transmits muscle tension to bone
Ligament	Connects bones and restrains excessive joint movement

Use perpendicular moment arms in a static model

1. **Load.** 20 N at 0.25 m gives 5.0 N metres about the joint.
2. **Muscle.** At a perpendicular moment arm of 0.025 m, tension $= 5.0/0.025 = 200$ N.
3. **Interpretation.** A small moment arm requires high force; geometry can favour movement speed/displacement. Limb weight, acceleration and other moments were omitted.

Identify the ball, socket and articular surfaces



The femoral head fits the pelvic acetabulum; this synovial joint permits several constrained movements.

Link each joint tissue to its role

Tissue or structure	Function
Articular cartilage	Distributes contact load and helps reduce friction
Synovial fluid	Lubricates the joint
Capsule and ligaments	Enclose the joint and restrain excessive movement
Muscles and tendons	Generate and transmit tensile forces that turn the bones

Describe movement relative to the same reference

Three kinds of movement are not one unrestricted rotation

Flexion/extension move the thigh forward/back relative to the pelvis.

Abduction/adduction move it away from/toward the body midline.

Internal/external rotation turn the femur around its long axis. Use a consistent anatomical reference.

Do not combine arcs from different planes

1. **Invented measurements.** From neutral: flexion 105°, extension 15°. The same-plane total arc is 120°.
2. **Different plane.** Abduction 35° and adduction 20° give 55°. Do not add this to produce one 175° hip range.
3. **Convention.** An included angle changing 150° $\rightarrow$ 95° changes by 55°; the final anatomical flexion angle needs a stated reference/convention.

Precision does not establish accuracy

Make camera, landmarks and reference explicit

Readings 54°, 56°, 55° have mean 55° and range 2°. This does not prove absolute accuracy of $\pm 1°$.

Align the camera with the movement plane; identify joint centre and segment landmarks consistently; repeat and compare observers.

Two-dimensional projection and landmark bias can persist across repeats. Use supplied images/models or comfortable approved movements; never force a joint range.

Separate rib action from gas exchange

Process	Mechanism
Inspiration	External intercostals raise ribs up/out; diaphragm helps increase thoracic volume
Active expiration	Expiratory internal intercostal portions can lower ribs
Quiet expiration	Much movement follows relaxation and elastic recoil
Antagonism	Different fibre orientations support opposing actions; stretching stores elastic energy including in titin

Follow force, volume and pressure in order

Moving ribs does not directly diffuse oxygen

Muscle tension moves the skeleton and changes thoracic volume.

The resulting pressure difference drives bulk airflow.

Oxygen and carbon dioxide diffuse separately across exchange surfaces. Neural coordination and the diaphragm also matter.

Give a named organism and a biological opportunity

Example	Reason for locomotion
Dolphin pursues fish	Foraging
Gazelle runs from predator	Escape
Male moth approaches pheromone source	Mate search
Many humpback populations move seasonally	Connect feeding and breeding regions; not identical journeys for every individual

A larger intake need not give a larger net gain

1. **Invented routes.** A: intake 120, travel cost 35. B: intake 150, travel cost 80.
2. **Net gains.** A $= 85$ energy units; B $= 70$. A is larger under the stated model.
3. **Limit.** Risk, handling costs, food composition and other demands are omitted. Faster or longer movement is not always better.

Explain a bottlenose dolphin feature by feature

Feature	Functional connection
Streamlined body	Reduces resistance during movement through water
Forelimb flippers	Contribute control and steering
Horizontal tail flukes	Up/down movement generates propulsion
Blowhole on upper head	Provides surface air access; closes underwater; lungs still require periodic air breathing

Avoid extending one cetacean model to every marine mammal

An airway is not a gill

A dolphin does not extract dissolved oxygen through a closed blowhole.

Seals and sea lions do not share the same cetacean tail design.

Connect streamlining to drag, flukes to thrust, flippers to control and the airway to air access. Adaptations evolve across generations.

Attempt the full thirteen-question handout set

State the structure, mechanism and model limit

Predict sarcomere, A-band, I-band and H-zone changes; distinguish ATP binding from ATP hydrolysis.

Use units $X = 5$, $Y = 8$, $Z = 12$ to calculate cumulative force and increments. Solve the 30 N, 0.20 m load with muscle arm 0.030 m.

Interpret joint arcs and repeated image readings; explain intercostal antagonism and dolphin adaptations.

Check numerical answers independently

1. **Sarcomere and motor units.** 2.5 $\rightarrow$ 2.0 μm is 20% shortening; thick filament unchanged. Forces 5, 13, 25; increments 5, 8, 12.
2. **Lever and arcs.** Load moment 6.0 N metres; tension 200 N. Flexion 100° + extension 20° gives 120° in one plane. Included angle 145° $\rightarrow$ 90° changes 55°.
3. **Repeats and energy.** 53°, 55°, 57°: mean 55°, range 4°. Net gains: C = 140 − 45 = 95; D = 180 − 100 = 80.

Check yourself

Use the correct scale and causal step

Movement versus locomotion; motor unit versus muscle fibre; contraction versus overall shortening.

Explain calcium regulation, ATP binding/detachment, hydrolysis/re-energization and energy-dependent calcium reuptake.

Use perpendicular moment arms and stated angle conventions. Link each adaptation to a mechanism and task.