Course Companion

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Every topic handout in one volume

全部专题讲义合集

exercises.lol

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Communication

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

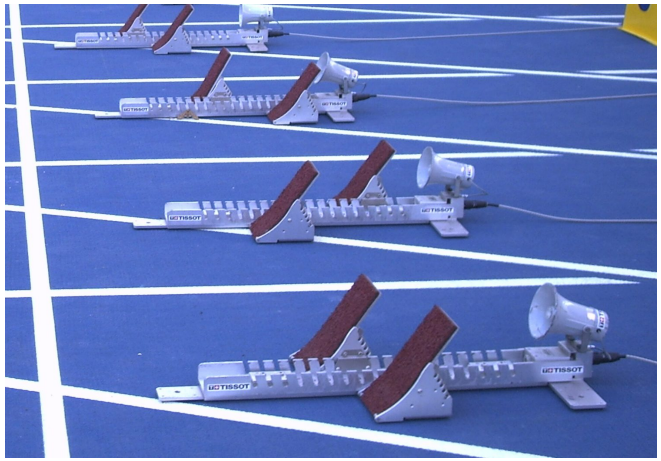
This handout teaches A.1 Communication for the course first assessed in 2026: how the nervous and endocrine systems control the body, how the cardiovascular and respiratory systems deliver oxygen and remove carbon dioxide, and how homeostasis keeps the internal environment stable during exercise. It is written for both SL and HL students. Sections marked **AHL** are for Higher Level only. Numerical physiological scenarios are invented teaching examples unless a dated source is named; they are not individual reference ranges or diagnostic tests.

Prerequisites: basic cell biology (cells, membranes and diffusion) and a simple idea of the heart and muscles. Units A.2 and A.3 build on this unit.

The nervous system

Faster than a false start

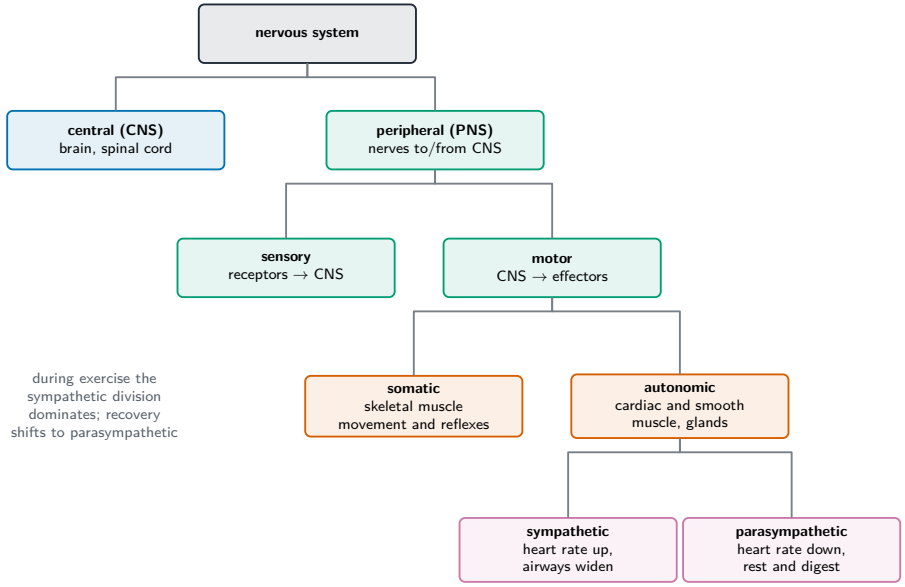
World Athletics' Berlin 2009 final results report Usain Bolt's 9.58 s race and 0.146 s start reaction. The measured start response includes sensory processing, motor signalling and the development of detectable force; it is not simply an impulse's travel time along one nerve. The 2026 technical rules use a recorded reaction below 0.100 s to flag a possible false start for officials to examine. A competition threshold is not proof of an absolute physiological limit for every person and measurement method. This unit explains how nerves, hormones, circulation and ventilation coordinate a response.



Pressure-sensitive starting blocks: a push within 0.1 s of the gun counts as a false start, faster than a nerve pathway allows a true reaction

Organisation of the nervous system

The **nervous system** 神经系统 detects changes, processes information and sends fast electrical signals to muscles and glands.



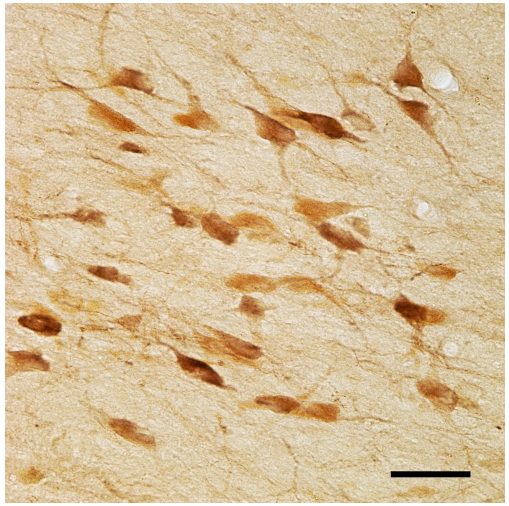
Divisions of the nervous system

- The **central nervous system** 中枢神经系统 (CNS) is the brain and spinal cord. It processes information and makes decisions.
- The **peripheral nervous system** 周围神经系统 (PNS) is all the nerves outside the CNS. Its **sensory** division carries impulses from receptors to the CNS; its **motor** division carries impulses from the CNS to effectors.
- The **somatic nervous system** 躯体神经系统 controls skeletal muscles, including voluntary movements such as kicking a ball and automatic somatic reflexes.
- The **autonomic nervous system** 自主神经系统 controls the heart, smooth muscle (in blood vessels and the gut) and glands without conscious thought. Its **sympathetic** 交感 branch prepares the body for action ("fight or flight": faster heart rate, wider airways, more blood to muscles); its **parasympathetic** 副交感 branch calms the body ("rest and digest": slower heart rate, more blood to the gut).

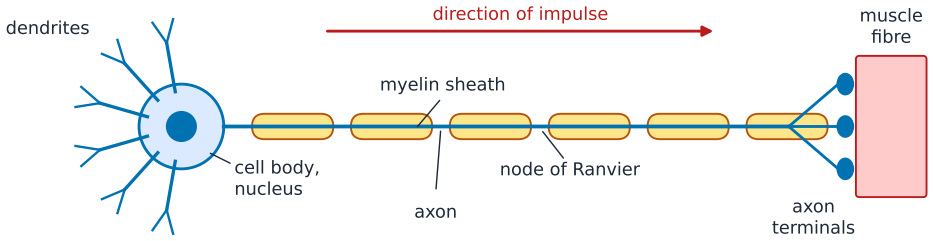
Before a race, the sympathetic system is already active: an athlete's heart rate can rise before the start, the **anticipatory rise**.

Neurons

The nervous system is made of nerve cells called **neurons** 神经元. The human brain is estimated to contain about 86 billion.



*Real **neurones** stained brown: you can see the cell bodies and the thin processes that carry signals to and from each cell*



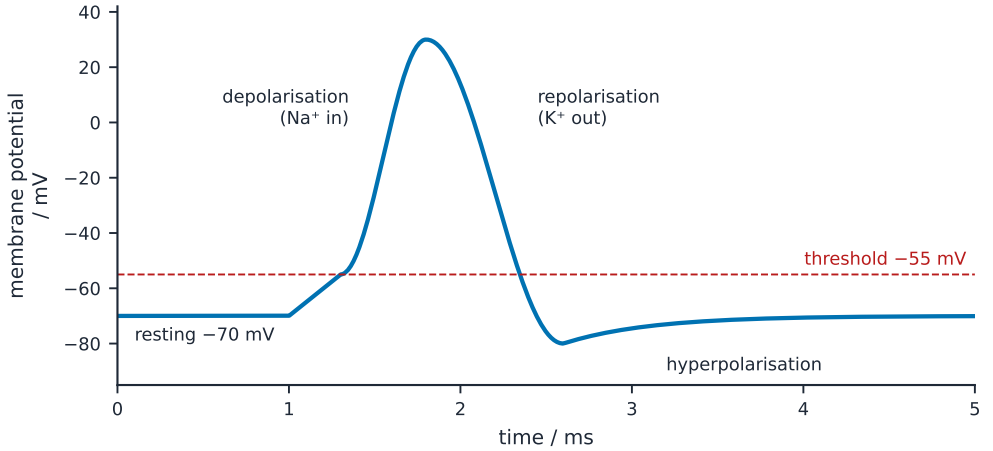
A motor neuron

Part	Function
Dendrites 树突	Receive impulses from other neurons or receptors
Cell body 细胞体	Contains the nucleus; keeps the cell alive
Axon 轴突	Carries the impulse away from the cell body, sometimes over a metre
Myelin sheath 髓鞘	Fatty insulating layer that speeds up the impulse
Nodes of Ranvier 郎飞结	Gaps in the myelin; the impulse jumps from node to node
Axon terminals	Pass the signal to the next cell

There are three types of neuron: **sensory neurons** carry impulses from receptors to the CNS, **relay neurons** connect neurons within the CNS, and **motor neurons** 运动神经元 carry impulses from the CNS to muscles or glands.

The nerve impulse

A nerve impulse is a wave of electrical change along the membrane of the axon, called an **action potential** 动作电位.



An action potential

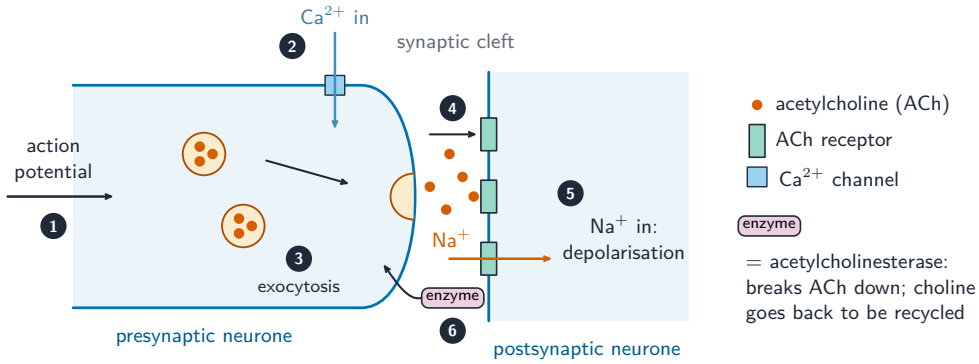
1. At rest, the inside of the axon is negative compared with the outside: the **resting potential** 静息电位 is about −70 mV. Sodium-potassium pumps keep more sodium ions outside and more potassium ions inside.
2. A stimulus makes the potential rise. If it reaches the **threshold** 阈值 (about −55 mV), sodium channels open, voltage-gated sodium channels allow sodium ions to enter and the inside becomes positive, about +30 mV (**depolarisation** 去极化).

3. Sodium channels inactivate and voltage-gated potassium channels open; potassium ions flow out and the potential falls again (**repolarisation** 复极化), briefly overshooting below −70 mV.
4. The change triggers the next section of membrane, so the impulse travels along the axon.

An action potential is **all-or-none**: if the threshold is reached, a full-sized impulse is sent; if not, nothing is sent. A stronger stimulus produces impulses more often, not bigger ones. In myelinated axons the impulse jumps between the nodes of Ranvier (**saltatory conduction**), reaching speeds of up to about 120 m/s, compared with about 1 m/s in unmyelinated axons.

Synapses and the neuromuscular junction

At a chemical **synapse** 突触, a presynaptic terminal communicates across a small synaptic cleft with a postsynaptic cell.



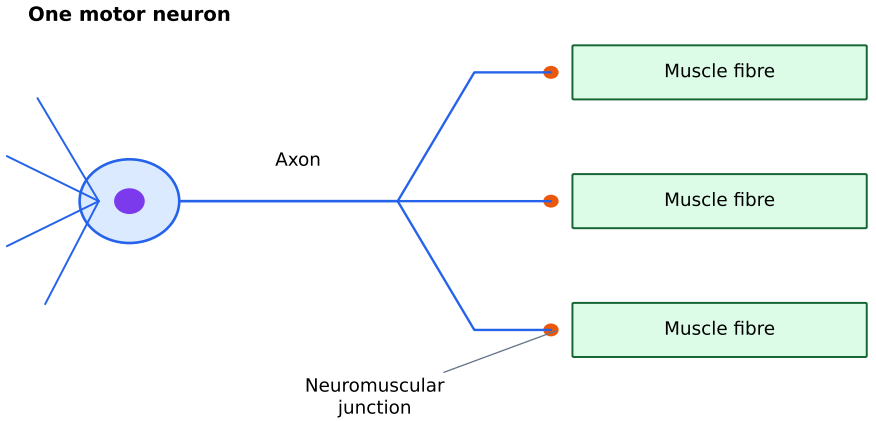
Ca^{2+} in, ACh released and bound, Na^{+} in on the far side; then the enzyme clears the cleft and the choline is recycled

1. An impulse arrives at the axon terminal.
2. Calcium entry triggers vesicles to release a chemical **neurotransmitter** 神经递质, which diffuses across the gap.
3. The neurotransmitter binds to receptors on the next cell and may trigger a new impulse.
4. Transmitter action ends through breakdown, reuptake or diffusion, depending on the synapse.

Where a motor neuron meets a muscle fibre, the synapse is called the **neuromuscular junction** 神经肌肉接头. The neurotransmitter there is **acetylcholine** 乙酰胆碱, which triggers an action potential in the muscle fibre and so starts contraction (unit B.1). The enzyme acetylcholinesterase then breaks the acetylcholine down, so the muscle can relax.

Motor units and the control of force

A **motor unit** 运动单位 is one motor neuron and all the muscle fibres it controls. A motor-neuron action potential normally activates all the muscle fibres it innervates. This all-or-none electrical activation does not mean the unit always produces its maximum possible mechanical force. Twitch force can vary with firing frequency, muscle length, fatigue and other conditions; recruitment and rate coding grade force.



One motor neuron and the muscle fibres it supplies form a motor unit; recruiting more and larger units raises force

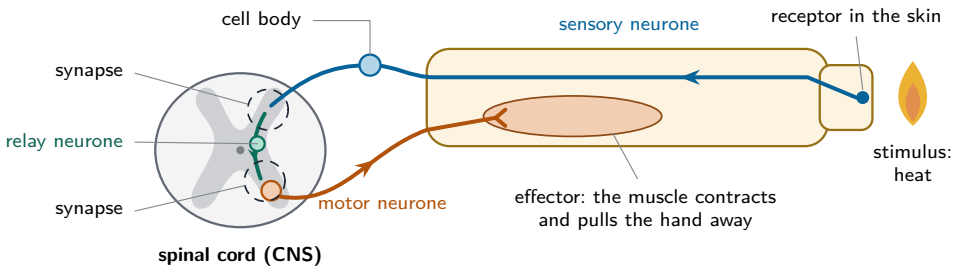
- Muscles for fine control, such as the eye muscles, have small motor units of about 10 fibres each.
- Large muscles for powerful movements, such as the calf (gastrocnemius), have motor units of up to about 2000 fibres.

How can a muscle produce a small force for a putt and a large force for a drive? The nervous system varies:

- **recruitment** 募集: how many motor units are active (small units are usually recruited first, then larger ones);
- **frequency**: how fast each motor unit fires; rapid impulses make twitches merge into a stronger, sustained contraction (**tetanus**).

Receptors, proprioception and reflexes

Proprioceptors 本体感受器 tell the CNS about the position and movement of the body without looking:



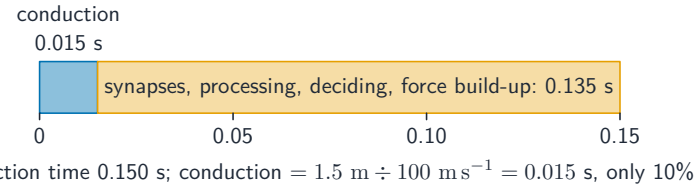
Spinal withdrawal reflex: impulses pass from the receptor to the effector through the spinal cord; the conscious part of the brain is not involved.

- **muscle spindles** 肌梭 detect stretch in a muscle and trigger the stretch reflex, which makes the muscle contract;
- **Golgi tendon organs** 高尔基腱器 detect force transmitted through the tendon and contribute to feedback regulating muscle force; the familiar inhibitory spinal pathway is a simplified example, not a switch that always relaxes a muscle in every movement;
- receptors in joints and the inner ear detect joint angle, balance and head movement.

A **reflex** 反射 is an automatic response without a conscious decision; its circuitry may involve the spinal cord or brainstem. In a **reflex arc**, impulses pass from a receptor along a sensory neuron to the spinal cord, then (often through a relay neuron) to a motor neuron and an effector. The knee-jerk reflex takes only about 0.05 s, much faster than a voluntary reaction.

Worked example: where the time goes

A sprinter's reaction time is 0.150 s. The nerve path from the ear to the brain and from the brain to the calf muscles is about 1.5 m long, and impulses travel along it at about 100 m/s.



Where a 0.150 s reaction time goes

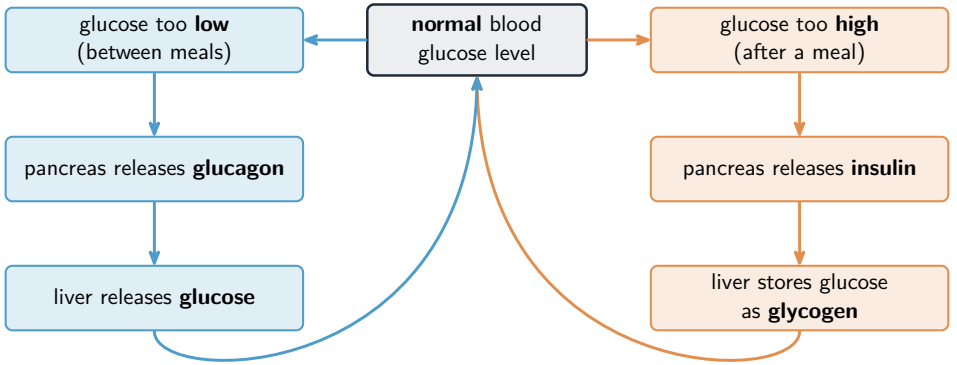
1. Time for nerve conduction = distance ÷ speed = 1.5 ÷ 100 = 0.015 s.
2. Fraction of the reaction time = 0.015 ÷ 0.150 = 0.10, so only about 10 %.
3. The other 0.135 s is mainly taken by synapses, processing and deciding in the brain, and the muscles building up force.

This is why training, focus and anticipation can improve reaction time, while the speed of the nerves themselves cannot be trained much.

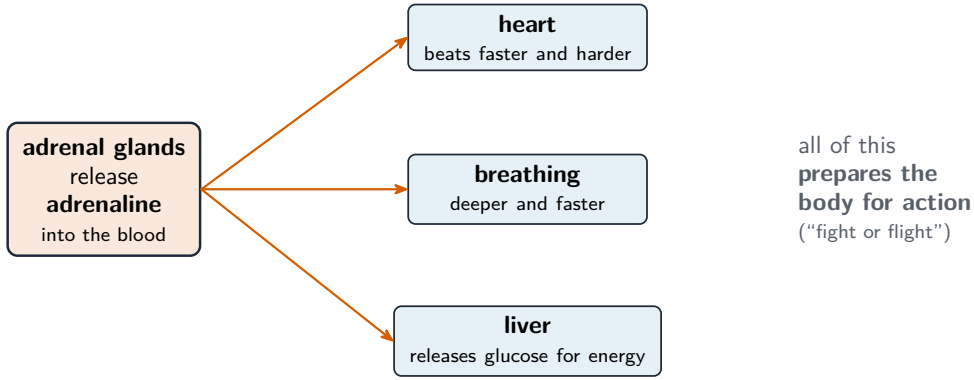
The endocrine system

Hormones

The **endocrine system** 内分泌系统 is a set of **glands** 腺体 that release chemical messengers called **hormones** 激素 into the blood. The blood carries them around the body, but each hormone acts only on **target cells** with matching receptors.



Insulin lowers blood glucose and glucagon raises it, keeping it near a normal level



Adrenaline prepares the body for action by acting on several target organs

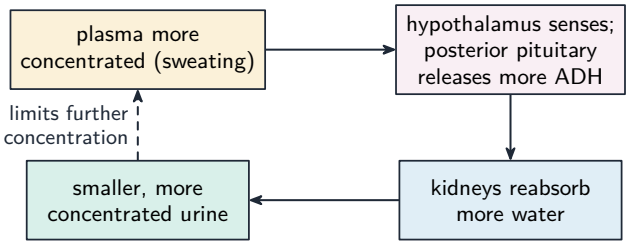
Hormone	Gland	Main effects relevant to exercise
Adrenaline 肾上腺素	Adrenal glands (medulla)	Raises heart rate and stroke volume, widens airways, releases glucose from the liver, redirects blood to muscles
Insulin 胰岛素	Pancreas	Promotes glucose uptake in responsive tissues and storage; circulating levels often fall during sustained exercise while contraction can increase muscle uptake
Glucagon 胰高血糖素	Pancreas	Raises blood glucose by breaking down liver glycogen; rises during exercise
Cortisol 皮质醇	Adrenal glands (cortex)	Promotes fuel mobilisation and hepatic glucose production; responses depend on intensity and duration
Growth hormone 生长激素	Pituitary gland	Growth and repair of tissues; fat use; rises with intense exercise and sleep
Testosterone	Testes (and smaller amounts from ovaries and adrenals)	Muscle and bone growth

Hormone	Gland	Main effects relevant to exercise
Erythropoietin 促红细胞生成素 (EPO)	Kidneys	Stimulates production of red blood cells, which carry oxygen
Antidiuretic hormone 抗利尿激素 (ADH)	Made in hypothalamic neurons; released from posterior pituitary	Increases renal water reabsorption in response to water-balance signals (unit A.2)

Several hormones are misused as drugs in sport. Synthetic EPO can raise red-cell mass and enhance oxygen transport and endurance performance under some conditions; it also thickens the blood and raises the risk of clots, heart attack and stroke. Exogenous EPO misuse is prohibited in sport; the physiological role of naturally produced EPO is different from a claim about drug use.

Additional endocrine links

Norepinephrine (noradrenaline) acts as a sympathetic neurotransmitter and a circulating adrenal hormone. Together with epinephrine (adrenaline), receptor-specific effects help coordinate cardiac activity, vascular resistance and fuel availability. "Sympathetic" does not mean every organ simply speeds up: responses depend on the target and receptor.



ADH conserves water by negative feedback

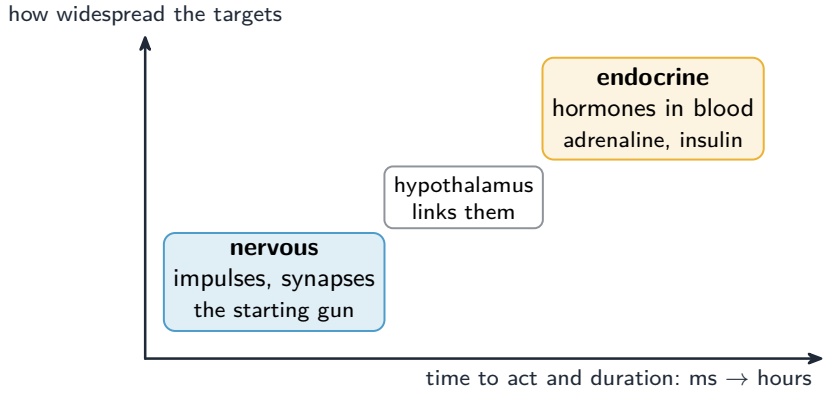
ADH links brain sensing to a kidney response. Greater plasma concentration can stimulate hypothalamic signals and ADH release; the kidneys reabsorb more water, so urine volume can fall. A dilute, larger-volume urine response can occur when water retention is less necessary. ADH does not replace water already lost. Distinguish where ADH is made and released and explain the feedback direction.

Reproductive hormones also affect physiology relevant to performance. Progesterone can raise regulated resting temperature after ovulation and influence sleep and fuel use. Oestrogen influences substrate use, including glycogen sparing under some exercise conditions, and connective-tissue properties. Testosterone supports protein synthesis, bone maintenance and erythropoietic pathways. These mechanisms do not establish one performance ranking, injury prediction or compulsory training plan from sex or cycle day alone. Hormone concentrations, symptoms, contraception, nutrition, task and individual variation matter; a calendar phase is an imperfect proxy for measured hormones. Use fictional or appropriately consented data and respect privacy.

Nerves and hormones compared

Feature	Nervous system	Endocrine system
Signal	Electrical impulses (and neurotransmitters at synapses)	Hormones in the blood
Speed	Very fast (milliseconds)	Slower (seconds to hours)
Duration of effect	Short	Often long-lasting
Target	Precise: specific muscles or glands	Widespread: any cells with receptors
Example	Reaction to the starting gun	Adrenaline before the race; insulin after a meal

The two systems work together. The hypothalamus in the brain links them: it controls the pituitary gland, and nerves of the sympathetic system make the adrenal glands release adrenaline.

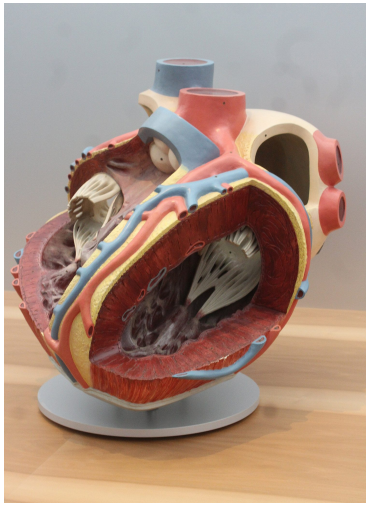


Fast and precise, or slow and widespread

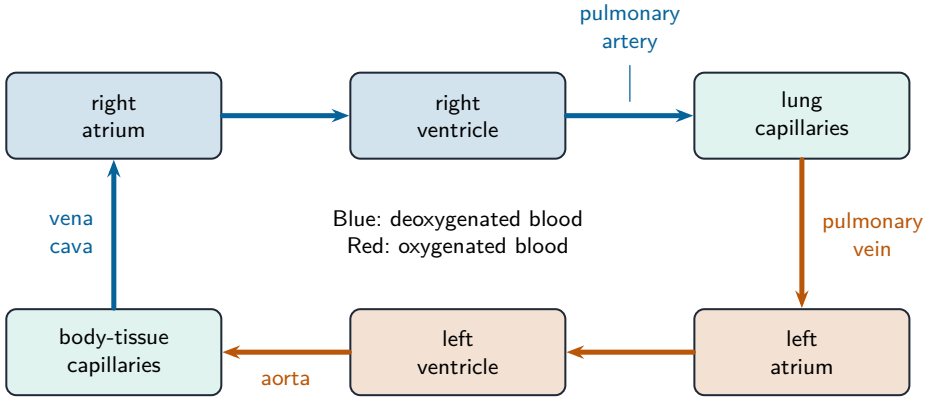
The cardiovascular system

The heart and the double circulation

The **cardiovascular system** 心血管系统 (heart, blood vessels and blood) carries oxygen, glucose, hormones and heat around the body and removes carbon dioxide and other wastes. Humans have a **double circulation** 双循环: blood passes through the heart twice in each complete circuit.



A model of the human heart: four chambers, with a visibly thicker left ventricle wall that pumps blood round the whole body

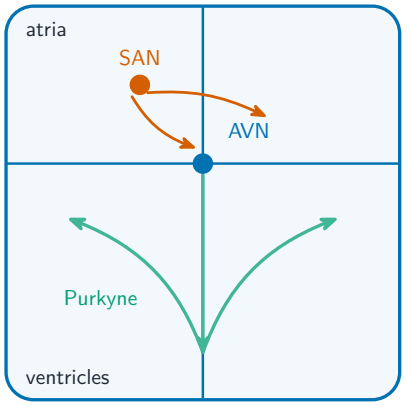


The pulmonary and systemic circulations

- The heart has four chambers: two **atria** 心房 receive blood, and two **ventricles** 心室 pump it out.
- **Valves** 瓣膜 stop blood flowing backwards: atrioventricular valves between atria and ventricles, and semilunar valves at the exits to the arteries.
- The left ventricle has the thickest muscular wall, because it pumps blood all around the body.

The heart's own pacemaker

Heart muscle is **myogenic** 肌源性: it starts its own beat without nerve impulses. The electrical signal passes through the heart in order:



SAN fires → atria contract → AVN delays → Purkyne → ventricles contract from the bottom up

The SAN sets the rhythm; the wave passes to the AVN, then the Purkyne tissue makes the ventricles contract bottom-up

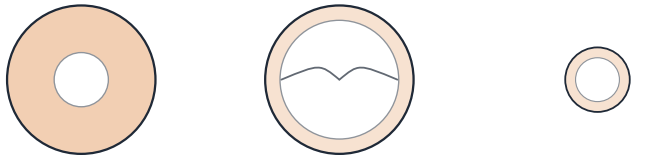
1. The **sinoatrial node** 窦房结 (SA node), the pacemaker in the wall of the right atrium, sends out an impulse; both atria contract.
2. The **atrioventricular node** 房室结 (AV node) delays the impulse by about 0.1 s, so the atria finish emptying into the ventricles.
3. The impulse travels down the bundle of His and spreads through the **Purkinje fibres** 浦肯野纤维 in the ventricle walls.
4. The ventricles contract from the bottom (apex) upwards, pushing blood into the arteries.

The contraction phase is **systole** 收缩期 and the relaxation and filling phase is **diastole** 舒张期. The heart sets its own rhythm, but the rate is changed by the autonomic nervous system (sympathetic nerves speed it up, the vagus nerve of the parasympathetic system slows it down) and by adrenaline. This is another example of communication between body systems.

Cardiovascular responses vary with workload, exercise mode, body size, age, sex-related physiology and training. These are influences, not sufficient grounds to predict an individual from a group label. Compare matched conditions and distinguish an acute response from adaptation across repeated training.

Blood vessels and blood

Vessel	Structure	Function
Arteries 动脉	Thick, elastic, muscular walls; narrow lumen	Carry blood away from the heart at high pressure
Capillaries 毛细血管	Walls one cell thick; very narrow	Exchange of gases, nutrients and wastes with tissues
Veins 静脉	Thinner walls; wide lumen; valves	Return blood to the heart at low pressure



artery
thick muscular, elastic wall; narrow lumen; high pressure

vein
thin wall; wide lumen; has **valves**; low pressure

capillary
wall one cell thick; lets substances be exchanged

Arteries, veins and capillaries are each built for their job

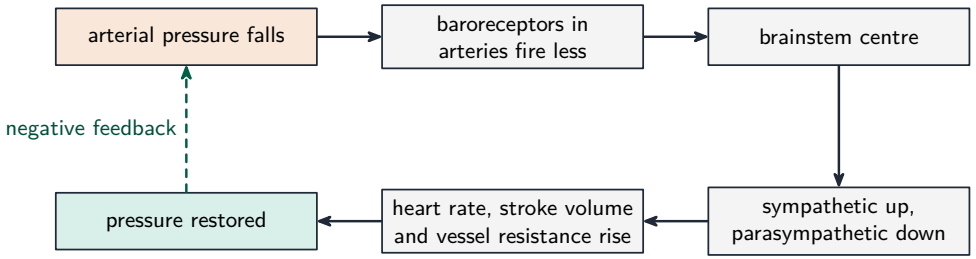
Blood is plasma (water carrying glucose, hormones, carbon dioxide and heat) plus **red blood cells** 红细胞, white blood cells and platelets. Red blood cells contain **haemoglobin** 血红蛋白, which carries about 98 % of the oxygen in the blood.

Blood pressure 血压 is force per unit area exerted by blood on vessel walls, given as systolic over diastolic pressure; a typical resting value is about 120/80 mmHg. **Venous return** 静脉回流, the flow of blood back to the heart, is helped by the **skeletal muscle pump** (contracting leg muscles squeeze the veins), the **respiratory pump** (pressure changes in the chest during breathing) and valves in the veins. Within physiological limits, increased filling can raise stroke volume through the Frank–Starling mechanism. Stroke volume also depends on contractility and the pressure against which the heart ejects; it does not rise without limit. A gradual recovery can help maintain circulation, but a textbook mechanism is not a personal exercise prescription.

Intrinsic rhythm and extrinsic feedback

The SA node generates the heart's rhythm intrinsically; sympathetic, parasympathetic and hormonal signals modify it. The brain does not normally have to initiate each heartbeat. Baroreceptors sense stretch in major arteries. In a simplified resting feedback example, a fall in arterial pressure reduces baroreceptor firing; brainstem responses can increase sympathetic and reduce parasympathetic activity, helping raise

cardiac output and vascular resistance. A rise can produce the opposite response. During exercise, regulation is adjusted to the activity rather than simply opposing every rise in heart rate or pressure.



the SA node sets the rhythm; these signals only modify it

The baroreflex: a fall in pressure triggers responses that raise it again

Vasodilation in working muscle also involves local metabolic signals. The share of flow to an organ and its absolute flow are different: 20% of 5 L/min is 1 L/min; 80% of 20 L/min is 16 L/min in an invented comparison. Skin flow is also important during heat stress. Neither a heart-rate reading nor a blood-pressure value by itself measures total fitness.

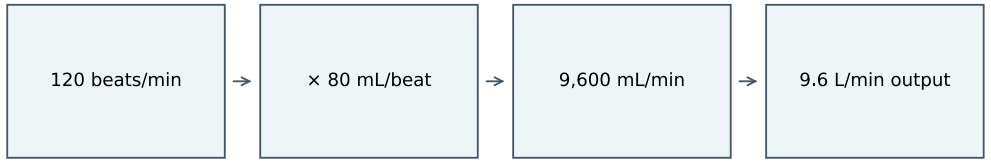
For a classroom comparison, use voluntary informed participation, teacher supervision and an approved low-intensity workload. Record a resting heart-rate baseline, keep the workload standardized and measure recovery at fixed times. Stop for discomfort; do not use maximal exertion or diagnose health. A lower recovery heart rate alone does not establish greater fitness unless workload and participant conditions are comparable.

■ Cardiac output

Cardiac output 心输出量 is the volume of blood the heart pumps per minute:

$$\text{cardiac output} = \text{heart rate} \times \text{stroke volume}$$

where **stroke volume** 每搏输出量 is the volume pumped in each beat.



Cardiac output = heart rate × stroke volume = 120 × 80 mL = 9.6 L/min

Worked example.

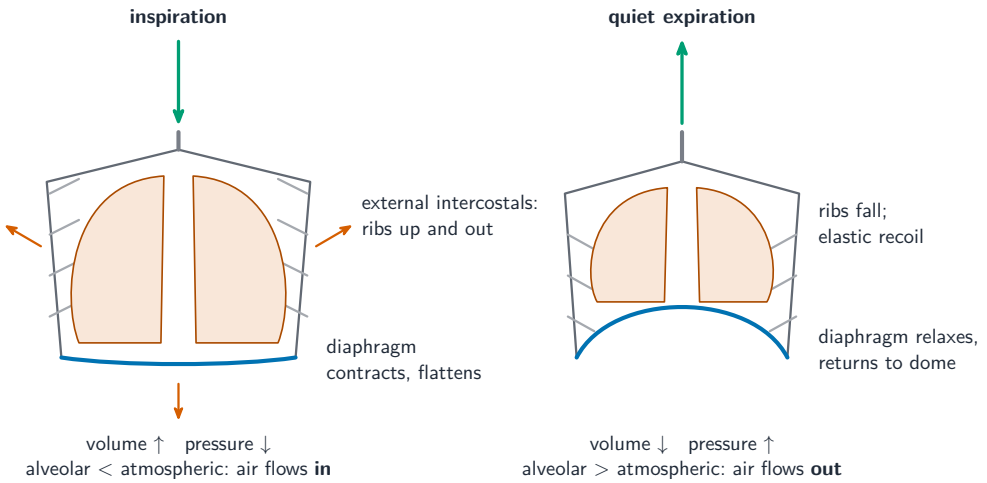
1. At rest, an athlete's heart rate is 70 beats per minute and stroke volume 70 mL: cardiac output = 70 × 70 = 4900 mL/min, about 4.9 L/min.
2. In an invented anticipatory-response example, heart rate is 120 beats per minute and stroke volume 80 mL: cardiac output = 120 × 80 = 9600 mL/min = 9.6 L/min.
3. The cardiac output has almost doubled (9.6 ÷ 4.9 ≈ 2.0) before the athlete has moved, preparing the muscles for work.

During exercise, blood is also redirected by the **vascular shunt** 血管分流: small arteries to the muscles widen and those to the gut narrow, so the share of cardiac output going to working muscles rises from about 15 to 20 % at rest to about 80 % during hard exercise.

The respiratory system

■ Breathing in and out

The **respiratory system** 呼吸系统 brings oxygen into the body and removes carbon dioxide. Air passes through the nose or mouth, the trachea, the bronchi and the bronchioles to millions of tiny air sacs, the **alveoli** 肺泡.

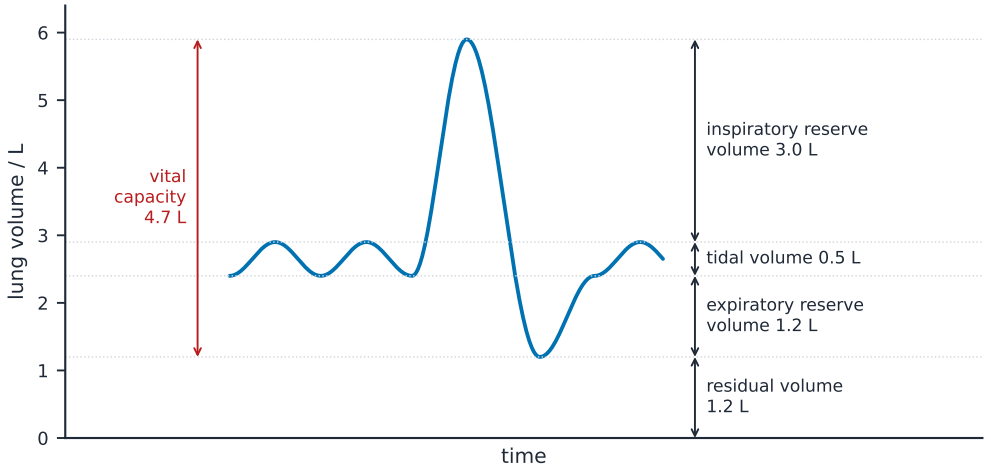


Muscles change the thoracic volume; the pressure difference, not the lungs themselves, moves the air

- **Inspiration** 吸气: the **diaphragm** 膈 contracts and flattens, and the external intercostal muscles lift the ribs up and out. The volume of the chest increases, the pressure inside falls below air pressure, and air flows in.
- **Expiration** 呼气 at rest is passive: the muscles relax and the lungs recoil. When ventilation demand is high, expiration can become active: the internal intercostal and abdominal muscles pull the ribs down and push the diaphragm up, so air leaves faster.

Lung volumes

A **spirometer** 肺量计 measures air moved into and out of the lungs. Simple spirometry cannot directly measure residual volume, which does not leave the lungs; that requires an additional method.



Illustrative lung-volume model; values vary with body size and other factors. Residual volume is shown for context, not measured by a simple spirometer.

Volume	Meaning	During exercise
Tidal volume 潮气量	Air breathed in or out in one normal breath	Increases
Inspiratory reserve volume	Extra air that can be breathed in after a normal breath in	Decreases
Expiratory reserve volume	Extra air that can be breathed out after a normal breath out	Decreases slightly
Residual volume 余气量	Air left in the lungs after a maximal breath out	Stays about the same
Vital capacity 肺活量	Largest volume breathed out after the deepest breath in	Stays about the same

Minute ventilation 每分通气量 is the volume of air breathed per minute:

$$\text{minute ventilation} = \text{tidal volume} \times \text{breathing frequency}$$

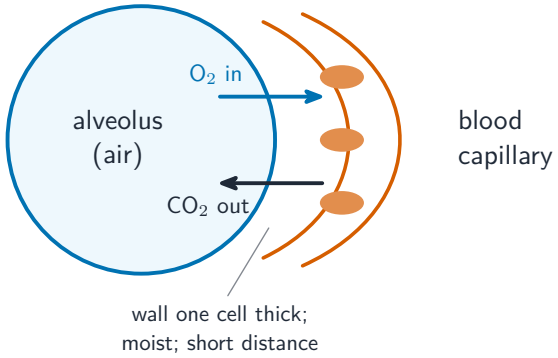
> **Worked example.** At rest, tidal volume is 0.5 L and breathing frequency 12 breaths per minute, so ventilation $= 0.5 \times 12 = 6$ L/min. During a hard run, tidal volume rises to 3.0 L and frequency to 40 breaths per minute, so ventilation $= 3.0 \times 40 = 120$ L/min, twenty times the resting value.

Gas exchange

Oxygen and carbon dioxide move by **diffusion** 扩散, down their respective partial-pressure gradients. Partial pressure concerns the freely dissolved gas; oxygen bound to haemoglobin increases carrying capacity without being equivalent to dissolved-gas pressure.



Real lung tissue stained for the microscope: the open spaces are alveoli and the thin pink walls are where gases cross; a small airway sits in the centre



Across the thin, moist wall, oxygen diffuses into the blood and carbon dioxide diffuses out

- **In the lungs:** air in the alveoli has a higher partial pressure of oxygen (about 100 mmHg) than the blood arriving from the body (about 40 mmHg), so oxygen diffuses into the blood; carbon dioxide diffuses the other way.
- **In the muscles:** working muscle uses oxygen and produces carbon dioxide, so oxygen diffuses out of the blood into the muscle cells and carbon dioxide diffuses into the blood.

The alveoli are adapted for fast diffusion: a very large total surface area (about 70 m^2, the size of a badminton court), walls only one cell thick, a dense network of capillaries and a moist lining. Most carbon dioxide is carried in the blood as hydrogen carbonate ions; smaller amounts are bound to haemoglobin or dissolved in plasma.

Control of breathing

The **respiratory centre** in the brainstem coordinates breathing through motor signals to respiratory muscles. **Chemoreceptors** 化学感受器 provide information about carbon dioxide, acidity and, in appropriate conditions, oxygen. A rise in carbon dioxide and hydrogen-ion concentration can stimulate ventilation, helping remove carbon dioxide and regulate pH. Neural feedforward and feedback from movement also increase ventilation during exercise: arterial carbon dioxide need not first accumulate, and can remain near its regulated level during steady moderate exercise. Ventilation, gas exchange and cellular respiration are connected but distinct processes.

Homeostasis

Keeping the internal environment stable

Homeostasis 稳态 is keeping conditions inside the body, such as temperature, blood glucose and water content, within narrow limits, even when exercise or the environment changes them. Most homeostasis uses **negative feedback** 负反馈: a change from the normal value (the **set point**) triggers a response that reverses the change.

Every control system has:

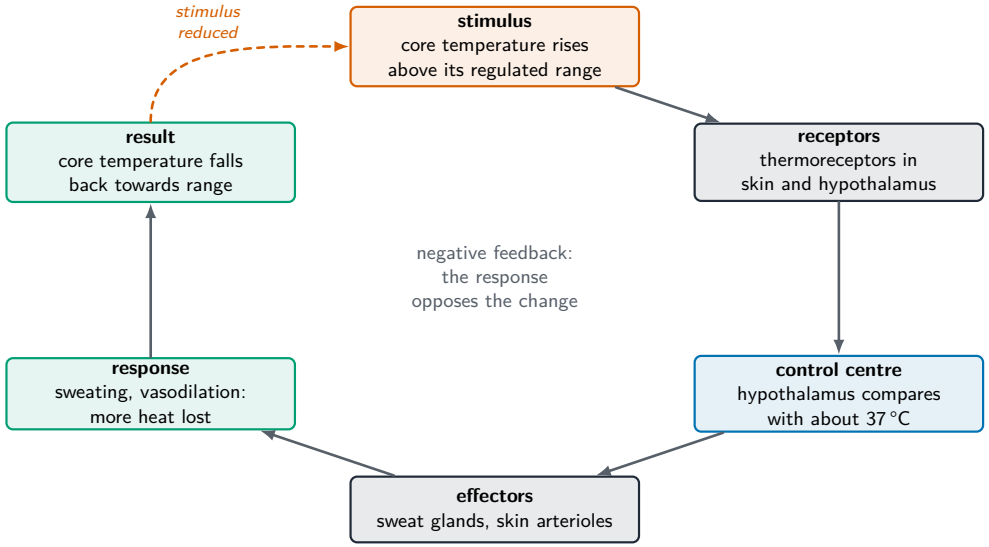
- **receptors** 感受器 that detect the change;
- a **control centre**, often in the brain, that compares it with the set point;
- **effectors** 效应器, muscles or glands, that carry out the response.

Temperature regulation during exercise

Working muscles turn most of the energy they release into heat: the proportion appearing as external mechanical work depends on the task, with the remainder largely contributing to heat. Without control, a marathon runner's body temperature would rise dangerously within minutes.



Sweat evaporating from the skin carries heat away: the main way the body sheds the heat that exercise produces



Negative feedback keeps core temperature near 37 °C

The **hypothalamus** 下丘脑 is the body's thermostat. When core temperature rises:

- **sweating**: sweat glands release sweat; evaporation takes heat from the skin. This can become the main route of heat loss during hard exercise, especially when hot surroundings limit radiation and convection;
- **vasodilation** 血管舒张: blood vessels in the skin widen, so more warm blood reaches the surface; radiation and convection remove heat when the relevant temperature gradients favour loss. Hot surroundings can instead add heat.

When the body is too cold, it does the opposite: **vasoconstriction** 血管收缩 keeps warm blood in the core, and **shivering** releases heat from rapid muscle contractions. Non-shivering thermogenesis also increases metabolic heat production. Insulation and behaviour affect heat transfer as well as physiological effectors.

Evaporation depends on the water-vapour gradient, airflow and clothing. High humidity can limit evaporative cooling even when sweating continues; dripping sweat does not remove the same heat as sweat that evaporates. Thermoregulation varies with training status and **acclimatisation** 热适应 (adjustment across repeated environmental exposure), body composition, environment and hormonal state. Core temperature is regulated around a range, not held at exactly 37 °C in every person and activity. Severe heat illness is an emergency; CDC's heat guidance distinguishes dangerous neurological dysfunction from a simple exercise temperature rise. Do not use one temperature threshold or a school observation to diagnose a person.

Blood glucose during exercise

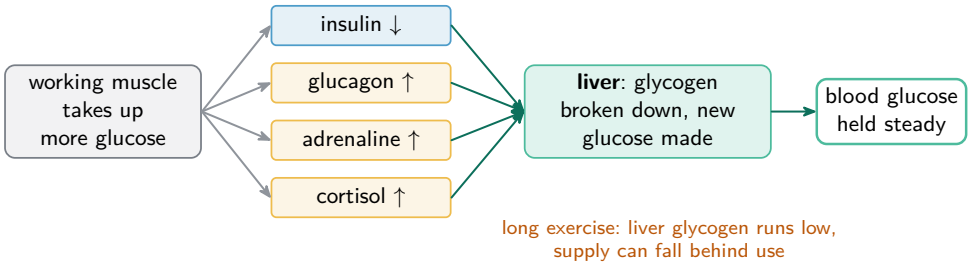
Muscles take up more glucose during exercise, so blood glucose tends to fall. In response:



A blood glucose meter: insulin and glucagon keep blood glucose within narrow limits, even as working muscles take it up

- circulating insulin commonly falls while glucagon helps support liver glucose output;
- adrenaline and cortisol rise;

- the liver breaks down glycogen and makes new glucose, keeping blood glucose stable.



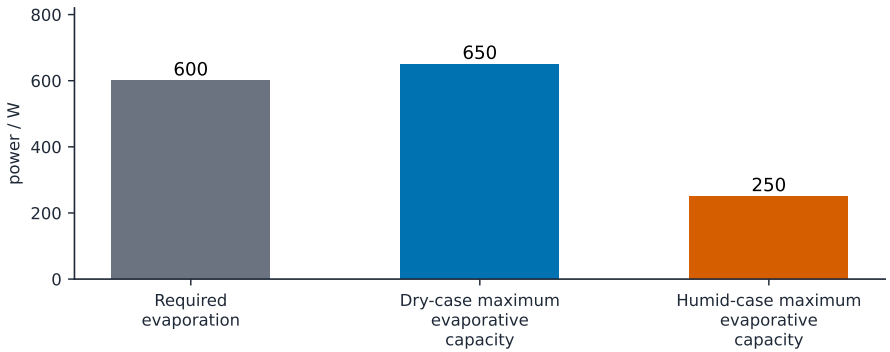
Hormones defend blood glucose during exercise

During prolonged exercise, glucose use can exceed glucose supply, particularly as liver glycogen becomes depleted. Hypoglycaemia is one possible contributor to impairment, not an inevitable result or the only cause of fatigue. Muscle glycogen is principally a local fuel store and does not directly release free glucose into blood in the same way as the liver. Nutrition, intensity and duration affect the balance (unit A.2).

AHL: Environment, acclimatisation and performance

■ Heat and humidity: distinguish an immediate response from adaptation

An immediate heat response includes increased skin blood flow and sweating. With appropriately managed repeated exposure, heat acclimatisation can expand plasma volume and improve sweating responses, reducing strain at a given workload in some conditions. Changes develop over time and vary between people; acclimatisation does not make dangerous heat harmless. Cold prompts vasoconstriction and heat production, but protection also depends on insulation, wind, wetness and the activity. Do not assume cold acclimatisation mirrors the sweating adaptations of heat.



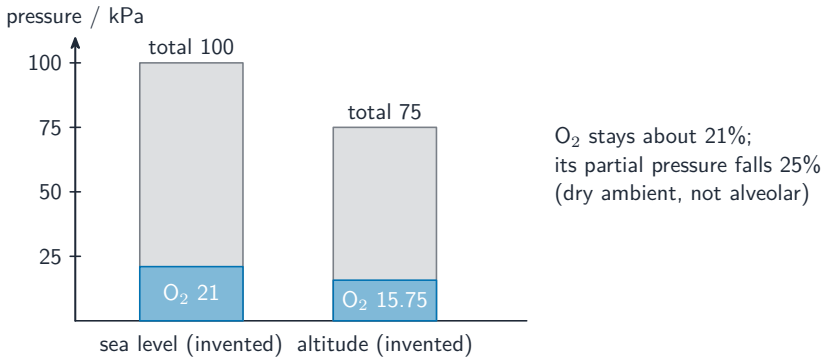
Invented model: dry reserve 50 W; humid minimum storage 350 W.
Capacity is a limit, not automatically the actual heat loss.

Invented capacities illustrate a mechanism; they are not safe-exposure limits or predictions for an individual.

Worked heat budget. Suppose metabolic heat production and net environmental heat gains together require 600 W of evaporative heat loss to prevent storage. In a dry-case environment, an invented maximum evaporative capacity is 650 W, leaving 50 W of capacity beyond that requirement. Actual evaporation need not reach the maximum: feedback can regulate it. With all other terms held constant, a humid-case capacity of 250 W leaves a minimum heat-storage rate of 600−250=350 W if that maximum is realised. Over 120 s this is 42 000 J=42 kJ of stored energy in the simplified model. Do not convert it to a clinical body-temperature prediction without justified body mass, heat capacity, distribution and other assumptions. More sweat secretion alone cannot overcome an environmental evaporation limit.

■ Altitude: percentage and partial pressure differ

At altitude, reduced barometric pressure lowers inspired oxygen partial pressure while oxygen remains about 21% of dry air. In an invented dry-air comparison, total pressures are 100 kPa and 75 kPa: oxygen partial pressures are 0.21×100=21 kPa and 0.21×75=15.75 kPa, a 25% fall. These are dry ambient values, not alveolar values: warming/humidification and gas exchange alter the gases reaching alveoli.



Same oxygen percentage, lower partial pressure (invented)

An immediate response to hypoxia includes increased ventilation and cardiovascular adjustments. Over time, ventilatory acclimatisation and changes supporting oxygen transport, including erythropoietin-stimulated red-cell production, can develop. They are not instantaneous, uniform or unlimited, and altitude illness remains possible. CDC's altitude guidance distinguishes acclimatisation from full restoration of low-altitude maximal performance.

■ Match the explanation to the event and evidence

Reduced oxygen pressure can limit sustained aerobic work; reduced air density can also alter aerodynamic drag, so the effect need not be identical for an endurance race and a brief sprint. Heat strain depends on metabolic heat load, environment and duration, not air temperature alone. Compare the same workload and conditions when judging an adaptation. An athlete whose heart rate is lower after ten days has not supplied a controlled causal experiment merely by repeating a test once.

altitude	**heat**
lower O_2 pressure: can limit sustained aerobic work lower air density: less drag, may help a brief sprint	strain depends on metabolic heat, environment and duration, not air temperature alone

judge an adaptation at the same workload and conditions;
one repeated test is not a controlled experiment

Altitude and heat affect events differently

Performance-support strategies can include planned familiarisation, appropriate clothing, environmental scheduling and individual monitoring under qualified supervision. For a school investigation use invented, published or consented low-risk observations; never induce dehydration, dangerous heat/cold exposure or hypoxia. To evaluate a claimed strategy, compare baseline and follow-up conditions, account for training, illness and learning, and use an appropriate comparison group. Blinding the obvious weather may be impossible; acknowledge that limitation rather than claiming a double-blind design from concealment of a spreadsheet label.

Practice

1. (a) Distinguish between the central and peripheral nervous systems. (b) Compare the roles of the sympathetic and parasympathetic nervous systems during and after exercise.
2. (a) Label the parts of a motor neuron and state the function of the myelin sheath. (b) Describe the changes in membrane potential during an action potential.
3. (a) Explain all-or-none action potentials and motor-unit activation. Explain why this does not mean maximum mechanical force on every impulse. (b) Explain how the nervous system varies the force produced by a muscle. (c) Explain why the muscles that control the eye have small motor units.
4. Describe how a signal crosses the neuromuscular junction.
5. (a) Outline the roles of muscle spindles and Golgi tendon organs. (b) A goalkeeper's nerve path is 1.2 m long and impulses travel at 80 m/s. Calculate the conduction time and the percentage of a 0.300 s reaction time it represents.
6. (a) Compare the nervous and endocrine systems. (b) Outline the effects of adrenaline on the body before a race.
7. A swimmer's heart rate rises from 65 to 150 beats per minute and stroke volume from 75 to 110 mL. Calculate the cardiac output at rest and during exercise, in litres per minute.
8. (a) Explain how negative feedback keeps body temperature stable during a long run. (b) Explain why running a marathon in hot, humid weather is more dangerous than in hot, dry weather.
9. Explain how blood glucose is kept stable during a long cycle race, and why it may still fall.
10. Describe the sequence of electrical events that makes the heart beat.
11. A rower has a tidal volume of 2.5 L and a breathing frequency of 36 breaths per minute. Calculate the minute ventilation and compare it with a resting value of 6 L/min.
12. Explain why a rise in ventilation during steady moderate exercise does not require arterial carbon dioxide to rise first. Contrast a hormone's release site with its site of synthesis using ADH.
13. **AHL:** (a) Use the invented heat-budget figure to find the humid-case heat-storage rate and energy over 120 s. (b) Find dry-air oxygen partial pressure at 75 kPa total pressure and 21% oxygen, and compare with 100 kPa. (c) Distinguish acute responses from acclimatisation and state two controls needed to assess a performance strategy.

Answers.

1. (a) The CNS is the brain and spinal cord, which process information and make decisions. The PNS is all the nerves outside it, carrying impulses from receptors to the CNS (sensory) and from the CNS to muscles and glands (motor). (b) The sympathetic system is active during exercise: it raises heart rate and stroke volume, widens airways and sends more blood to muscles. The parasympathetic system dominates after exercise: it slows heart rate and returns blood flow to the gut ("rest and digest").
2. (a) Dendrites, cell body with nucleus, axon, myelin sheath, nodes of Ranvier, axon terminals adjacent to muscle motor end plates. The myelin sheath insulates the axon, so the impulse jumps between the nodes and travels much faster. (b) At rest the inside is about −70 mV. A stimulus raises it to the threshold of about −55 mV; sodium channels open, sodium ions enter and the potential rises to about +30 mV (depolarisation). Potassium channels open, potassium ions leave and the potential falls back (repolarisation), briefly dropping below −70 mV before returning to rest.
3. (a) An action potential is generated if threshold is reached. A motor-neuron action potential normally activates its innervated fibres, but twitch force can vary; recruitment, firing rate, length and fatigue affect mechanical force. (b) By recruiting more (and larger) motor units, and by increasing the frequency of impulses so that twitches merge into a stronger contraction. (c) Small motor units (about 10 fibres) mean each impulse produces a small change in force, so eye movements can be controlled very precisely.
4. The impulse reaches the axon terminal; acetylcholine is released and diffuses across the gap; it binds to receptors on the muscle fibre, triggering an action potential and contraction; acetylcholinesterase then breaks down the acetylcholine.
5. (a) Muscle spindles report muscle length/stretch and contribute to stretch reflexes. Golgi tendon organs report force and contribute to force regulation through spinal and descending pathways; a simple inhibitory reflex is not their only role in every task. (b) Time $= 1.2 \div 80 = 0.015$ s. Percentage $= 0.015 \div 0.300 \times 100 = 5$ %.
6. (a) Nervous: electrical impulses, very fast, short-lived, precise targets. Endocrine: hormones in the blood, slower, longer-lasting, widespread targets. Both coordinate the body and are linked through the hypothalamus. (b) It raises heart rate and stroke volume (so cardiac output rises), widens the airways, releases glucose from the liver and redirects blood from the gut to the muscles.
7. Rest: $65 \times 75 = 4875$ mL/min ≈ 4.9 L/min. Exercise: $150 \times 110 = 16\,500$ mL/min $= 16.5$ L/min.
8. (a) Muscles produce heat and core temperature rises. Thermoreceptors detect the rise; the hypothalamus increases sweating and skin blood flow. Evaporating sweat removes heat; radiation and convection remove heat only when the temperature gradients favour loss. As temperature moves towards its regulated range, the corrective response decreases. Negative feedback opposes excessive warming without holding core temperature at exactly 37 °C throughout exercise. (b) At otherwise comparable heat load, airflow and clothing, higher humidity reduces evaporative capacity. Sweating may continue without enough evaporation to balance heat gain. Dry air does not guarantee safety: air temperature, radiation, workload, duration and hydration also matter.
9. Contraction can increase muscle glucose uptake even as circulating insulin falls. Glucagon and other counter-regulatory signals help the liver supply glucose through glycogen breakdown and gluconeogenesis. Supply can fail to meet use during prolonged exercise; fatigue has multiple causes and a meal does not guarantee prevention of every limitation.
10. The SA node (pacemaker) sends out an impulse and the atria contract; the AV node delays the impulse by about 0.1 s; the impulse passes down the bundle of His and through the Purkinje fibres; the ventricles contract from the apex upwards.
11. $2.5 \times 36 = 90$ L/min, fifteen times the resting value ($90 \div 6 = 15$).
12. Neural feedforward and movement feedback can increase ventilation in anticipation of, and alongside, metabolic demand; chemoreceptor feedback also regulates carbon dioxide/pH. ADH is synthesised in hypothalamic neurons and released from posterior-pituitary nerve terminals; these are different anatomical roles.
13. **AHL:** (a) 600−250=350 W minimum storage in the stated model when maximum evaporation is realised; 350×120=42 000 J=42 kJ. The dry-case 650 W capacity has 50 W reserve beyond the 600 W requirement, not proof of continuous actual 650 W evaporation. (b) 0.21×75=15.75 kPa versus 21 kPa; decrease 5.25/21×100=25%, while the oxygen percentage remains 21%. These are not alveolar pressures. (c) Acute responses occur during or soon after exposure; acclimatisation develops across repeated exposure. Match workload, temperature/humidity or altitude, timing, hydration and participant conditions; account for training and use a suitable comparison. Neither adaptation nor one lower heart-rate reading guarantees safety or causality.

Exam tips

- Use the correct names: CNS, PNS, somatic, autonomic, sympathetic, parasympathetic.
- Describe an action potential in order, with values: −70 mV, −55 mV, +30 mV, sodium in, potassium out.
- Name acetylcholine at the neuromuscular junction.
- Explain force control with both recruitment and impulse frequency.
- For homeostasis, name the receptor, control centre, effector and response, and say "negative feedback".
- Show working and units in cardiac output, ventilation and conduction-time calculations.
- Trace blood or air in order through the structures, naming each one.

A.2 · Hydration and nutrition

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

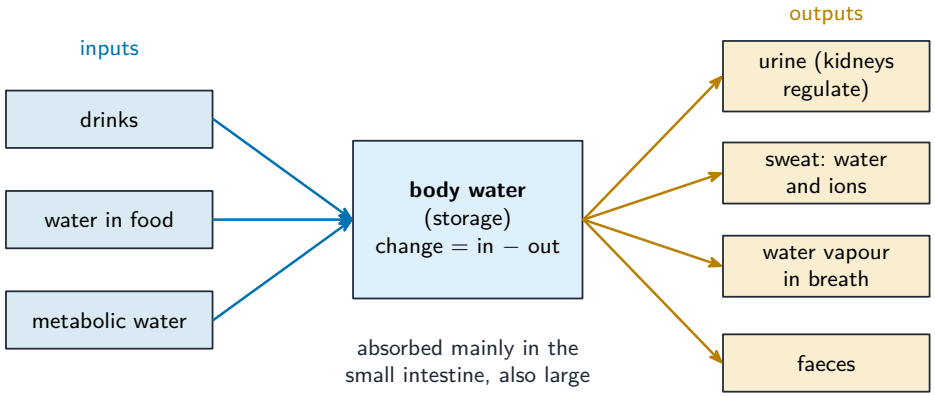
Two runners finish with the same change in body mass. One drank during the activity and the other did not. Did they lose the same amount of sweat? A useful explanation must account for inputs, outputs and stored material before interpreting a performance result.

This handout covers A2: water and electrolyte balance, fuelling for health and performance, and energy systems. Sections marked **AHL** are for Higher Level only. The practical comparisons and numerical datasets are original invented teaching examples, not measurements from real athletes or examination papers.

Prerequisites: percentages, rates, the roles of blood and the nervous/endocrine systems, and the difference between an acute response and a training adaptation. Use supplied data for classroom calculations; these examples are not individual diet, drinking or exercise prescriptions.

Water balance depends on inputs, outputs and storage

Water balance 水平衡 describes the relationship between water entering the body, leaving it and changing its stored amount. Food and drinks supply water; metabolism produces some water too. Absorption takes place through the digestive tract, importantly in the small intestine, with further water and electrolyte absorption in the large intestine. Do not treat the large intestine as the only entry route. The NIDDK digestive-system explanation distinguishes the two regions.



Body water changes by inputs minus outputs; sweat removes ions as well as water

Water leaves through urine, faeces, the respiratory tract and the skin. Sweat contains water and dissolved ions; evaporation removes water vapour from the skin while salts remain behind. Respiratory water vapour is another loss. The kidneys regulate how much water and solute leave in urine; describing this simply as "everything is excreted by osmosis" misses filtration, solute handling and regulated water reabsorption.

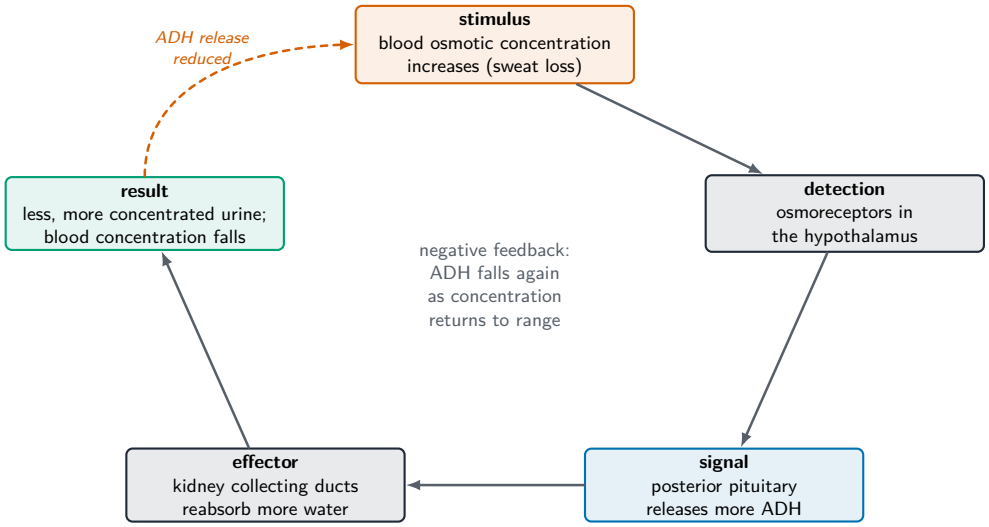
Electrolytes are dissolved substances producing ions, including sodium and potassium ions. Their concentration depends on the amount of solute relative to water, not just the total salt present. These ions contribute to osmotic conditions, nerve signalling and muscle function. A person can lose both water and sodium while the remaining fluid becomes more concentrated if water loss is relatively greater.

For an invented compartment with 100 arbitrary solute units in 10 water-volume units, concentration is 10. If it loses 10 solute units and two water units, concentration becomes $90/8 = 11.25$: a 12.5% increase despite less total solute. This accounting model does not reproduce all body compartments, kidney responses or clinical sodium measurements.

Hormonal feedback helps regulate internal fluid conditions

The hypothalamus detects changes in internal osmotic conditions and participates in thirst and hormonal regulation. Antidiuretic hormone, ADH or vasopressin, is made in hypothalamic neurons and released from the posterior pituitary. When conditions favour conserving water, increased ADH action makes the kidneys retain more water; less water then leaves in urine, which can become more concentrated. Falling osmotic concentration reduces that stimulus under ordinary feedback conditions.

This is negative feedback because the response opposes the initiating disturbance. The pituitary does not manufacture all of its released ADH, and the kidneys do not produce new water. Regulation includes blood-volume/pressure signals and other hormones affecting solute handling, so it is not a one-sensor switch controlled only by sweat. Detailed nephron anatomy is not needed for this unit's explanation.



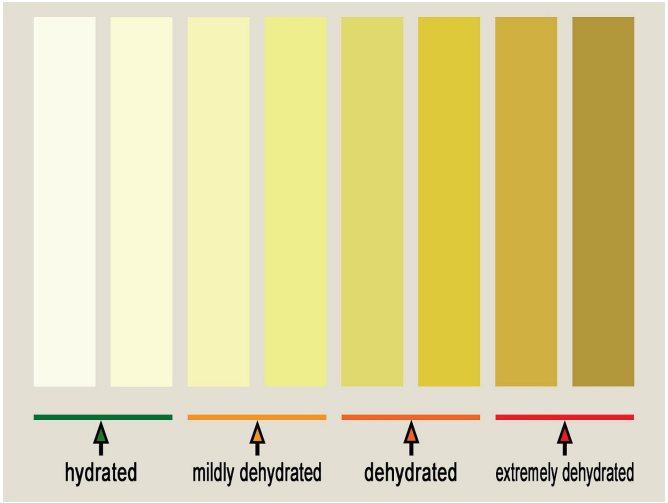
The kidney response tends to oppose increased concentration. Thirst and other regulatory signals also contribute.

Dehydration concerns loss of body water. Hypernatraemia means an abnormally high sodium concentration in blood; hyponatraemia means an abnormally low concentration. They are not interchangeable names for the same amount of sweating. Excessive intake of hypotonic fluid relative to losses and impaired water excretion can contribute to exercise-associated hyponatraemia; a sports drink does not automatically remove that risk. Water and solute must be considered together.

The NATA position statement explains why fluid replacement depends on individual losses, conditions and tolerance. "More drinking is always better" and "never drink until severe thirst" are both poor universal rules. In class, analyse records rather than inducing dehydration or excessive drinking. Illness during activity needs qualified assessment, not a diagnosis from a worksheet or a single sign.

Hydration indicators have different strengths and limitations

Body mass measured consistently before and after an interval can help estimate net mass change. Use comparable dry clothing, the same suitable balance and recorded food, drink and urine where relevant. Wet clothes, retained food, respiratory exchange and metabolic changes can affect the interpretation. A short-term fall in mass does not demonstrate loss of that mass as body fat.



A urine-colour chart: cheap and quick, but only a rough indicator of hydration status

body-mass change	urine colour & concentration	thirst
shows net loss over an interval	**shows** a quick check of the sample	**shows** an important cue
limited by clothing, food, drink, urine must be recorded	**limited by** pigments, supplements, timing; lags behind change	**limited by** access, conditions and perception vary

no single field measure captures water and electrolyte status: compare several

Each field indicator shows something and is limited by something: compare several

Urine colour offers a simple observation, but food pigments, supplements, medication, timing and lighting can affect it. Urine concentration can lag behind a changing exercise state. Osmolarity describes the number of osmotically active particles per volume of solution; osmolality uses mass of solvent instead. A measured urine value is not automatically identical to blood concentration. State the sample and method rather than writing "osmolarity was high" without a context.

Thirst is an important physiological cue, but perception, access to fluid, exercise conditions and timing influence its use as evidence. No one field indicator perfectly measures every aspect of water and electrolyte status. Compare measures and explain uncertainties; a single dark sample does not establish a precise percentage dehydration or a sodium diagnosis.

Sweat rate 出汗率 is sweat loss per time. A simplified field estimate is:

$$\text{sweat loss} \approx \text{pre-activity mass} - \text{post-activity mass} + \text{drink mass} - \text{urine mass}.$$

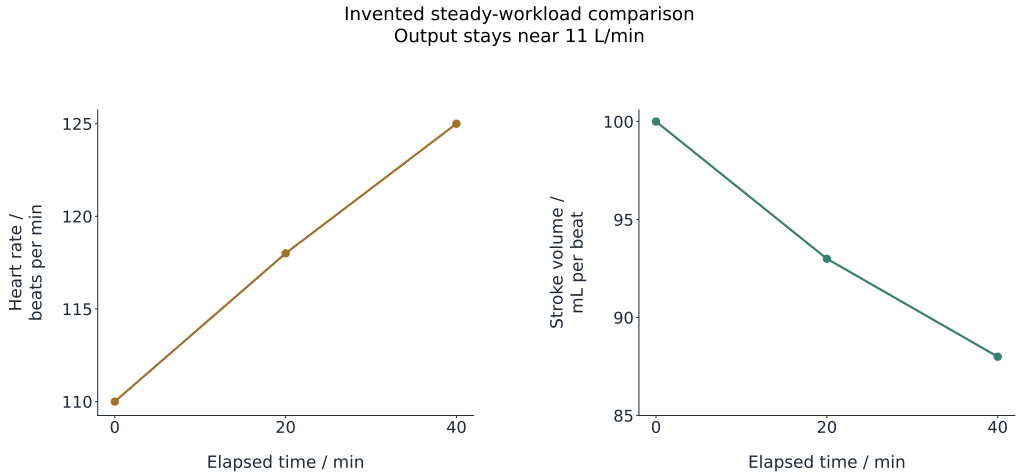
The signs follow mass balance. Drinking partly replaces lost mass, so it is added back when estimating sweat. Urine explains some of the mass lost separately from sweat, so subtract it. All terms must use compatible units; one kilogram of water is approximately one litre for this estimate, not an identity for every liquid.

Invented values 60.0 kg before, 59.6 kg after, drink 0.50 kg and urine 0.10 kg give sweat loss $60.0 - 59.6 + 0.50 - 0.10 = 0.80$ kg. Over 1.5 hours, estimated rate is $0.80/1.5 \approx 0.53$ kg per hour. The body-mass fall alone is 0.40 kg, or about 0.67% of initial mass; it is neither the whole sweat loss nor a complete fluid-status assessment. The approximation omits other exchanges, and recording uncertainty matters.

Heat and fluid loss can contribute to cardiovascular drift

During prolonged exercise at a steady submaximal external workload, heart rate may gradually rise while stroke volume falls: cardiovascular drift. Rising body temperature increases skin circulation demand; loss of fluid can reduce plasma volume, venous return and ventricular filling. Several interacting mechanisms alter how the circulation supports exercise and heat transfer. Drift can occur in thermoneutral as well as hot conditions; heat and water loss can increase the challenge.

Cardiac output is heart rate multiplied by stroke volume. An invented early value of 110 beats per minute and 100 mL per beat gives 11.0 litres per minute. Later, 125 and 88 give the same 11.0 litres per minute. A higher heart rate therefore need not mean more cardiac output or a higher external workload. Actual output may be maintained or fall depending on the circumstances; the model is not a universal fixed compensation.

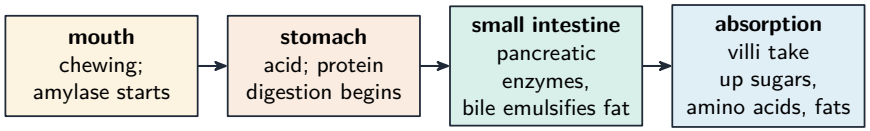


Heart rate rises while stroke volume falls; their product remains approximately 11 litres per minute in this model.

Environmental temperature, humidity, airflow, clothing, exercise intensity and acclimatization affect heat exchange and losses. Humidity limits evaporative cooling when the air's capacity to take up more water is reduced. More visible sweat does not necessarily mean more heat successfully removed; sweat that drips away contributes less evaporative cooling. Comparisons need matched workload and conditions, not simply two finish-line heart rates.

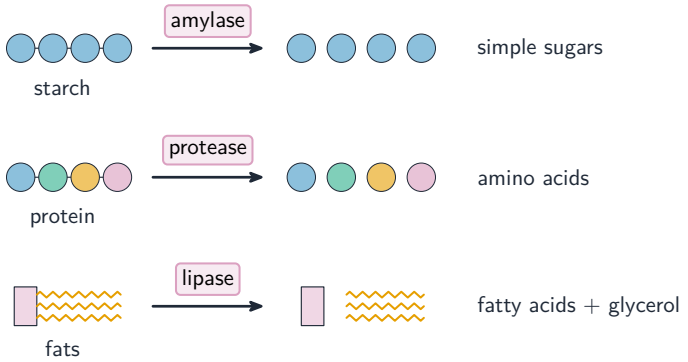
Digestion and absorption make dietary material available

Digestion 消化 breaks down food molecules mechanically and chemically. Carbohydrate-digesting enzymes form smaller sugars; proteases form peptides and amino acids; lipases help break triglycerides into absorbable products including fatty acids and monoacylglycerols. Bile emulsifies lipid into smaller droplets and supports absorption; it is not itself an enzyme. Pancreatic bicarbonate helps neutralize acidic contents entering the small intestine.



bile is not an enzyme; bicarbonate neutralises acid entering the intestine

Along the gut



Digestive enzymes break large insoluble molecules into small soluble ones

Absorption 吸收 moves digested products across the intestinal surface into the body. Villi and microvilli provide a large exchange area, while a thin epithelium shortens transfer distance. Sugars and amino acids enter blood; much absorbed dietary lipid is packaged and initially transported through lymph before reaching blood. Enzyme breakdown, membrane transport and bulk circulation are different steps. Water and ions can be absorbed without first being digested like a starch molecule.

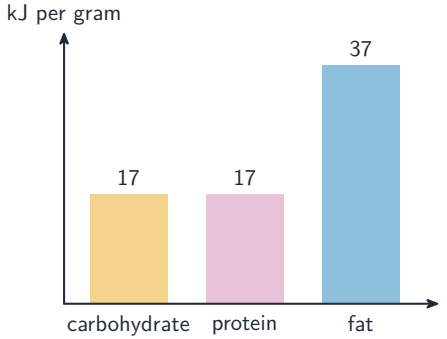
Food tests detect components under controlled conditions: Benedict reagent with approved heating for reducing sugars, iodine for starch, Biuret reagent for protein and an ethanol emulsion test for lipids. Use suitable positive and negative controls; ethanol must be kept away from flames. A positive test does not measure the whole diet's quality, show how much nutrient is absorbed or prove that a food causes a health outcome. Classroom protocols require teacher approval and appropriate handling/disposal.

Macronutrients have energy and structural roles

Carbohydrates can support relatively rapid ATP supply and are stored as glycogen in liver and muscle. Liver glycogen helps support blood glucose; muscle glycogen mainly supports the muscle using it. Lipids provide substantial stored energy and also contribute to membranes and other functions. Proteins provide amino acids for tissue synthesis, enzymes and repair; they can contribute to energy metabolism, but their role is not limited to fuel.

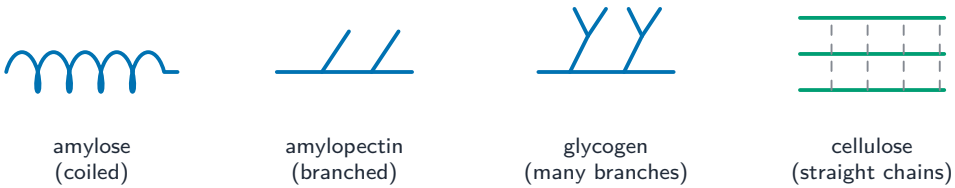


Bread is rich in carbohydrate, the macronutrient that refuels muscle and liver glycogen



fat stores the most energy per gram;
carbohydrate supplies ATP faster;
protein builds and repairs first

Energy per gram of each macronutrient



The shapes of storage polysaccharides (starch, glycogen) and structural cellulose

Approximate metabolizable energy factors used for calculations are 17 kJ per gram for carbohydrate, 17 for protein and 37 for fat. These are teaching approximations, not ATP yields or a guarantee of complete usable energy from every food. Fibre, digestibility and how a food label is constructed can affect an actual estimate. Fat's higher energy per gram does not make it the fastest ATP-supply route during an explosive action.

An invented food portion containing 60 g carbohydrate, 20 g protein and 10 g fat has estimated energy $60(17)+20(17)+10(37) = 1730$ kJ. Fat contributes $370/1730\times100 \approx 21.4\%$ of that estimate. Its percentage of nutrient mass, $10/90\times100 \approx 11.1\%$, answers a different question. Do not mix a mass fraction with an energy fraction.

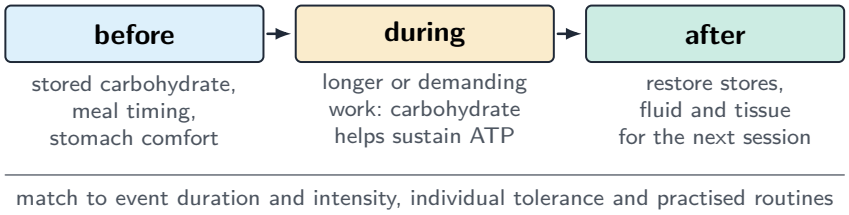
Nutrient requirements vary with growth, age, body composition, activity, training load and individual circumstances. Sex-related physiological differences and reproductive status can affect needs, but a category alone cannot prescribe an individual's intake. Energy is needed during rest and recovery as well as exercise. A balanced argument considers adequate overall intake, nutrient availability and tolerance rather than declaring one macronutrient universally good or bad.

Fuelling strategies must match demands and gastrointestinal tolerance

Before activity, food choice and timing affect stored carbohydrate, available energy and stomach comfort. Large meals close to exercise, or high fat/fibre amounts that are poorly tolerated in that context, can cause discomfort. During longer or more demanding activity, carbohydrate availability can help sustain ATP supply; during a brief activity, consuming a product does not instantly change the energy system doing the most work. Individual tolerance, event duration/intensity and opportunity to eat or drink matter.



Sports supplements and a shaker: a fuelling plan is judged by the event's demands and the gut's tolerance, not by the label



Fuel before, during and after: match the plan to the event and the athlete

Match nutritional planning to the changing demands of a training programme: a heavy training day and a rest day are not identical tasks, yet both require fuel for normal physiology and recovery. Practise approved strategies under supervision rather than treating a new product as automatically beneficial on competition day. An experiment comparing two drinks should control carbohydrate concentration, fluid amount, prior food, workload and environmental conditions, or acknowledge what it cannot separate.

Low energy availability means too little energy remains available for physiological functions after accounting for exercise expenditure. Problematic prolonged and/or severe low availability can contribute to relative energy deficiency in sport, RED-S or REDs, affecting health and performance. Possible consequences include impaired bone health, hormonal/reproductive function, immunity, recovery and adaptation. It can affect male and female athletes and does not require low body mass or a diagnosed eating disorder.

For an invented daily model, calculate energy availability as intake minus exercise expenditure, divided by fat-free mass. With intake 8000 kJ, exercise expenditure 2000 kJ and fat-free mass 50 kg, the estimate is 120 kJ per kilogram fat-free mass per day. Raising exercise expenditure to 3000 while intake stays fixed gives 100. This is an accounting example, not a diagnostic cut-off or instruction to target these intakes. It is different from whole-day energy balance, which includes other expenditure.

The IOC consensus on REDs treats its assessment as more complex than a single arithmetic value. Food/exercise records have error, duration matters and clinical assessment considers multiple findings. Do not diagnose peers or prescribe restriction from these examples.

ATP is continually resynthesized by overlapping energy systems

ATP hydrolysis supplies energy for cellular work, including contraction and ion transport. The small immediately available ATP store needs continual resynthesis from ADP and phosphate. The three named systems describe major ATP-supply pathways; they do not take turns as mutually exclusive switches.

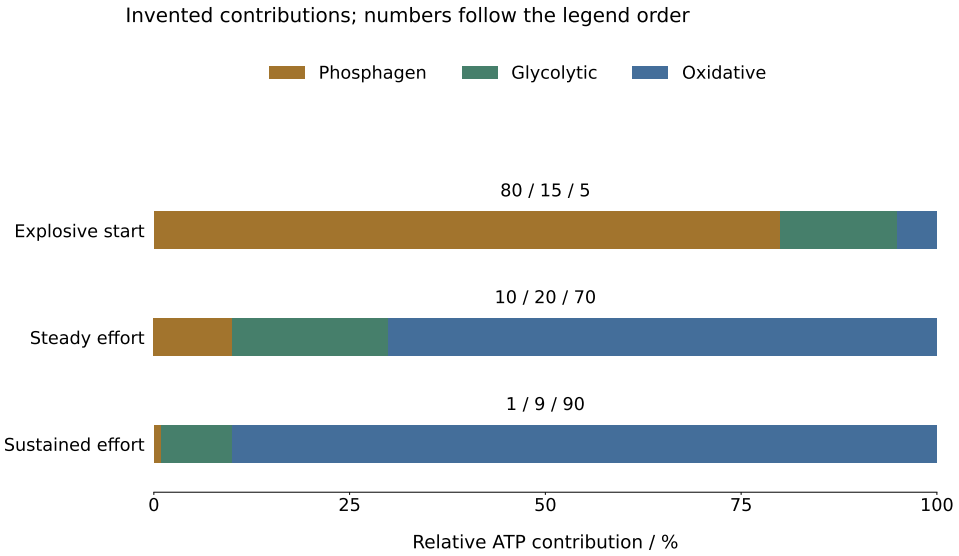


A hard sprint relies on anaerobic respiration, building up lactic acid.

The phosphagen system uses phosphocreatine to rapidly transfer phosphate to ADP, resynthesizing ATP. It supports very rapid demand but has limited stored capacity. It does not require oxygen directly in that phosphate-transfer reaction; restoration of phosphocreatine during recovery is strongly supported by oxidative metabolism. “Anaerobic” does not mean all other reactions in the body stop using oxygen.

Glycolysis breaks down carbohydrate in the cytosol and supplies ATP rapidly. Converting pyruvate to lactate helps regenerate NAD^+ for continued glycolysis when that route is needed. Lactate can be produced even when oxygen is available; it is not merely a useless poison or proof that all cells lack oxygen. It can be transported and used as a fuel by other tissues.

Oxidative ATP supply uses oxygen-dependent metabolism, principally in mitochondria, from carbohydrate and lipid fuels, with amino acids contributing in some conditions. It can support sustained activity but its maximum ATP-supply rate is lower than rapid anaerobic pathways. Oxygen delivery, mitochondrial capacity and fuel availability limit it. Detailed Krebs-cycle and electron-transport reactions are not needed to compare these systems here.



The percentages are invented examples, not fixed time cut-offs or measured contributions for named sports.

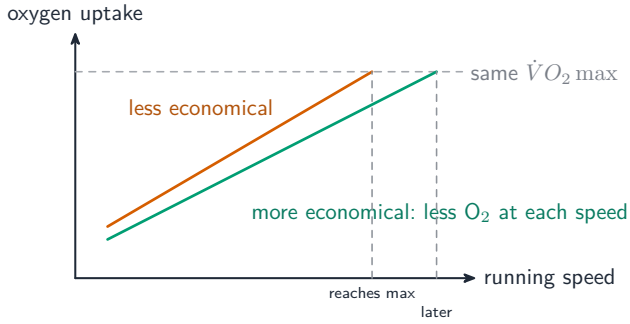
An explosive-start model assigns 80%, 15% and 5% to phosphagen, glycolytic and oxidative supply. A sustained-activity model assigns 1%, 9% and 90%. All contributions sum to 100%, but the percentages alone do not state the absolute ATP used. A high-intensity surge can increase anaerobic contribution during an otherwise oxidative event. Relative contributions depend on intensity, duration, training, fuel and preceding activity, not just a stopwatch boundary.

Oxygen uptake and movement economy describe different constraints

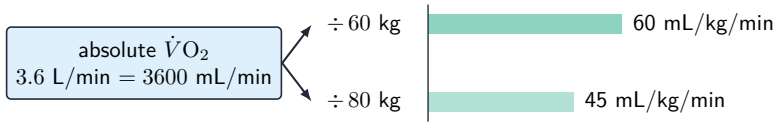
Maximal oxygen consumption, $\dot{V}O_2\,\text{max}$, describes the highest oxygen-uptake rate achieved under an appropriate maximal test. Its expression depends on units: absolute uptake in litres per minute differs from body-mass-relative uptake in millilitres per kilogram per minute. A reported peak in a test is not always accompanied by a demonstrated plateau; protocols and effort affect interpretation. In class, analyse supplied records rather than perform unsupervised maximal tests.



Marathon runners work almost entirely aerobically, so economy (oxygen used per kilometre) shapes their pace



Same VO2max, different economy



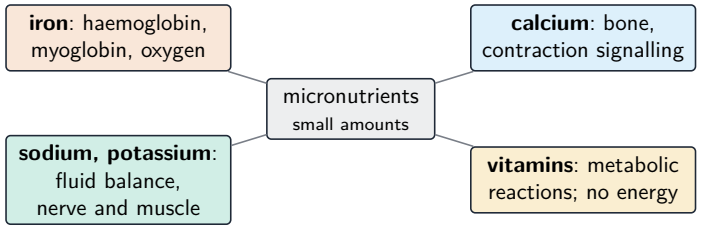
Relative VO2max depends on the denominator: 3.6 L/min is 60 at 60 kg but 45 at 80 kg

An invented absolute value 3.6 litres per minute equals 3600 millilitres per minute. At body mass 60 kg, this is 3600/60 = 60 millilitres per kilogram per minute; at 80 kg, the same absolute uptake is 45. Changing the denominator changes the relative number without necessarily changing absolute oxygen-delivery capacity. These comparisons do not justify a weight-loss target.

Age, body composition, physiological sex-related differences, genetics, training and lifestyle can influence values, with substantial individual overlap. Endurance performance also depends on how much oxygen is required at a given speed, sustainable intensity, pacing and conditions. Running economy compares oxygen or energy cost at matched submaximal speeds. A supplied comparison of 2.4 versus 2.1 litres per minute at the same speed gives a 12.5% lower oxygen cost relative to 2.4; it does not by itself establish a higher maximum uptake or guarantee race victory.

AHL: Micronutrients enable specific physiological processes

Micronutrients are needed in smaller quantities than macronutrients but have essential roles. Iron is part of haemoglobin and myoglobin, supporting oxygen carriage in blood and oxygen handling within muscle. Inadequate available iron can constrain these functions; adding iron beyond adequate status does not automatically increase performance. A laboratory finding and symptoms require professional interpretation, not a classroom supplement recommendation.



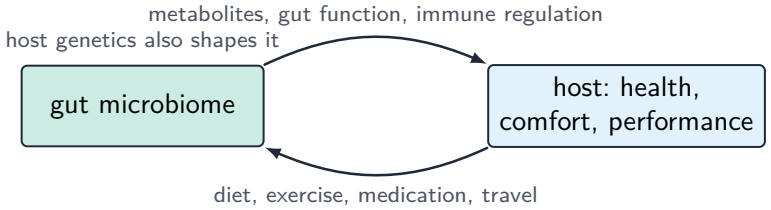
Each micronutrient has a specific job; vitamins supply no energy

Calcium contributes to bone structure and signalling for muscle contraction. Sodium and potassium support fluid balance, membrane potential and excitation of nerves and muscle. Their roles are not interchangeable, and a supplement is not equivalent to restoring every aspect of a balanced diet. Vitamins support metabolic reactions and tissue synthesis; they do not themselves supply kilojoules like carbohydrate or fat. Specific vitamin lists are not needed for the objective here.

A food's energy content and its micronutrient contribution answer different questions. An adequate-energy diet can still be poor in particular nutrients, and a vitamin-rich low-energy intake can still leave physiological energy needs unmet. Evaluate a claim by naming the limiting process, the person's measured status and credible evidence, rather than assuming "more" always means "better".

AHL: The gut microbiome interacts with diet and physiology

The gut microbiome includes a diverse community of microorganisms and their collective genetic functions. Host genetics, diet, medication and lifestyle help shape its composition and activity. Microbial metabolism can change the products available to the host, including metabolites from otherwise poorly digested carbohydrate, and interact with gut function and immune regulation. Effects can influence health and performance indirectly through nutrient availability, comfort and illness, not only through an immediate energy boost.



Diet, exercise and the microbiome influence each other in both directions

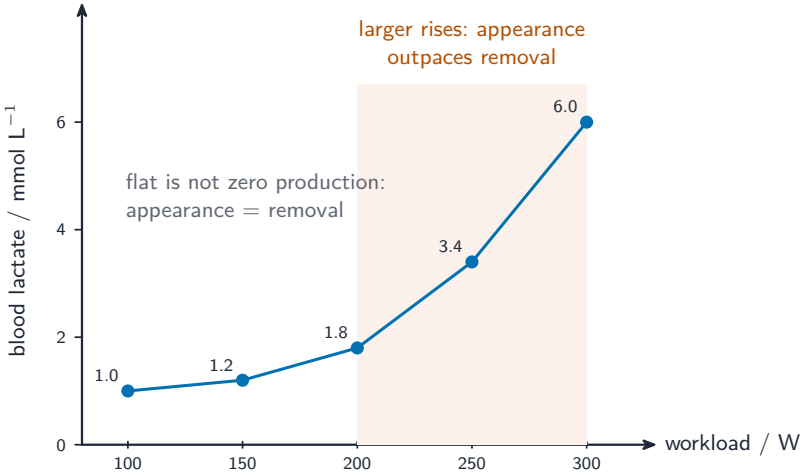
The relationship is bidirectional: diet and exercise can alter the microbiome, while microbial activity can affect the host. Finding a difference between trained and untrained groups does not show that one organism caused the performance difference. Dietary patterns, medication, travel and training itself may explain an association. Relative sequence abundance is not automatically an absolute cell count or a direct measurement of metabolic function.

A useful controlled comparison states the intervention, strain or food, dose, duration, prior diet and outcome; it uses a suitable comparison group and records variation and adverse effects. A rise in one microbial proportion is not enough to prove improved endurance. Different strains and hosts can respond differently, so "all probiotics improve all performance" exceeds the evidence. Do not invent a real trial result or recommend an untested product from a teaching example.

AHL: Lactate concentration reflects production and removal

Blood lactate concentration depends on appearance and clearance. At a steady value, lactate can still be produced and consumed rapidly at equal rates. With increasing exercise intensity, a sustained rise can indicate that appearance exceeds removal under the tested conditions. The lactate inflection point describes the change towards accumulating lactate as intensity increases; assessing a maximum sustainable balance requires an appropriate protocol, not one universal concentration for everyone.

In an invented staged test at workloads 100, 150, 200, 250 and 300 W, lactate values are 1.0, 1.2, 1.8, 3.4 and 6.0 millimoles per litre. The larger rises appear between 200 and 300 W, but five short stages do not locate a unique maximum steady-state workload. Stage duration, sampling timing and the operational definition matter. Lactate accumulation does not mean oxidative ATP production has stopped.



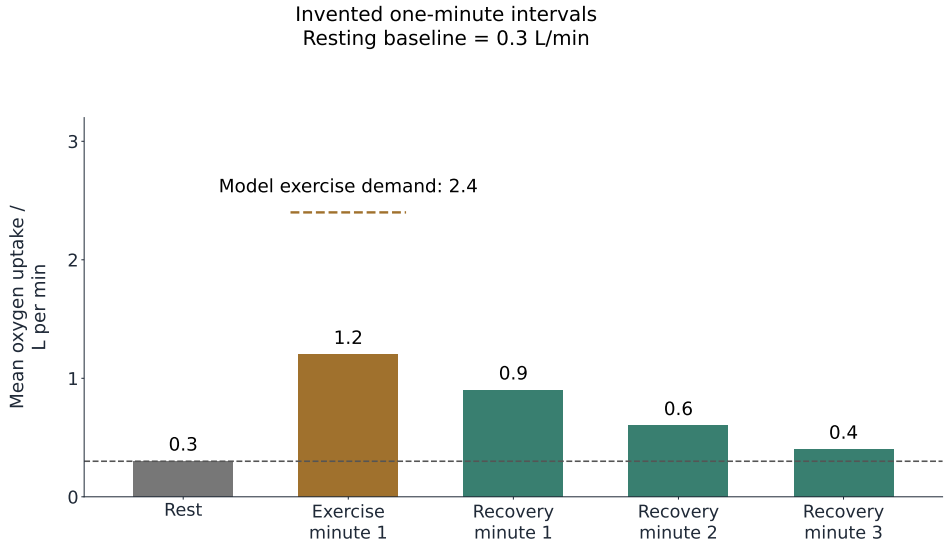
The invented staged test: a flat start still has production, balanced by removal; the larger rises come above 200 W

Training and individual physiology influence lactate production, transport and use at a given workload. Interpret a shift with comparable methods and conditions. Lactate concentration alone does not identify every cause of fatigue, and delayed muscle soreness is not simply lactate left in the muscle for days.

AHL: Recovery oxygen uptake has fast and slow components

At exercise onset, oxygen uptake may rise towards demand with a delay. The oxygen deficit is an estimate of the gap between the activity's oxygen-equivalent demand and measured uptake over that period. Anaerobic ATP pathways help meet the demand during this adjustment; deficit is an integrated amount, not the uptake rate at one instant.

After activity, oxygen uptake can remain above the resting baseline: excess post-exercise oxygen consumption, EPOC. Faster recovery processes include restoring oxygen stores and ATP/phosphocreatine. Slower contributions include continued temperature and hormonal effects, ventilation/circulation, substrate processing and restoration of internal conditions. Lactate can be oxidized or used in other pathways; EPOC is not solely a literal debt to remove "lactic acid". Its magnitude and time course depend on the activity, intensity, duration and recovery conditions.



Each non-rest bar represents a separate one-minute interval; the model demand applies to the exercise interval only.

For an invented first exercise minute with mean uptake 1.2 litres per minute and oxygen-equivalent demand 2.4, the interval deficit estimate is $(2.4 - 1.2)(1) = 1.2$ litres. A resting baseline is 0.3 litres per minute. Mean recovery rates over three successive one-minute intervals are 0.9, 0.6 and 0.4. Excess amounts are 0.6, 0.3 and 0.1 litres, totalling 1.0 litre for those intervals. Their raw uptake totals 1.9 litres; forgetting to subtract resting use overestimates the excess.

This short recovery record does not show that all EPOC is complete after three minutes, or that EPOC must equal the onset deficit exactly. Fast/slow describes overlapping processes, not a universal boundary that makes every recovery graph identical. Interpret the baseline, interval widths and measured range before calculating an area.

Practice

1. Distinguish total solute from concentration. A model starts with 120 solute units in 12 water units and loses 12 solute units and three water units. Calculate final concentration and percentage change; explain the model's limits.

2. Trace increased osmotic concentration through hypothalamus, pituitary ADH release and kidney action. Explain negative feedback without saying the kidneys create water or the pituitary makes all released ADH.
3. Compare body mass, urine colour and a concentration measurement as evidence of hydration. Give two confounders and explain why none alone establishes a sodium diagnosis.
4. Mass falls 55.0 to 54.5 kg; drink is 0.40 kg and urine 0.20 kg over 45 minutes. Estimate sweat loss and rate, and percentage body-mass fall. Explain the signs and one limitation.
5. At unchanged external workload, heart rate changes from 120 to 135 beats per minute and stroke volume from 90 to 80 mL per beat. Calculate cardiac output at both times; explain possible drift without inferring increased workload.
6. Separate digestion, absorption and transport for carbohydrate, protein and lipid. Explain bile's role, one food test with controls and a limit of the resulting health inference.
7. A model portion has 40 g carbohydrate, 15 g protein and 8 g fat. Using 17, 17 and 37 kJ per gram, calculate energy and fat's energy percentage. Explain why mass percentage differs.
8. Using intake 9000 kJ, exercise expenditure 2400 kJ and fat-free mass 55 kg, calculate the defined energy-availability estimate. Explain LEA/RED-S without treating that single value or body mass as a diagnosis.
9. Compare fuels, maximum supply rate, capacity and oxygen dependence of the three ATP systems. Explain the invented contribution figure and why an oxidative event can contain anaerobic surges.
10. Convert 3.0 litres per minute at 50 kg and at 75 kg to relative oxygen uptake. At matched running speed, uptake falls from 2.0 to 1.8 litres per minute: calculate percentage reduction and distinguish economy from maximum uptake.
11. Six of 24 participants report an outcome after a dietary exposure. Calculate percentage and design a more informative comparison, accounting for prior diet, workload and other confounders. Explain why the fraction is not causal proof.
12. **AHL:** Link iron, calcium, sodium/potassium and vitamins to specific processes. Explain why neither adequate total energy nor taking an extra supplement guarantees correction of a limiting nutrient problem.
13. **AHL:** Evaluate a claim that higher relative abundance of a gut microbe in trained people proves that a probiotic improves endurance. Identify alternative explanations and evidence needed.
14. **AHL:** Interpret the staged lactate values and explain why steady concentration does not mean zero turnover. Calculate onset deficit, three-interval recovery uptake and EPOC from the oxygen model; distinguish the quantities and state a limit.

Worked answers

1. Initially $120/12 = 10$; later $108/9 = 12$, a 20% rise despite loss of solute. The model has fixed accounting units and omits compartments, excretion and feedback; it is not a clinical sodium calculation.
2. Increased concentration can stimulate hypothalamic signalling and posterior-pituitary ADH release. Kidneys reabsorb more water, tending to reduce the disturbance; urine water loss falls. ADH is synthesized in the hypothalamus. Volume signals, thirst and other regulatory pathways also matter.
3. Standardized mass gives net change with intake/output corrections; urine colour is affected by pigments/timing; concentration depends on sample and method. Wet clothing, food, medication and recording error can confound. Several measures and qualified assessment are needed for clinical interpretation.
4. Sweat estimate $55.0 - 54.5 + 0.40 - 0.20 = 0.70$ kg. Time $45/60 = 0.75$ hour; rate $0.70/0.75 \approx 0.93$ kg per hour. Mass fall $0.50/55.0 \times 100 \approx 0.91\%$. Add drink to restore replaced mass; subtract urine as another output. Other exchanges and balance/clothing error limit the estimate.
5. $120(90) = 10800$ and $135(80) = 10800$ mL per minute, both 10.8 litres per minute. Increased heart rate can partly compensate for reduced filling/stroke volume during thermal/fluid challenge; the values do not prove increased work or uniquely identify hydration state.
6. Enzymes form absorbable sugars, amino acids and lipid products; epithelial transport brings them into blood/lymph. Bile emulsifies lipid but is not an enzyme. Use a suitable component test with positive/negative controls and approved handling. Detection does not quantify overall diet quality or establish a disease cause.
7. $40(17) + 15(17) + 8(37) = 1231$ kJ. Fat contributes $296/1231 \times 100 \approx 24.0\%$ of energy. Its nutrient-mass share is $8/63 \times 100 \approx 12.7\%$, with a different denominator and unequal energy factors.
8. $(9000 - 2400)/55 = 120$ kJ per kilogram fat-free mass per day. Problematic insufficient availability can impair normal functions and contribute to RED-S, in males and females. This estimate lacks the clinical context, duration and reliable full history needed for diagnosis; it is not whole-day net energy balance.
9. Phosphagen transfers stored phosphate rapidly with limited capacity; glycolysis supplies ATP from carbohydrate rapidly; oxidative metabolism uses oxygen and carbohydrate/lipid fuels for sustained supply with a lower maximum rate. Systems overlap. Relative percentages sum to 100 but do not determine absolute ATP, and a surge can increase anaerobic contribution.
10. $3000/50 = 60$ and $3000/75 = 40$ millilitres per kilogram per minute. Economy comparison: $(2.0 - 1.8)/2.0 \times 100 = 10\%$ lower oxygen cost at matched speed. Relative maximum and submaximal economy are different measures; neither alone fixes endurance performance.

11. $6/24 \times 100 = 25\%$. Compare suitable groups or a controlled, approved design with matched prior diet, workload, environment and measurement timing; record allocation, missing data and variation. Confounding, reverse causation and sampling can explain an association.
12. **AHL:** Iron supports haemoglobin/myoglobin oxygen functions; calcium supports bone and contraction; sodium/potassium support osmotic and electrical conditions; vitamins enable metabolic/tissue processes without supplying food energy. Identify the actual limiting factor and evidence; excess supplementation is not automatic benefit.
13. **AHL:** Training, diet, medication and other host differences can affect composition; relative abundance does not supply absolute counts or prove function. A suitable controlled intervention needs a specified strain/product, duration, outcomes and consistent conditions. An association does not establish universal probiotic benefit.
14. **AHL:** Larger stage increases occur above 200 W, but a protocol-dependent inflection/steady-state limit needs appropriate testing. Steady concentration can coexist with equal nonzero appearance and removal. Deficit 1.2 litres; recovery uptake $0.9 + 0.6 + 0.4 = 1.9$ litres; excess $1.9 - 3(0.3) = 1.0$ litre. The truncated recovery record need not capture all EPOC or equal the deficit; lactate handling is only part of recovery.

Exam tips

Name the compartment, quantity, time interval and denominator. Separate sweat loss from net mass change, energy share from mass share, and relative from absolute oxygen uptake. Trace feedback through the correct hormone source and target. State that ATP pathways overlap and judge a nutrition claim using method and context rather than a product label.

- **AHL:** Keep nutrient function, microbial association and intervention evidence distinct. A steady lactate concentration still permits turnover; recovery oxygen use includes a resting baseline that must be subtracted when calculating EPOC.

Response

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

This handout teaches A.3 Response for the course first assessed in 2026: how the body responds to a single bout of exercise, what causes fatigue, how athletes recover, how training is planned, and how the body adapts to training and to hot, cold and high-altitude environments. It is written for both SL and HL students. Sections marked **AHL** are for Higher Level only. Training principles and health benefits are common; target-group planning and the detailed fatigue/recovery material extend HL study. Numerical scenarios and plotted physiological values below are invented teaching examples, not measurements of a named athlete or personal training prescriptions.

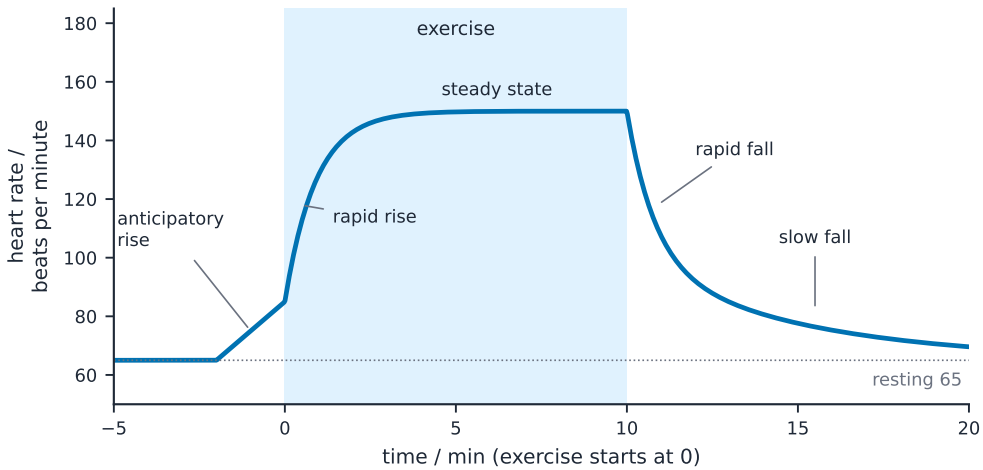
Prerequisites: unit A.1 (the cardiovascular and respiratory systems, cardiac output and minute ventilation) and unit A.2 (energy systems, hydration and nutrition).

Acute responses to exercise

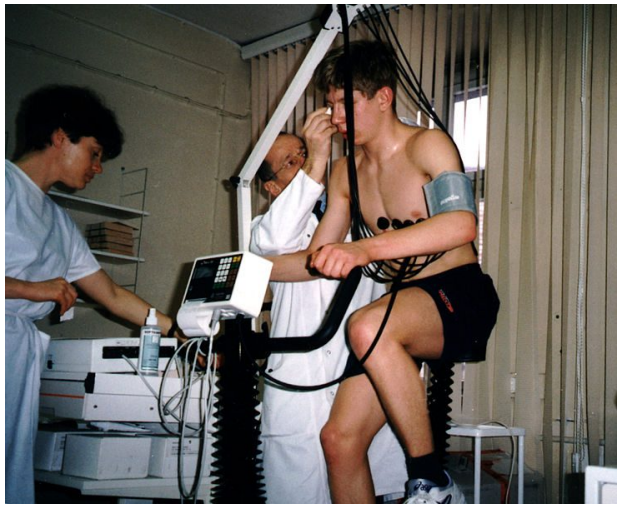
Two hours under two

On 12 October 2019 in Vienna, Eliud Kipchoge completed the supported INEOS challenge over 42.195 km in 1:59:40.2, averaging about 21.16 km/h (event account). That performance does not tell us his heart rate, temperature or oxygen uptake at each moment. Do not invent those measurements. An **acute response** 急性反应 occurs during or after a bout, such as a rise in heart rate; recovery times differ between variables. A **training adaptation** 训练适应 is a more persistent change following repeated training, such as greater mitochondrial capacity. Distinguish the timescale and evidence for each.

Heart rate



Heart rate response to steady submaximal exercise



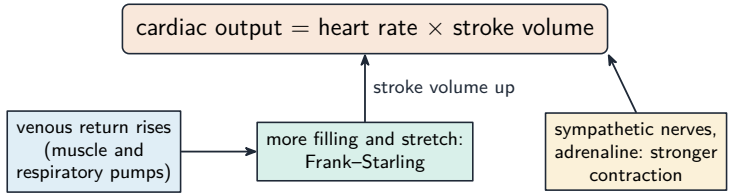
An exercise stress test: heart rate and the ECG are recorded while the cycling workload rises step by step

- **Anticipatory rise.** Before exercise starts, the sympathetic nervous system and adrenaline raise heart rate. The athlete has not moved yet.
- **Rapid rise.** At the start, receptors in muscles and joints signal movement, and the cardiac control centre in the medulla increases heart rate quickly.
- **Steady state** 稳定状态. During steady **submaximal** 次最大 exercise, heart rate may approach a plateau at a fixed workload. A flat heart-rate trace alone does not measure oxygen uptake or prove an exact match between oxygen supply and demand; prolonged exercise, heat and hydration can change the trace.
- **Recovery.** Heart rate falls quickly at first, then slowly back to the resting value.

In incremental exercise, where the intensity rises every few minutes, heart rate rises roughly in a straight line with intensity until it reaches the **maximum heart rate** 最大心率. Age-based equations such as 220 − age are population estimates with substantial individual error, especially when applied outside the population studied. They are not an exact measured maximum or a personal target for a child. Use the supplied maximum in a calculation; do not infer one from age unless the question explicitly asks about that estimation model.

Stroke volume and cardiac output

Stroke volume 每搏输出量 (the volume of blood pumped by the left ventricle in each beat) rises during exercise because:



illustrative scale: about 5 L/min at rest, 20 L/min in hard exercise (not norms)

What raises stroke volume, and so cardiac output

- more blood returns to the heart (the skeletal muscle pump and the respiratory pump increase **venous return** 静脉回流);
- the ventricle fills more and is stretched more, so it contracts more strongly. This is the **Frank–Starling mechanism**;
- sympathetic nerves and adrenaline make the heart muscle contract more forcefully.

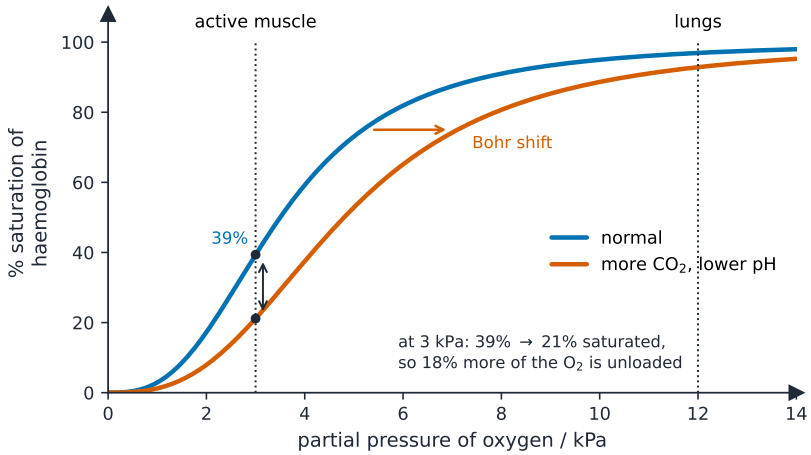
Stroke volume can plateau or continue to rise depending on posture, intensity, training and the individual; there is no universal plateau at one percentage of effort. Because cardiac output = heart rate × stroke volume, both factors contribute. Values such as 5 L/min at rest and 20 L/min during hard exercise illustrate the scale of a response; they are not diagnostic norms or fixed limits for everyone.

Blood pressure

- In **aerobic** exercise such as running, **systolic pressure** 收缩压 rises (from about 120 to 180 mmHg or more) because cardiac output rises. **Diastolic pressure** 舒张压 stays about the same or falls slightly, because arterioles in the working muscles widen.
- In heavy **resistance exercise**, both systolic and diastolic pressure rise sharply, especially if the athlete holds their breath while straining.

Oxygen delivery and extraction

Blood is redistributed by the **vascular shunt** (unit A.1): the fraction and absolute flow to working muscle can rise substantially. The exact distribution depends on workload, environment and the competing needs of other tissues. The muscles also take more oxygen out of each litre of blood.



Bohr shift (right): ↑ CO_2/ ↓ pH → lower O_2 affinity → unload at tissues

Working muscle is warmer, more acidic and higher in carbon dioxide, so haemoglobin unloads more oxygen there

The **arteriovenous oxygen difference** 动静脉氧差 (a-vO_2 diff) is the difference between the oxygen content of arterial blood and of venous blood. At rest arterial blood holds about 200 mL of oxygen per litre and venous blood about 150 mL, so the difference is about 50 mL per litre. In hard exercise venous blood from working muscle may hold only 50 mL, so the difference rises to about 150 mL per litre.

Haemoglobin releases more oxygen in working muscle because the muscle is warmer, more acidic and has more carbon dioxide. Increased carbon dioxide and hydrogen-ion concentration lower haemoglobin's oxygen affinity: the **Bohr shift** 波尔效应. Higher temperature can also shift the dissociation curve towards easier unloading; do not define the Bohr effect simply as warming.

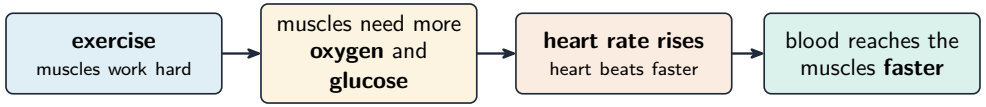
The **Fick equation** links oxygen uptake to delivery and extraction:

$$\text{oxygen uptake} = \text{cardiac output} \times \text{a-v}O_2 \text{ diff}$$

Worked example (invented). For whole-body Fick calculations, use arterial minus mixed-venous oxygen content with whole-body cardiac output. A sample from one working muscle is not automatically representative of all venous return. At rest, cardiac output is 5 L/min and the a-vO_2 diff is 50 mL per litre: oxygen uptake = 5 × 50 = 250 mL/min. In a hard run, cardiac output is 20 L/min and the a-vO_2 diff is 150 mL per litre: oxygen uptake = 20 × 150 = 3000 mL/min = 3.0 L/min, twelve times the resting value. Cardiac output rose four times and extraction three times; both matter.

Ventilation and temperature

- **Minute ventilation** 每分通气量 rises in two steps: a rapid rise at the start (signals from the motor cortex and from receptors in muscles and joints), then adjustment involving chemical feedback and other inputs. During moderate exercise arterial carbon dioxide need not rise: ventilation can increase enough to match its greater production.
- In very hard exercise, ventilation rises faster than oxygen uptake, because extra carbon dioxide from buffering acid must be breathed out. The point where this starts is the **ventilatory threshold** 通气阈.
- Body temperature rises because only about 20 to 25 % of the energy used by muscles becomes movement; the rest is heat. Sweat removes heat when it evaporates; skin blood flow supports exchange, whose direction depends on the temperature gradient (unit A.1).
- In long exercise in the heat, heart rate slowly rises while the workload stays the same, because sweating lowers blood volume and stroke volume falls. This is **cardiovascular drift** (unit A.2).



check the heart's activity by feeling the **pulse**, listening to the valves, or with an **ECG**

During exercise the heart rate rises so blood reaches the muscles faster

Measuring responses safely in class. Record a resting baseline, use a standard, low-intensity workload (for example a 3-minute step test at a set rate), and time the recovery readings. Participation must be voluntary, with informed consent and teacher supervision; stop for any discomfort, and never use a classroom test as a health diagnosis.

Not true: "A lower heart rate after a step test proves that one student is fitter." The workload, room temperature, time of day, recent food and caffeine, and the students' body size all affect the reading. Only a comparison under matched conditions can

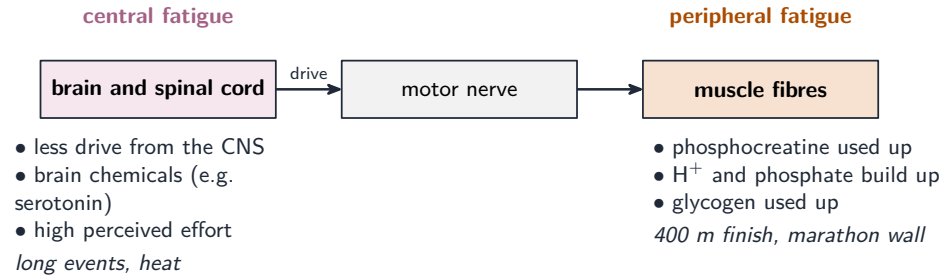
suggest a difference in fitness.

AHL: Fatigue

What fatigue is

Fatigue 疲劳 is a fall in the ability to produce force or power, so the athlete cannot keep the same performance. Its causes depend on the type of exercise.

Type of fatigue	Main causes	Example
Peripheral fatigue 外周疲劳 (in the muscle)	Phosphocreatine (PCr) used up; acid (hydrogen ions) and phosphate build up; glycogen used up	Last 20 m of a 400 m race; "hitting the wall" in a marathon
Central fatigue 中枢疲劳 (in the brain and spinal cord)	Less drive from the CNS to the muscles; changes in brain chemicals such as serotonin; high perceived effort	Long events, exercise in the heat

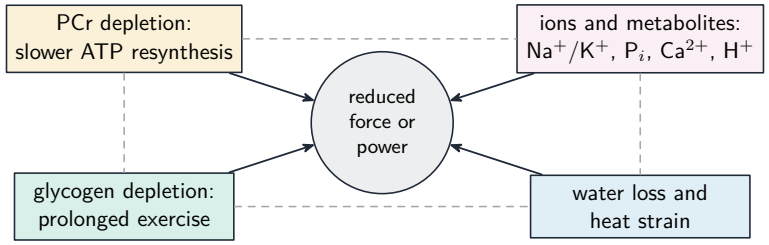


fatigue: a fall in force or power; the energy systems overlap, so one cause rarely explains it all

Central fatigue reduces the drive; peripheral fatigue happens in the muscle itself

Peripheral causes

- **Phosphocreatine depletion.** Falling PCr availability limits rapid ATP resynthesis during repeated or sustained high-power work. All ATP systems overlap: a fall in sprint speed cannot be attributed to PCr alone.
- **Ionic and metabolite changes.** Changes in sodium and potassium gradients affect membrane excitability. Inorganic phosphate accumulation and changes in calcium handling can impair force production; increased hydrogen-ion concentration can also contribute under some conditions. Several sites and mechanisms interact.
- **Glycogen depletion.** Reduced muscle glycogen and liver carbohydrate availability can constrain prolonged exercise. Initial stores, intensity, duration and intake matter; there is no universal 90-minute exhaustion clock. Fat has a large energy capacity but cannot support every high ATP-demand rate.
- **Water and heat.** Fluid loss and thermal strain can impair performance, with effects dependent on task, conditions and individual responses. A percentage mass loss is not a universal point at which everyone fails.



sites interact and systems overlap: no single cause, no universal clock

Peripheral contributors to fatigue interact

Not true: "Lactate alone causes all fatigue and stays in the muscles until tomorrow's soreness." Lactate can be transported and used as fuel; its concentration reflects appearance and removal. Its formation does not mean oxidative metabolism has stopped, nor does its removal prove all recovery is complete. Do not treat lactate formation as a simple hydrogen-ion production equation explaining every fatigue mechanism.

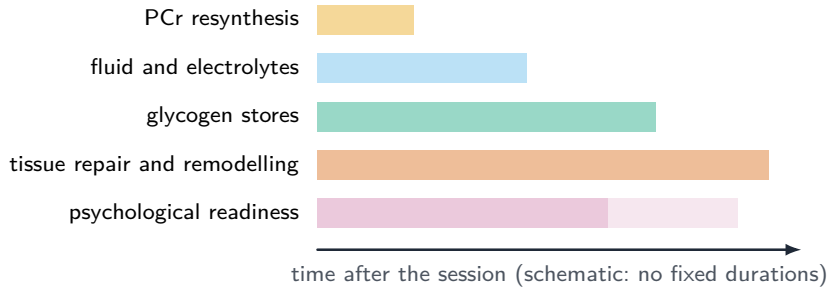
Delayed-onset muscle soreness

Delayed-onset muscle soreness 延迟性肌肉酸痛 (DOMS) is pain and stiffness 24 to 72 hours after unaccustomed exercise, especially **eccentric** contractions (a muscle lengthening while it contracts, such as running downhill). Unaccustomed loading can produce tissue disruption and inflammatory responses associated with soreness; soreness severity is not a precise measure of structural damage or readiness. Lactate left behind for days is not the explanation. It is a reason to increase new types of training gradually.

AHL: Recovery

Different recovery outcomes

Recovery 恢复 is multidimensional: restoration of energy stores, fluid balance, tissue function and psychological readiness need not occur together. Ask "recovery of what, measured when, for which next task?" rather than assigning the whole athlete one recovery time.

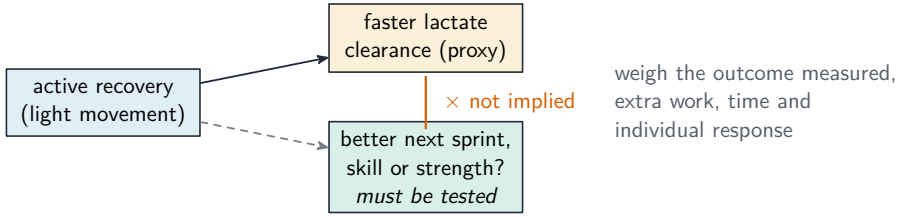


Recovery of what? Each process recovers on its own timescale (schematic)

Process	Mechanism and useful evidence	Interpretation limit
PCr restoration	Oxidative ATP supply supports resynthesis during rest; assess repeat-sprint performance	A fixed rest interval does not guarantee complete restoration for every person
Substrate restoration	Carbohydrate availability supports glycogen replacement; protein supports tissue repair/remodelling	Needs depend on depletion, total intake, timing and subsequent demands
Water/electrolyte balance	Intake, absorption and continuing outputs determine net restoration	Body-mass change alone does not specify all losses or a safe universal drink volume
Tissue function	Force, movement and symptoms can recover on different trajectories	Less soreness does not prove full force recovery
Psychological readiness	Perceived fatigue, mood and willingness provide relevant information	A subjective rating is useful but not interchangeable with a physiological measurement

■ Evaluate strategies rather than promising a cure

Active recovery 积极性恢复 is light movement between or after efforts. It may change lactate clearance compared with passive rest, but faster clearance is not evidence that the next sprint, skill or strength task improves. Extra work also uses energy. Specify the comparison, timing and outcome.



A proxy is not the outcome

Nutrition supports recovery through water/electrolyte replacement and adequate energy, carbohydrate and protein availability. Choose the strategy for the activity, recovery interval, prior intake and tolerance; an example amount is not a universal prescription. **Creatine monohydrate** can increase muscle creatine availability and support repeated high-intensity work in appropriate contexts; this differs from proving immediate repair of all exercise damage. **Polyphenol-rich foods** are studied for effects on soreness and function, but a food, extract and isolated compound are not interchangeable. Check the actual preparation, participants, comparison, duration and outcome before generalising. Supplements raise additional questions about purity and suitability; this is analysis of evidence, not advice to classmates to take one (IOC consensus).

Myofascial release, such as foam rolling, applies pressure to soft tissues; **compression** applies external pressure; **thermotherapy** changes thermal exposure, including cold or heat approaches. Proposed mechanisms, subjective comfort and measured subsequent performance are separate claims. Compare with an appropriate control, account for expectations, examine effect size and uncertainty, and consider cost, discomfort, timing and possible interference with adaptation. A lower soreness score alone does not establish that every tissue has healed.

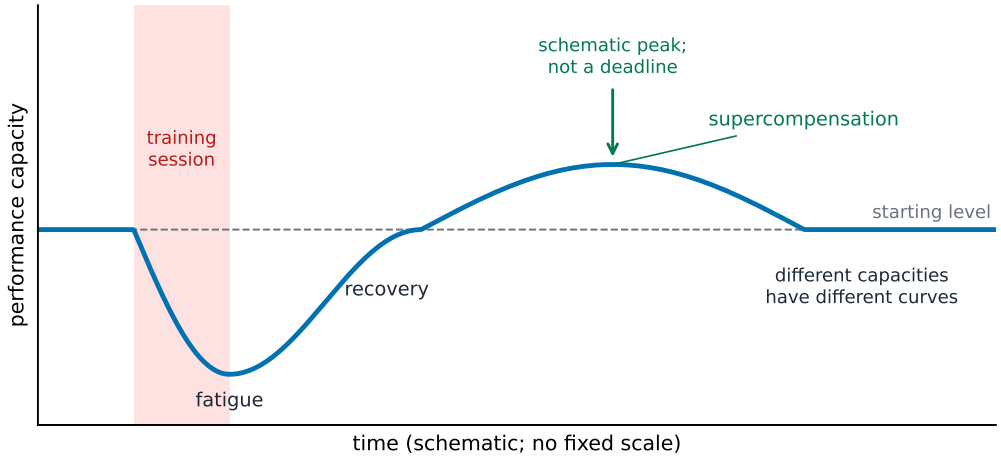
Sleep and planned rest support recovery. Consider schedule regularity, school and psychological stress, travel fatigue and circadian disruption across time zones. Adjusting load and protecting sleep opportunity address demands directly; one recovery gadget cannot compensate for an unsuitable programme. The excess oxygen used after exercise is discussed in A.2 and is not a complete measure of readiness.

Worked evaluation (invented). After matched sessions, an intervention group reports mean soreness 3/10 versus 5/10 in a comparison group: a difference of 2 scale points. Both groups' repeat-task performance remains 8% below baseline. The symptom result and performance result answer different questions. Without group

sizes, allocation, baseline comparability and uncertainty, do not conclude that the intervention caused either difference or fully restored performance. Do not call a 2-point reduction a 2% reduction.

Principles of training

Supercompensation

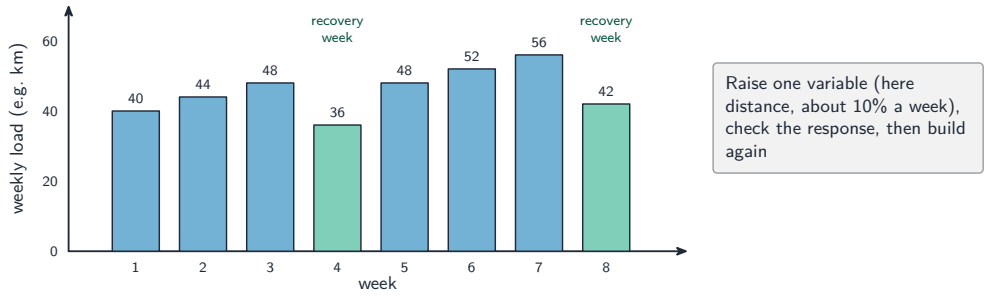


Training, fatigue, recovery and supercompensation

The **supercompensation** 超量恢复 model sketches fatigue followed by recovery and a possible temporary rise above baseline. It is a teaching model, not a measured universal curve. Glycogen, force, skill and psychological readiness have different trajectories. Planned training can sometimes occur before full recovery; a coach uses the goal, recent load and repeated observations rather than trying to hit one magic peak. Adaptation and fatigue interact during and between sessions; a single late session does not erase every gain.

The principles

Principle	Meaning	Example
Specificity 专项性	Adaptations match the training: the energy system, muscles, movement and speed used	Swimming technique requires swimming practice; other activities can support relevant capacities
Progressive overload 渐进超负荷	Load must be gradually increased above what the body is used to	Progress one suitable load variable after assessing response and technique
Reversibility 可逆性	Adaptations are lost when training stops	A prolonged reduction in stimulus can reduce adaptations; rates differ by capacity and person
Individual differences 个体差异	People respond differently to the same training	Genes, age, sex, starting fitness and recovery differ
Variety	Purposeful variation can support motivation and manage repeated loading	A runner adds cycling and swimming
Recovery	Balance stimulus and recovery so repeated loading remains appropriate	Hard days followed by easy days



Progressive overload: raise one variable in small steps, with lighter weeks for recovery

The amount of training is planned with **FITT**: **f**requency (sessions per week), **i**ntensity (how hard), **t**ime (how long) and **t**ype (which activity).

Individual responses depend on baseline capacity, training history, age, health, recovery, psychological stress and other circumstances. Differences between two measured changes can also reflect measurement error and programme adherence. Do not infer

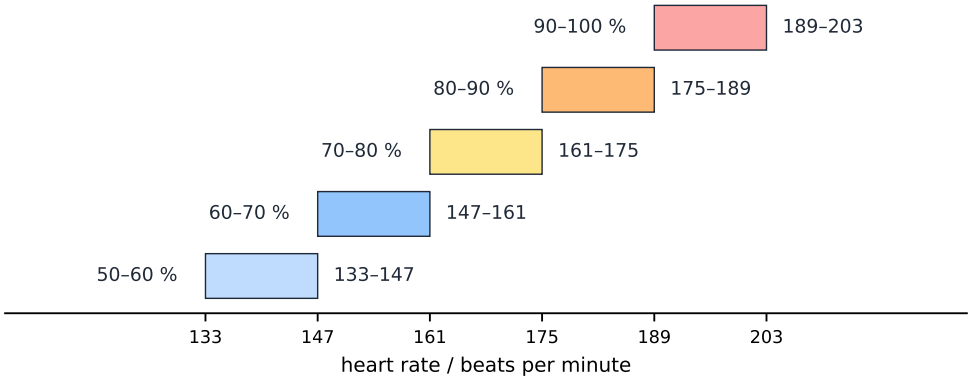
a genetic cause from one person improving less. Menstrual and reproductive circumstances may matter to an individual's experience and planning, but an assumed cycle phase does not dictate an identical programme for everyone; respect privacy and respond to relevant individual evidence.

Measuring intensity

- **Percentage of maximum heart rate**, for example 70 % of 200 = 140 beats per minute.
- **Heart rate reserve** 心率储备 (the Karvonen method): heart rate reserve = maximum heart rate − resting heart rate, and the target heart rate = resting heart rate + percentage × heart rate reserve. It allows for a low resting heart rate in trained athletes.
- **Rating of perceived exertion** 主观用力程度 (RPE): the Borg 6 to 20 scale and CR-10 are distinct scales. A rating is not a direct measurement or reliable individual conversion to heart rate. State the scale and anchors; session-load calculations here use CR-10.
- **Percentage of one-repetition maximum** (1RM), the heaviest load that can be lifted once, for resistance training. Definition of 1RM does not require pupils to perform a maximal lift in class.
- **Percentage of maximal oxygen uptake** 最大摄氧量, measured in a laboratory.



A GPS sports watch logs pace and heart rate, two common measures of training intensity



Invented reserve-percentage bands; named lactate or ventilation zones cannot be inferred from this arithmetic alone.

> **Worked example.** Given a hypothetical maximum of 203 and resting heart rate of 63 beats/min, reserve = 203 − 63 = 140 beats/min. At 70% reserve the model value is 63 + 0.70 × 140 = 161 beats/min. At 70% maximum it is 0.70 × 203 = 142.1 beats/min. These are different definitions, not interchangeable intensities or personal prescriptions. The supplied maximum was not inferred from the person's age.

Training methods and periodisation

Training methods

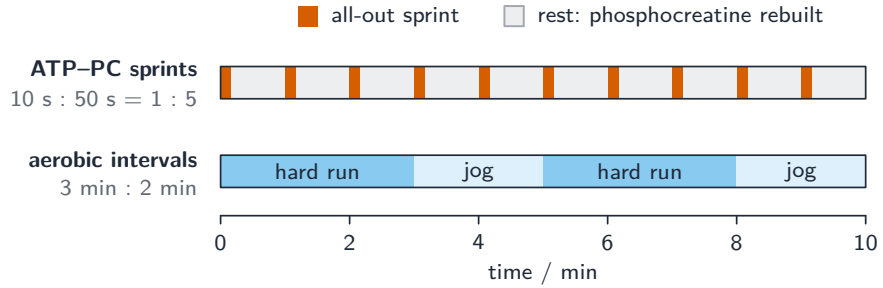
Method	Description	Mainly develops
Continuous training 持续训练	Sustained effort without planned recovery breaks; duration depends on the purpose	Aerobic endurance
Interval training 间歇训练	Repeated work periods with planned rest; set by intensity, work time, rest time and number of repetitions	Aerobic or anaerobic power, depending on the design
Fartlek 法特莱克训练	Continuous activity with changes of pace, which can be planned or responsive	Aerobic and anaerobic; game-like
Resistance training 抗阻训练	Weights, bands or body weight, in sets and repetitions	Strength, power, muscular endurance
Plyometrics 增强式训练	Jumps and bounds using a fast stretch then a fast contraction	Power
Circuit training 循环训练	A series of exercises at stations	General fitness
Flexibility training	Static, dynamic or PNF stretching	Range of movement



Interval training: hard work bouts separated by planned recovery

Resistance adaptations depend on load, total volume, effort, movement, contraction speed, rest and training history. Heavier loads commonly support maximal-strength development; sufficient challenging work can produce **hypertrophy** 肌肥大 across more than one narrow repetition range. Lighter repeated work can develop local endurance. These outcomes overlap; do not treat one repetition boundary as a biological switch or copy an elite programme into a classroom.

For interval training, the **work-to-rest ratio** matters. Short, very hard efforts that use the ATP–PC system need long rests, such as 10 s of sprinting with 50 s of rest (1 : 5), so phosphocreatine can be rebuilt. Aerobic intervals use shorter rests, such as 3 minutes of hard running with 2 minutes of jogging.

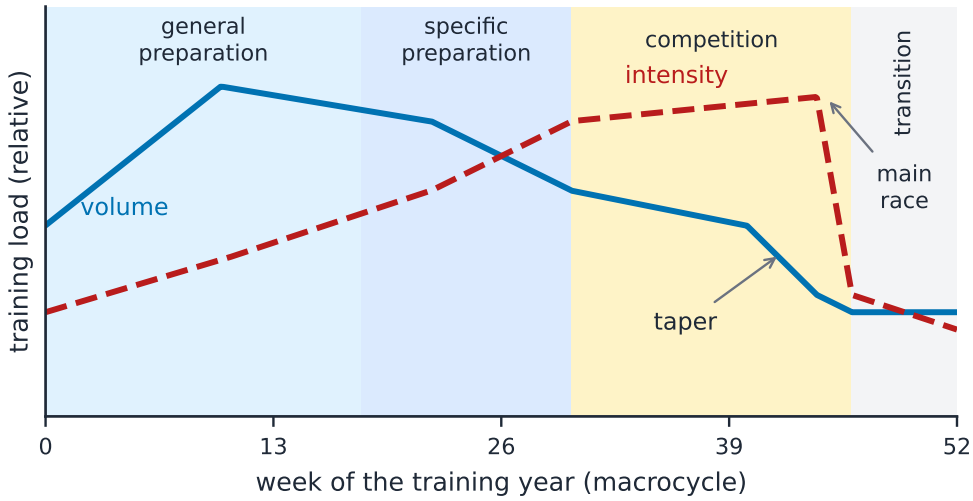


Short all-out sprints need long rests so phosphocreatine is rebuilt; aerobic intervals use shorter, active rests.

Periodisation

Periodisation 周期化 divides the training year into planned blocks to organise preparation and recovery around important events. It supports planning but guarantees neither a peak performance nor prevention of overtraining.

- A **macrocycle** 大周期 is the long-term plan, often a whole season or year.
- A **mesocycle** 中周期 is a block of about 3 to 6 weeks with one main aim.
- A **microcycle** 小周期 is usually one week of sessions.



A simple periodised year for an endurance athlete

1. **Preparation phase.** General preparation builds a base with high volume at lower intensity; specific preparation makes training more like the sport.
2. **Competition phase.** Intensity stays high, volume falls, and the athlete keeps fit between events.
3. **Transition phase.** Light, varied activity allows physical and mental recovery.

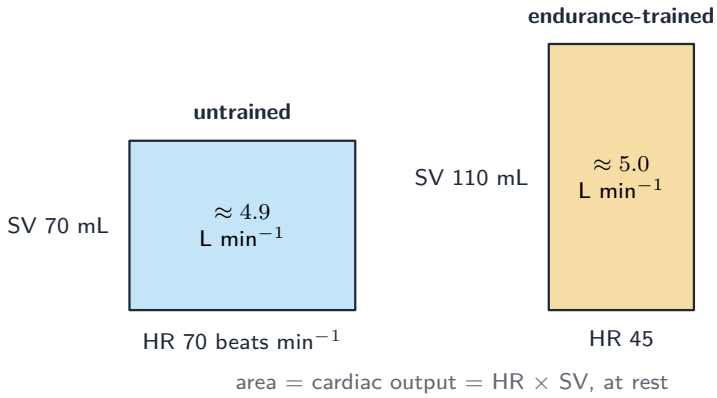
A **taper** 减量训练 reduces accumulated fatigue before a priority event while aiming to retain relevant fitness and readiness. The amount, duration and maintained intensity depend on the sport and individual. In an invented plan, weekly volume falls from 600 to 360 minutes: reduction $= (600 - 360)/600 \times 100 = 40\%$. That arithmetic does not establish a 40% change in intensity or any guaranteed percentage improvement in race performance.

Adaptations to training

■ Cardiovascular and respiratory adaptations

Adaptation (endurance training)	Effect
Larger left ventricle chamber; stronger heart muscle	Larger stroke volume
Lower resting heart rate (**bradycardia** 心动过缓)	A larger stroke volume can support a similar output at a lower rate
Blood-volume adaptations vary; plasma volume and red-cell mass need not change by the same proportion	Larger stroke volume; better temperature control
More capillaries around muscle fibres	More time and area for oxygen diffusion
Higher maximal cardiac output	Higher maximal oxygen uptake
Stronger respiratory muscles	Higher maximal ventilation; breathing feels easier

Resting cardiac output hardly changes with training: the lower heart rate is balanced by a larger stroke volume. For example, untrained 70×70 mL $= 4.9$ L/min and trained 45×110 mL ≈ 5.0 L/min. These invented values illustrate the product: $45 \times 110 = 4950$ mL/min. A low pulse alone is not a diagnosis of good health or a complete fitness measure.



Training reshapes the rectangle, not its area: a lower resting heart rate with a larger stroke volume (invented values).

Lung volumes and maximal ventilation are different quantities. Training can alter ventilatory demands and respiratory-muscle function without proportionately enlarging

lung volume. Limits to performance depend on the person, activity and environment; do not rule out respiratory constraints in every healthy athlete. Cardiac structural adaptations likewise depend on loading pattern and individual context, rather than an absolute endurance-chamber/resistance-wall rule.

Muscular adaptations

Endurance (aerobic) training	Resistance and sprint (anaerobic) training
More and larger **mitochondria** 线粒体	Larger muscle fibres (hypertrophy), mainly type II
More **myoglobin** 肌红蛋白 to store and carry oxygen in muscle	More PCr and more glycolytic enzymes
More aerobic enzymes	Better buffering of acid
More glycogen and fat stored in muscle	Stronger tendons and denser bones
More fat used at a given pace, so glycogen lasts longer	Neural changes: more motor units recruited, firing better together

endurance (aerobic) training
more and larger mitochondria
more myoglobin
more capillaries
greater fat use at a given load

resistance and sprint training
fibre hypertrophy, mainly type II
more PCr and glycolytic capacity
greater strength and power
neural recruitment improves

the stimulus decides the adaptation (specificity)

The training stimulus decides the muscular adaptation

Strength can rise before a clearly measurable increase in muscle size. These early gains are mainly **neural adaptations** 神经适应: more motor units are recruited, they fire at higher frequencies and in better time, and opposing muscles relax more.

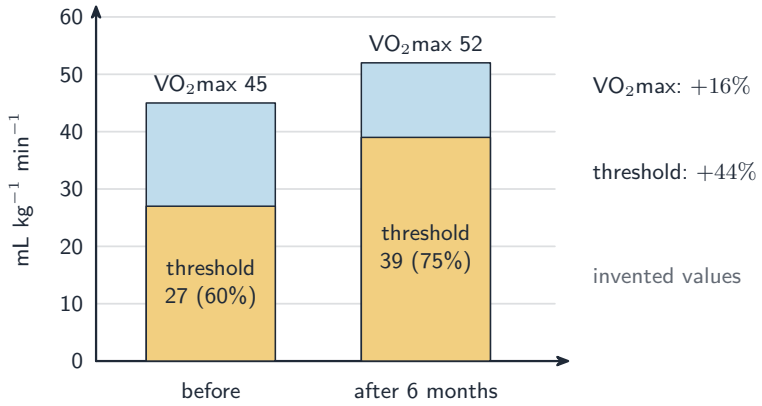
Thresholds and maximal oxygen uptake

- The **lactate threshold** 乳酸阈 is defined using a specified blood-lactate/workload protocol. Training can alter the workload or fraction of maximal uptake associated with it. It is not a universal concentration, exact switch to anaerobic metabolism or direct measure of all fatigue.
- **Maximal oxygen uptake**, VO_2max, can improve with training, but the change depends on baseline, programme, duration and individual factors. An average response does not determine an individual's result.

- **Running economy** compares the oxygen or energy cost at matched submaximal speed (A.2); it is distinct from the maximum uptake and can change without an identical change in it.



A maximal oxygen uptake test: the mask samples every breath while treadmill speed and gradient rise until the runner can go no further



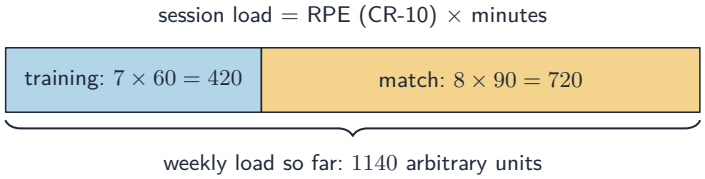
Threshold can rise much more than VO2max: sustainable fraction matters as well as the maximum

Worked example. Before training, an athlete's VO_2max is 45 mL per kg per minute and their lactate threshold is at 60 % of it. After six months it is 52 mL per kg per minute and the threshold is at 75 %. The threshold rose from $0.60 \times 45 = 27$ to $0.75 \times 52 = 39$ mL per kg per minute, a 44 % increase, much larger than the 16 % rise in VO_2max. These invented results show why both maximum capacity and sustainable fractional use can matter. They do not prove one universal predictor is always superior, nor determine an actual running speed without additional measurements.

Training load and health

Too much load, too little recovery

A short-term performance reduction can follow planned loading and resolve with recovery (**functional overreaching** 功能性过度训练). Longer, maladaptive underperformance may be described as non-functional overreaching or **overtraining syndrome** 过度训练综合征 after appropriate assessment. These are not diagnoses obtained from a fixed number of days or one morning pulse. Illness, injury, psychological stress and problematic low energy availability can produce overlapping signs; further evaluation may be needed.



Session RPE turns each session into one load number; the weekly total flags changes to investigate

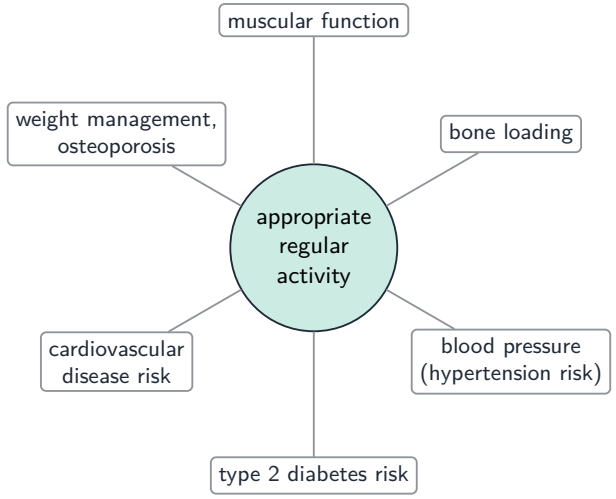
Warning signs include falling performance despite training, a higher resting heart rate in the morning, poor sleep, low mood and motivation, frequent colds and loss of appetite. Stress from school, travel and too little energy intake (unit A.2) add to the training load.

Coaches monitor load and response to inform adjustment; a monitoring score cannot guarantee prevention. **Session RPE** multiplies the rating (on the CR-10 scale) by the session length in minutes.

Worked example. A footballer does 60 minutes of training at RPE 7 and a 90-minute match at RPE 8. Load $= 7 \times 60 + 8 \times 90 = 420 + 720 = 1140$ arbitrary units. A weekly total can flag a change for investigation, but is not a validated universal injury threshold. Equal totals can hide very different intensity distributions, movements and recovery intervals. Arbitrary units are not kilojoules or a diagnosis.

Health benefits are broader than performance

Appropriate regular physical activity supports muscular function, bone loading and cardiometabolic health and can reduce the risk of hypertension, cardiovascular disease and type 2 diabetes. Activity can contribute to prevention or management of obesity and osteoporosis, but risk reduction is not a guarantee that an individual will avoid disease. Energy intake, total expenditure and energy stored in tissues are related; one exercise session does not establish a whole-day energy deficit or a body-composition change. Benefits do not require elite performance. Immune health is influenced by sleep, nutrition, exposure and training/recovery balance; "more training always improves immunity" is an overclaim (WHO guidelines).

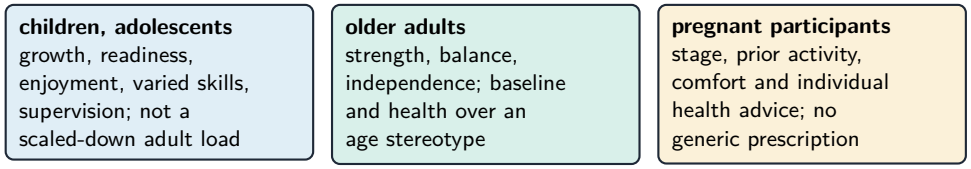


Regular activity reduces risk across body systems

Suitable loading can strengthen muscle and bone; poorly progressed or excessive loading can cause harm. Describe the mechanism and intended benefit, then consider baseline, access, preferences and limitations. A health programme and a competition programme can have different success criteria.

AHL: Planning for different groups and environments

For **children and adolescents**, consider growth, developmental readiness, enjoyment, varied skills and appropriate supervision. Do not simply scale down an adult elite load or assume the same age means the same readiness. Avoid public disclosure of body, health or reproductive information.



Planning adapts to the group

For **older adults**, goals may include strength, balance, functional independence and enjoyable participation. Baseline capacity, previous activity, health conditions, accessibility and progression matter more than a single age stereotype. Appropriate adaptation can enable participation rather than treating age as a reason for exclusion.

For **pregnant participants**, planning needs to account for pregnancy stage, prior activity, changing comfort and relevant individual health advice. A generic worksheet does not determine suitability or prescribe an identical intensity for every pregnancy. Evaluate a proposed programme against its context, goals and appropriate professional guidance; do not infer that all activity must stop or that all elite training should continue unchanged.

Environmental responses are treated in A.1. At altitude, oxygen fraction remains near 21% while reduced total pressure lowers the **partial pressure of oxygen** 氧分压. Acclimatisation can alter ventilation; kidney release of **erythropoietin** 促红细胞生成素 can support red-cell production. Timing and magnitude vary. "Live high, train low" aims to combine an altitude stimulus with lower-altitude training quality, but benefit is conditional, with sleep, illness, logistics and individual response to evaluate. **Heat acclimatisation** 热习服 can change sweating and cardiovascular strain; it does not remove heat risk. Cold, wind and wet conditions alter heat loss; **hypothermia** 体温过低 means dangerously low core temperature, not simply cold skin. Neither school investigations nor a model programme require exposing pupils to hazardous conditions.

Practice

All numerical records below are invented. Explain mechanisms and limits as well as showing working.

1. Distinguish an acute response from a training adaptation. Describe possible phases of a heart-rate response before, during and after steady exercise, and explain why a plateau alone does not prove an oxygen balance.
2. Explain two reasons stroke volume can rise. Calculate cardiac output for rest HR 70 beats/min, SV 70 mL/beat and exercise HR 170, SV 105; find the factor increase.
3. Compare blood-pressure responses to dynamic running and heavy resistance exercise. Explain oxygen unloading, then use Q = 18 L/min and whole-body a-vO_2 difference = 140 mL/L to find oxygen uptake.
4. Explain the supercompensation model and two limits to using its peak as an exact training deadline. Apply specificity, overload and reversibility to one sport.
5. Given maximum HR 200 and rest HR 68 beats/min, calculate the model value at 75% reserve. Compare with 75% maximum; explain why age or these fractions alone cannot identify an individual's lactate threshold.
6. An interval model uses 40 s work and 160 s recovery. Find the work:rest ratio and explain what additional information is needed to judge its purpose. Explain preparation, competition, transition and tapering; calculate the volume reduction from 600 to 360 minutes.
7. Explain how a larger stroke volume can maintain resting cardiac output at a lower heart rate. Compare muscular adaptations to endurance and resistance training and explain strength gains before a clear increase in muscle size.
8. An athlete's maximal uptake changes from 45 to 52 mL/kg/min and the fraction at a defined threshold from 60% to 75%. Calculate both threshold values and their percentage increase; compare with the maximum's percentage increase. State a limit to the inference.
9. A swimmer completes four 75-minute sessions at CR-10 RPE 6 and one 20-minute race at RPE 9. Calculate weekly session load and give two limitations of this number.
10. Explain how appropriate activity can support muscle, bone and cardiometabolic health. Evaluate "a person who exercises cannot develop type 2 diabetes" and "one session proves a daily energy deficit".
11. Two people follow the same programme and their test scores change by different amounts. Explain three possible reasons, design a more defensible comparison and state why a genetic explanation is not established.
12. **AHL:** Explain interacting peripheral and central fatigue mechanisms in short high-power and prolonged exercise. Evaluate the claim that lactate left in muscle causes next-day downhill-running soreness.

13. **AHL:** A recovery intervention changes mean soreness from 5/10 to 3/10, but task performance stays 8% below baseline. Evaluate the evidence and compare nutritional, physical and sleep/load strategies with reference to distinct recovery outcomes.
14. **AHL:** Explain how planning differs for adolescents, older adults and pregnant participants. Evaluate a "live high, train low" proposal without assuming universal benefit.

Answers.

1. Acute: a bout-related HR rise; adaptation: more persistent increased mitochondrial capacity after repeated training. Anticipatory autonomic rise, rapid onset rise, possible plateau, then faster and slower recovery phases. A plateau measures only HR; uptake, output and temperature may still differ or change.
2. Greater venous return stretches the ventricle (Frank–Starling); sympathetic input raises contractility. Rest = $70 \times 70 = 4900$ mL/min = 4.9 L/min. Exercise = $170 \times 105 = 17\,850$ mL/min = 17.85 L/min. Factor = $17\,850/4900 = 3.642857\ldots \approx 3.64$.
3. Running usually raises systolic pressure while diastolic changes less as working-muscle arterioles dilate; heavy resistance can increase both substantially. Increased CO_2/H^+ lowers Hb affinity (Bohr effect); warmth also favours unloading. Uptake = $18 \times 140 = 2520$ mL/min = 2.52 L/min. The oxygen-content sample must match the whole-body boundary.
4. The model sketches fatigue, recovery and a possible above-baseline response. Different capacities recover at different rates; its curve is not an individual's measured timetable. Football-specific changes of direction train relevant movement; gradual suitable progression adds stimulus; reduced stimulus can reverse some adaptations. Timing follows aims and monitoring, not one universal peak.
5. Reserve = $200 - 68 = 132$; value = $68 + 0.75 \times 132 = 167$ beats/min. Percentage maximum = $0.75 \times 200 = 150$ beats/min. Neither calculation measures blood lactate or supplies an exact individual threshold. A supplied maximum is not the same as an uncertain age prediction.
6. 40:160 = 1:4. Need intensity, activity, repetitions, participant history and next-task aim; several energy systems contribute. Preparation develops capacities and sport relevance; competition balances events and maintenance; transition permits recovery and variation. Taper aims to reduce fatigue while retaining readiness. Volume cut = $240/600 \times 100 = 40\%$; no automatic performance gain follows.
7. Output is the product of rate and stroke volume: $45 \times 110 = 4950$ mL/min = 4.95 L/min, similar to $70 \times 70 = 4.9$ L/min. Endurance can increase mitochondrial/aerobic capacity and capillarisation; resistance can increase fibre size and neural force production. Recruitment, firing and task coordination can improve before visible hypertrophy; the processes overlap.
8. Before = $0.60 \times 45 = 27$; after = $0.75 \times 52 = 39$ mL/kg/min. Increase = $12/27 \times 100 = 44.444\ldots\%$. Maximum increase = $7/45 \times 100 = 15.555\ldots\%$. These are different metrics; they do not determine speed, prove cause or make one predictor universally superior.
9. Four sessions: $4 \times 75 \times 6 = 1800$; race: $20 \times 9 = 180$; total = 1980 arbitrary units. The score depends on the stated subjective scale and timing and hides movement/intensity distribution. It is not energy expenditure or a guaranteed injury predictor.
10. Mechanical loading can support muscle and bone; appropriate activity improves cardiometabolic function and reduces several disease risks. Reduced risk does not imply zero risk. Daily energy balance requires intake and all expenditure over the stated period, not one activity measurement.
11. Baseline fitness/training history, adherence, recovery/stress, individual physiology and test noise are possible explanations. Standardise tests and exposure, repeat measurements and record relevant differences; use a suitable comparison. Different change scores alone cannot isolate genetic effects.
12. **AHL:** PCr availability limits rapid resynthesis; altered Na^+/K^+ gradients, phosphate and calcium handling can reduce force. High-power fatigue is multifactorial, not lactate alone. Prolonged work may also involve glycogen availability, heat/water strain and reduced central drive. DOMS commonly follows unfamiliar eccentric loading; it is associated with tissue/inflammatory responses, not lactate retained for days. Soreness is not a direct measure of every recovery process.
13. **AHL:** Soreness differs by 2 scale points; this is not 2%. Performance has not returned to baseline. Need allocation, group sizes, baseline balance, comparable workload, expectations and uncertainty before a causal claim. Water/electrolytes and adequate energy/macronutrients support specified restoration; assess evidence for creatine or polyphenol preparations rather than assuming all products work. Myofascial, compression and thermal approaches need outcome-specific comparisons. Sleep opportunity, stress/travel and load adjustment address wider recovery; none guarantees immediate complete readiness.
14. **AHL:** Match goals, baseline and progression: development/enjoyment/supervision for adolescents; function, strength and balance with access needs for older adults; pregnancy stage, prior activity and individual health guidance for pregnant participants. Avoid stereotypes and fixed elite templates. Altitude may provide a red-cell stimulus and lower training permits higher quality, but response, timing, sleep, illness, logistics and relevant evidence determine whether a particular proposal is suitable; cost alone does not establish benefit.

Exam tips

- Say whether a change is an acute response (one bout) or a training adaptation (many sessions).
- Describe a heart rate graph in phases: anticipatory rise, rapid rise, steady state, rapid fall, slow fall.
- Explain stroke volume with venous return and the Frank–Starling mechanism.
- Distinguish an indicator from a mechanism and a symptom from measured task performance.
- Name the principle of training and give a sport-specific example of it.
- In Karvonen calculations, show the maximum heart rate, the reserve and the target, with units.
- Link each adaptation to its effect on performance, for example “more mitochondria, so more ATP is made aerobically”.

B.1 · Generating movement in the body

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

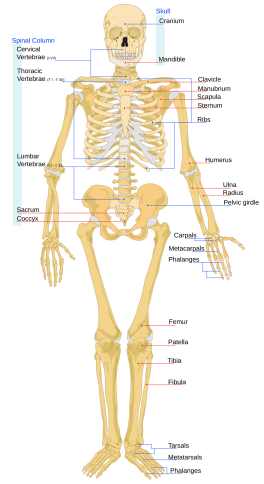
Scope and prerequisites

Why can a muscle need a much larger force than the weight held in a hand? The answer depends on attachment positions and turning effects, not simply on whether the athlete is strong. Follow a movement from anatomical description, through joints and muscle activation, to the lever that transfers force.

This handout covers B1: generating movement in the body. Shared teaching includes skeletal organization, positions and movements, connective tissues and joints, muscular function, and lever systems. Sections marked **AHL** are for Higher Level only. Prerequisites are force, distance, simple ratios and the distinction between acute responses and training adaptations. Numerical examples and simplified diagrams are original invented teaching models, not measurements from athletes or examination papers.

Anatomical position gives descriptions a common reference

In anatomical position the person stands upright, looking forwards, with arms at the sides and palms facing forwards. Left and right refer to the person’s own sides. A photograph taken from the front reverses these sides for the viewer. Terms retain this reference when the person changes posture: the palm does not become the back of the hand when someone turns it downwards.



Axial skeleton (skull, vertebral column, ribs, sternum) and appendicular skeleton (girdles and limbs)

The axial skeleton includes the skull, vertebral column, ribs and sternum. It supports the central body and protects structures such as the brain, spinal cord and organs in the chest. The appendicular skeleton includes the shoulder and pelvic girdles and the upper and lower limbs. It provides attachments and linked segments for movement. Protection, support, mineral storage and blood-cell formation are skeletal functions; these do not belong exclusively to one division.

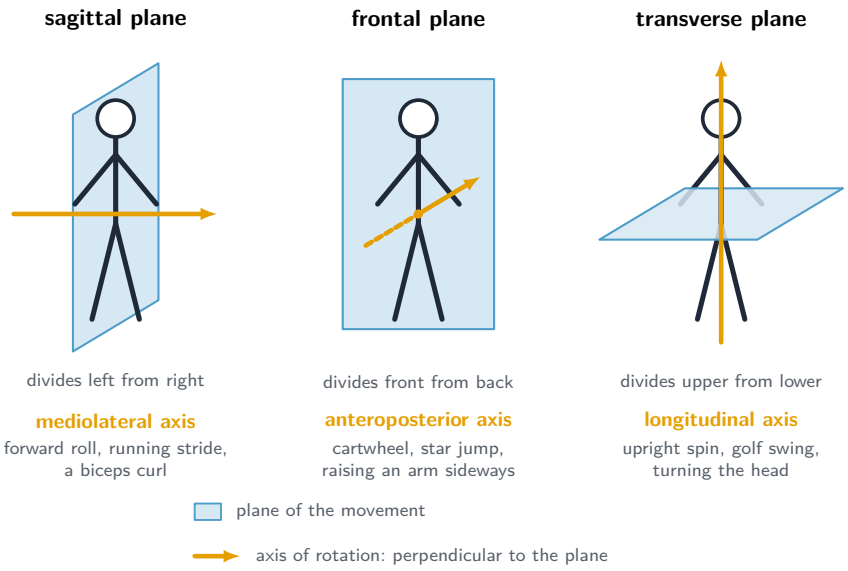
Recognize the scapula and clavicle at the shoulder; humerus in the upper arm; radius and ulna in the forearm; carpals, metacarpals and phalanges in the hand. The pelvic girdle links the lower limb to the trunk. The femur is in the thigh; patella at the knee; tibia and fibula in the lower leg; and tarsals, metatarsals and phalanges in the foot. In anatomical position the radius lies on the thumb side, lateral to the ulna. The tibia is medial to the fibula. Use a labelled skeleton to locate these bones rather than memorizing an isolated word list.

Superior means towards the head and inferior towards the feet. Anterior is towards the front and posterior towards the back. Medial means closer to the body's midline; lateral means farther from it; intermediate means between structures. Proximal and distal compare distance from a limb's attachment to the trunk. The elbow is distal to the shoulder but proximal to the wrist. Calling the elbow simply "proximal" leaves the comparison unfinished. These terms describe position, not the direction a force acts.

Planes describe motion; axes describe rotation

A **plane** 平面 is an imaginary flat surface. A sagittal plane divides left and right portions; only the midsagittal plane gives equal halves. A frontal plane divides anterior and posterior portions. A transverse plane divides superior and inferior portions. Many sporting movements combine all three.

An **axis** 轴 is a line about which rotation occurs. It is perpendicular to the plane of the rotation. In a simplified forward roll, motion mainly in the sagittal plane is about a mediolateral axis running from side to side. A cartwheel's main rotation is in a frontal plane about an anteroposterior axis running from front to back. A straight upright spin is in a transverse plane about a longitudinal axis running head to foot. Naming "the sagittal axis" when you mean a sagittal plane confuses a surface with a line.

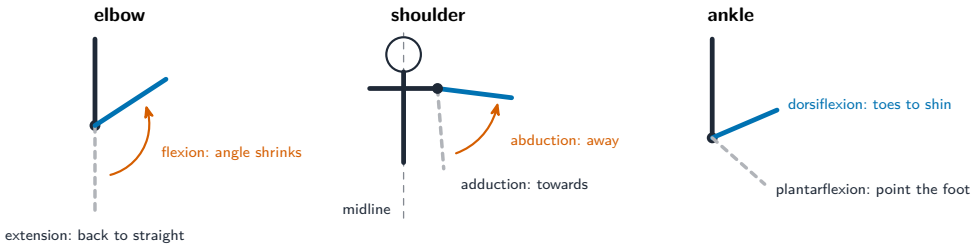


Each named axis is perpendicular to its movement plane. Sporting actions are simplified here; a real sequence can combine rotations.

To analyse a video, name the joint and phase, describe the relative movement of the segments, and then assign a plane and axis. A side view may suit elbow flexion, but it hides out-of-plane rotation. Calibrate distance, know frame rate, keep the camera fixed and approximately perpendicular to the main movement plane, and use visible landmarks consistently. Perspective and obscured landmarks create uncertainty; one two-dimensional recording does not establish the cause of an injury.

Use movement terms for a specified joint and phase

Flexion usually decreases the angle between articulating segments; extension increases it. During a curl, bending the elbow is flexion; lowering the hand towards a straight elbow is extension even if the elbow flexors remain active. At the ankle, dorsiflexion brings the top of the foot towards the shin; plantarflexion points the foot away. Do not call every upward movement flexion: lifting the whole arm sideways is shoulder abduction.



Name the joint, then the movement: each term comes in an opposite pair

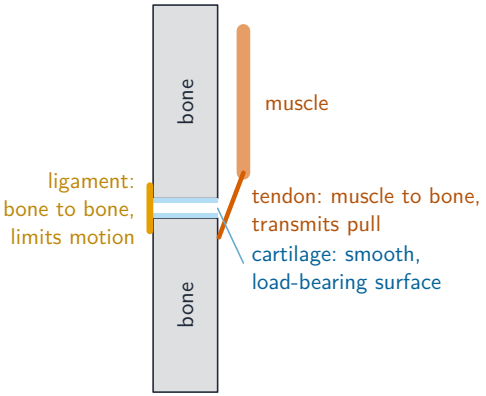
Abduction moves a limb away from the midline and adduction brings it towards the midline. For fingers, the reference is the middle finger; for toes, it is the second toe. Horizontal flexion moves a raised upper arm across the front of the body, as in bringing the arms together in a chest fly; horizontal extension reverses this action. These are mainly transverse-plane movements at the shoulder, unlike raising the arms sideways in a jumping jack.

Rotation turns a segment about its long axis. Circumduction combines successive movements so the distal end traces a cone; it is not simply the bone spinning about its own length. At the forearm, supination returns the palm forwards in anatomical position; pronation turns it backwards as the radius crosses the ulna. “Palm up” and “palm down” work for a bent elbow held horizontally, but anatomical reference makes the definition consistent in other positions.

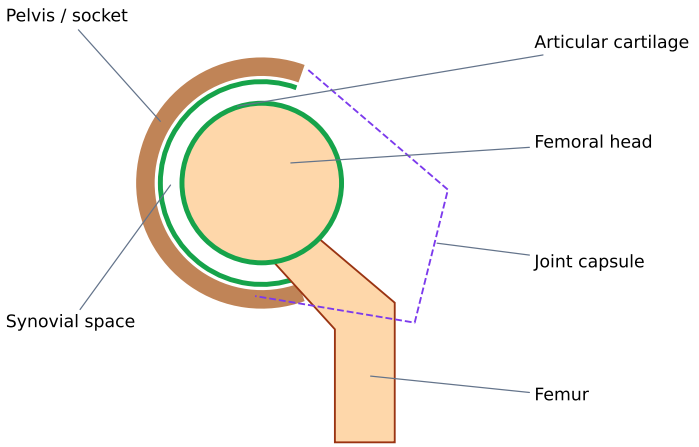
Protraction brings the shoulder girdle forwards around the chest; retraction moves it backwards. Elevation raises a structure, as when shrugging the shoulders; depression lowers it. Opposition brings the thumb towards the fingertips; reposition returns it. Inversion turns the sole towards the midline and eversion turns it away, involving joints in the foot rather than simply pointing the toes. In a real throw, several joints and muscle groups contribute in sequence: a single label for the entire throw loses useful information.

Connective tissues transmit forces and constrain movement

Bone provides a relatively rigid support and a lever for muscle force. Tendons connect muscle to bone and transmit tensile force; some store and return elastic energy. Ligaments usually connect bone to bone and help limit excessive joint motion. Cartilage provides support and, at many joint surfaces, a smooth low-friction load-bearing covering. Fascia is connective tissue that surrounds and links muscles and other structures, helping organize and transmit forces. Do not swap tendon and ligament or describe all connective tissue as rigid.



Tendon, ligament, cartilage



The diagram separates tissues to show their roles. It is not a medical image or a measurement of a person’s joint.

Joints are articulations between skeletal elements. In a fibrous joint, dense connective tissue links bones, as in skull sutures; movement is generally limited. Cartilaginous joints use cartilage, as at the pubic symphysis and between vertebral bodies; their movement depends on structure. Synovial joints have a cavity with synovial fluid, articular cartilage and a surrounding capsule. Fluid supports lubrication, cartilage distributes loads and the capsule and ligaments help stability. Muscles crossing the joint provide additional dynamic stabilization. Not every joint is freely movable or has a fluid-filled cavity.

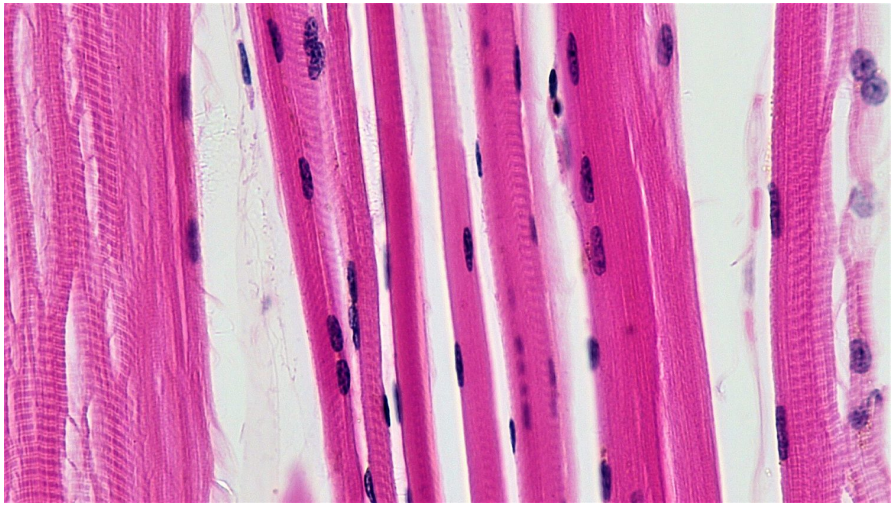
Synovial classes differ in the movements their shapes permit. A hinge, such as the

elbow's main articulation, mainly allows flexion and extension. A pivot, such as the proximal radioulnar joint, allows rotation. A ball-and-socket joint, such as shoulder or hip, allows movement about several axes. A condyloid joint, such as the radiocarpal wrist joint, permits movement mainly about two axes; a saddle joint at the base of the thumb supports flexion/extension and abduction/adduction, helping opposition. Plane joints between some carpal bones permit gliding. The knee is a modified hinge with some rotation: the simple categories are models, not claims that a living joint has only one possible motion.

The shoulder's large range supports throwing and reaching but requires substantial soft-tissue control. The hip's deeper socket and strong surrounding structures support load bearing and stability. More movement is not automatically better in every task. Describe the particular structure, useful movement and stability demand rather than declaring one joint universally superior. Cellular details of connective tissue are not needed for this unit.

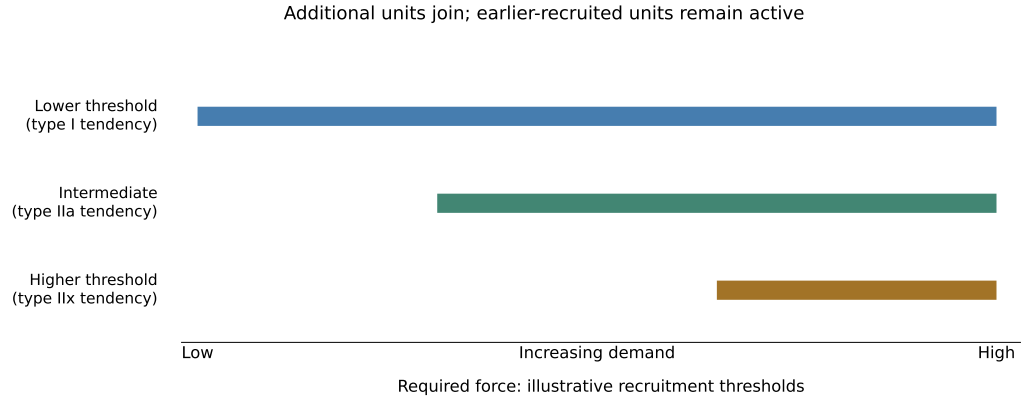
Muscle activation produces graded force and controlled movement

A **motor unit** 运动单位 consists of one motor neuron and the muscle fibres it supplies. A motor-neuron action potential normally activates all the fibres of its unit. The all-or-none principle applies to the electrical response to a sufficient stimulus; it does not mean a whole muscle can produce only zero force or its maximum force. Twitch force also depends on muscle length, fatigue and other conditions.



Skeletal muscle fibres under the microscope: long, striped cells with many nuclei; force is graded by how many motor units fire, and how often

Whole-muscle force changes through recruitment of additional motor units and changes in their firing rate. At low demands, smaller, lower-threshold units are generally recruited first; additional higher-threshold units contribute as demand rises. Type I fibres are relatively slow and fatigue resistant, with strong oxidative capacity. Type IIa are faster and combine substantial oxidative and glycolytic capacities. Type IIx have high shortening speeds and rapid force potential but fatigue more rapidly in sustained repeated work. Lower-threshold units generally have smaller motor neurons and axons; higher-threshold fast units generally have larger neurons with larger-diameter axons. Neuron size relates to recruitment threshold and conduction, but axon diameter alone cannot predict sporting performance. These are relative tendencies; all active fibres require ATP, and "fast" does not mean never using oxygen.



The schematic shows additional units joining those already active, not one fibre class switching off as another switches on. Thresholds are illustrative.

A posture task and a maximal explosive task therefore differ in recruitment demands. Hypertrophy increases muscle-fibre size and can increase force capacity; atrophy reduces it. The neural drive needed for a given external load can change as muscle capacity changes, while training also produces neural adaptations. A larger muscle does not automatically have more motor neurons, and fibre size alone cannot predict the recruitment pattern in every movement.

Muscles generate tension while shortening, maintaining length or lengthening under load. During concentric action the active muscle shortens; during eccentric action it lengthens while resisting the load; during isometric action its overall length remains approximately constant. Holding a dumbbell still at a fixed elbow angle involves isometric activity. Raising it by elbow flexion involves concentric elbow-flexor activity; lowering it under control involves eccentric elbow-flexor activity. "Eccentric" does not mean the muscle is relaxed or pushing the bones apart.

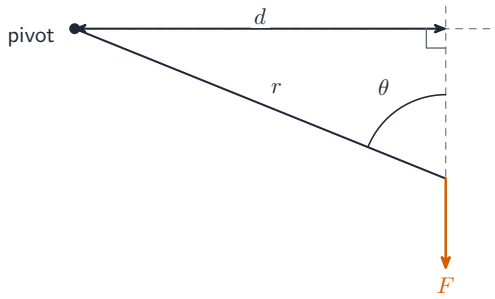
The syllabus uses isotonic concentric and isotonic eccentric for these dynamic actions. Strictly, isotonic means constant tension; ordinary free-weight movements do not maintain exactly constant muscle tension through their whole range. Isokinetic action maintains a specified angular velocity, usually using specialized equipment that varies resistance. Constant velocity does not mean constant force, and an isometric

hold still consumes ATP even though external mechanical work on a stationary load is zero.

The agonist is the muscle or group producing the specified action; the antagonist can oppose it. In elbow flexion the elbow flexors are agonists and the extensors are antagonists; the roles change for an active extension. Synergists assist and stabilizers hold other segments appropriately. Reciprocal inhibition can reduce activation of an antagonist while an agonist is activated, supporting movement. However, co-contraction also occurs, particularly when stability is needed: antagonists are not necessarily completely inactive. ATP metabolism supports contraction and restoration of ionic conditions in all these tasks.

Levers convert muscle force into turning effects

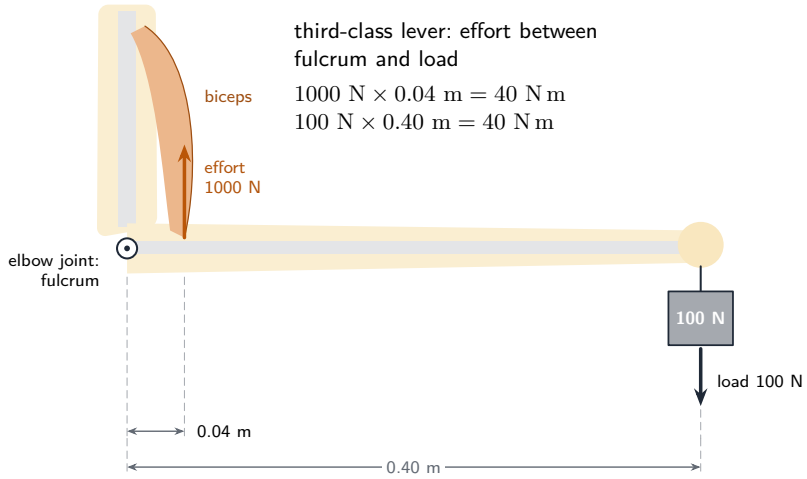
A lever has a fulcrum or pivot, an effort and a load. Classification depends on their relative positions. In a first-class lever the fulcrum lies between effort and load, as in a simple seesaw or a simplified head-extension model about the upper cervical joint. In a second-class lever the load lies between fulcrum and effort. A wheelbarrow illustrates this; in a simplified heel raise, the forefoot contact is the fulcrum, body weight is the load and the Achilles tendon supplies effort. A third-class lever has effort between fulcrum and load, as in elbow flexion holding a weight, or a forearm moving an implement held in the hand.



The moment depends on the perpendicular distance d from the pivot to the line of action of the force

An implement can extend the lever outside the body. With angular motion, a longer distance from the axis can produce greater endpoint speed for the same angular velocity, but may increase the turning effect of a resisting load and the rotational inertia. A longer racket is not automatically easier to accelerate. First-class levers do not always have a force advantage: the arm lengths determine the ratio.

The moment of a force about a pivot is force multiplied by the perpendicular distance from the pivot to the force's line of action. Use metres for distance and newton metres for moment. A force applied obliquely may have a much smaller moment arm than the distance measured along the bone. Mechanical advantage for an ideal lever is effort arm divided by load arm. When it exceeds one, less effort force can balance the load; when it is below one, more effort force is needed. This exchanges force for movement distance and speed, not free energy.



For the horizontal segment, a 100 N downward load at 0.40 m balances a 1,000 N upward effort at 0.04 m. Joint reaction and segment weight need separate treatment in a fuller model.

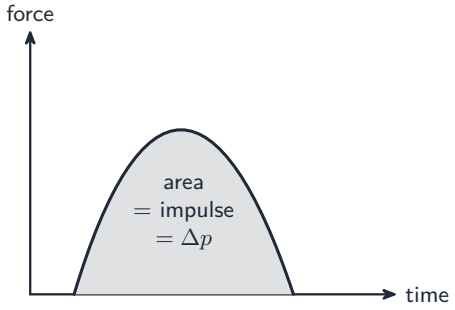
In this invented static model, load moment is $100 \times 0.40 = 40$ newton metres. Required effort is $40/0.04 = 1000$ N and mechanical advantage is $0.04/0.40 = 0.10$. The muscle's force exceeds the external load because its moment arm is shorter. If effort arm increases to 0.05 m with other conditions unchanged, required effort falls to $40/0.05 = 800$ N. This does not mean anatomical attachment positions can be changed by a coaching instruction.

Adding segment weight changes the result. A 20 N forearm-and-hand weight acting 0.15 m from the pivot adds $20(0.15) = 3$ newton metres. The effort must now balance 43 newton metres, requiring $43/0.04 = 1075$ N. The joint reaction balances the remaining forces; it is not automatically equal to the weight in the hand. A dynamic analysis also needs angular acceleration and other forces.

Connect this model to impulse and safe movement analysis

Impulse 冲量 is net force integrated over time and equals change in momentum. The landing example connects this unit to B2 forces and motion. For the same momentum change of 150 kg metres per second, stopping over 0.30 s requires a net average force magnitude of $150/0.30 = 500$ N; over 0.60 s it is 250 N. Greater stopping time can reduce average net force. The peak force need not halve, and net force is not automatically the ground reaction: weight and other forces must be included with directions.

A 120 kg metre per second change over 0.40 s gives 300 N; 180 over 0.50 s and 1.00 s gives 360 N and 180 N.



Impulse is the area under a force-time graph, equal to the change in momentum

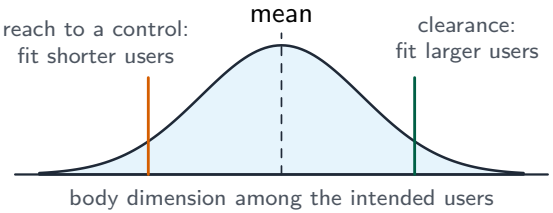
The **base of support** 支撑面 is the area enclosed by the supporting contacts. Its size and the position of the centre of mass affect stability, which B2 develops further. Joint angles, muscle actions, levers and momentum describe different aspects of the same movement. Name the body or segment, direction and movement phase before combining them. Use supplied data or consented teacher-approved ordinary low-risk movements. Do not deliberately increase impacts or prescribe rehabilitation from a classroom video.

AHL: Anthropometry supports equipment design, not a single ideal body

Anthropometry measures body dimensions and proportions, including segment lengths, breadths, circumferences and reach. Define landmarks, posture, equipment and measurement procedure. Repeated measurements by the same and different observers help assess reliability; an agreement problem can reflect inconsistent landmarks rather than real changes in the person.



Wheelchair basketball: each sports wheelchair is set up to its athlete's body dimensions and role



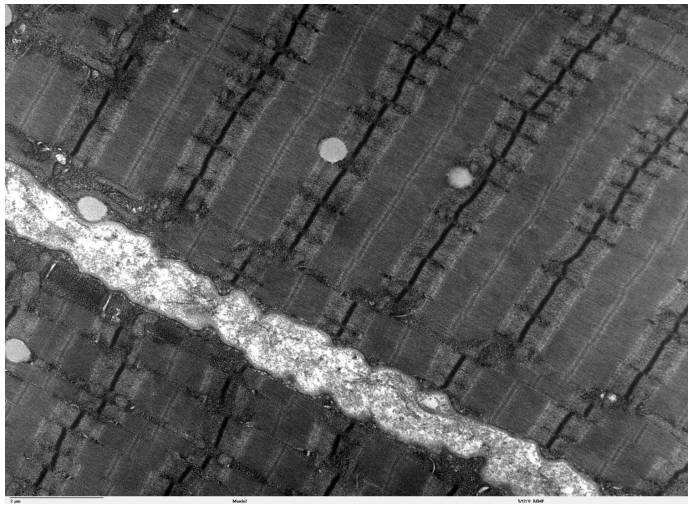
Design for the users at the limit, not the mean

Design must match its purpose. A control that must be reachable by most users should account for shorter reaches; a clearance opening must account for larger dimensions. Designing every measurement around the mean can exclude users at both ends. Adjustable equipment can accommodate a range, but its adjustment limits and the relevant combinations of dimensions still need testing. A database must represent intended users in age, body proportions and other relevant characteristics. Adult elite-athlete dimensions do not automatically suit schoolchildren or wheelchair athletes.

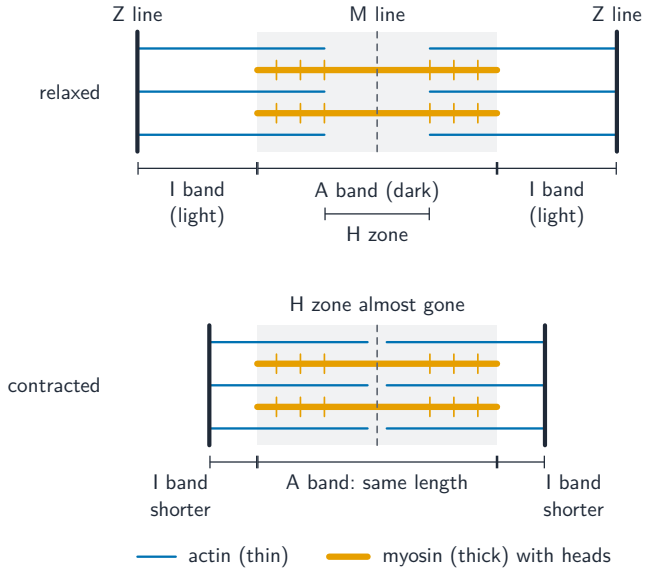
In an invented sample, hand lengths are 160, 165, 170, 175, 180, 185, 190, 195, 200 and 205 mm. The median is $(180+185)/2 = 182.5$ mm. A fixed grip that works comfortably only for hand lengths 175–195 mm includes five of these ten records, or 50%, despite containing the median. Hand length alone still cannot establish grip fit: breadth, finger reach, gloves, grip force and the task matter. Ergonomic design seeks comfortable, effective interaction with the implement and must be evaluated by appropriate users, not by claiming the largest segment guarantees the best performance.

AHL: Sliding filaments explain force at the sarcomere

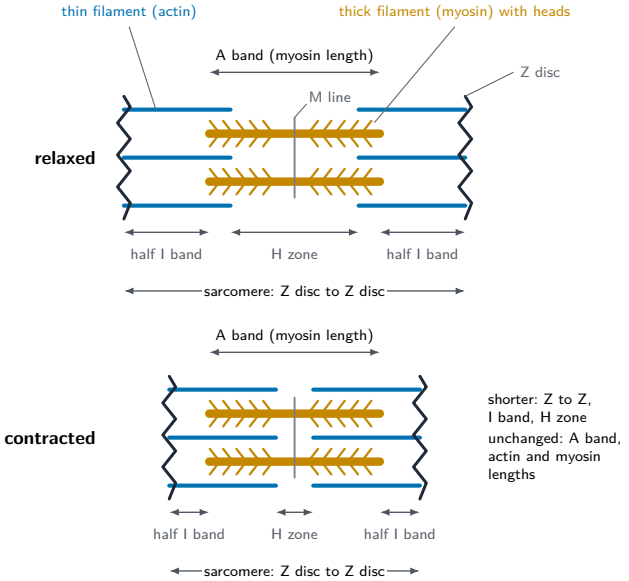
A skeletal-muscle fibre contains myofibrils built from repeating sarcomeres, each between two Z discs. Thin filaments contain actin and are anchored towards the Z discs; thick filaments contain myosin towards the centre. Shortening occurs as thin filaments slide farther between thick filaments, increasing overlap and bringing the Z discs closer. The filaments themselves do not become shorter. The A band, spanning the thick filaments, stays approximately constant; the I bands and H zone become narrower during normal shortening.



This is where the name "striated" comes from. Each repeating dark-light block is one sarcomere; the bands are the thick and thin filaments overlapping by different amounts. When the muscle contracts, the filaments slide past each other and each sarcomere gets shorter



In contraction the A band keeps its length; the I band and H zone shorten as actin slides over myosin



The two schematic states keep actin and myosin lengths fixed. Z-disc separation decreases; the central thick-filament span stays constant.

An excitation signal leads to calcium release from the sarcoplasmic reticulum. Calcium

binds troponin, changing the position of tropomyosin so myosin-binding sites on actin are accessible. An energized myosin head attaches to actin, forming a cross-bridge. Its power stroke moves the thin filament relative to the thick filament; products of ATP hydrolysis are released during this cycle. ATP binding to myosin permits detachment from actin. Hydrolysis of ATP re-energizes the head for another cycle. Many heads act in overlapping cycles, maintaining tension.

Cycling can continue while activation, suitable filament overlap and ATP availability permit it. Calcium removal into the sarcoplasmic reticulum requires active transport using ATP; as calcium falls, the regulatory proteins again limit cross-bridge formation. ATP is therefore needed for detachment and restoration as well as for the mechanical cycle. "No ATP causes immediate relaxation" is incorrect: persistent attachment helps explain rigor. Calcium does not provide the mechanical energy by itself.

In an invented micrograph comparison, a sarcomere shortens from 2.4 to 2.0 micrometres: a fall of $0.4/2.4\times100 \approx 16.7\%$. If the thick-filament span remains 1.6 micrometres in both, that supports sliding rather than shortening of myosin. A static image cannot reveal every step of the molecular cycle; compare structural evidence with the mechanism rather than treating an artist's diagram as direct measurement.

Practice

1. Classify skull, sternum, scapula, femur and pelvic girdle into axial or appendicular skeleton. Compare the elbow's position with shoulder and wrist, and the tibia with the fibula.
2. Name the main plane and perpendicular axis for a simplified forward roll, cartwheel and upright spin. Explain why a single camera view can miss part of a throw.
3. Describe elbow flexion/extension, shoulder abduction/adduction and horizontal flexion/extension. Distinguish rotation from circumduction.
4. Explain pronation/supination, inversion/eversion, dorsiflexion/plantarflexion, protraction/retraction, elevation/depression and thumb opposition/reposition using anatomical reference.
5. Compare tendon, ligament, cartilage and fascia. Explain why muscle control matters even when a joint has intact passive supports.
6. Compare fibrous, cartilaginous and synovial joints. Name a hinge, pivot, ball-and-socket, condyloid, saddle and plane joint, linking each to a permitted movement.
7. Explain how a muscle can produce graded force despite the all-or-none principle. Compare types I, IIa and IIx and explain why a force-demand increase does not switch type I off.
8. Classify elbow-flexor activity while raising, holding and slowly lowering a dumbbell. Distinguish isokinetic from isometric action and explain antagonist involvement.
9. Identify the class when the order is effort–fulcrum–load; fulcrum–load–effort; and fulcrum–effort–load. Give an external implement example and explain why lever length has a trade-off.
10. A static lever has a 120 N load 0.30 m from the pivot and effort arm 0.045 m. Calculate load moment, required effort and mechanical advantage. Then add a 15 N segment weight acting at 0.12 m; recalculate effort. Assume all distances are perpendicular arms.
11. Momentum changes by 180 kg metres per second over 0.50 s and then over 1.00 s in two models. Calculate average net force magnitudes. Explain why this does not determine peak ground reaction or injury risk.
12. **AHL:** Invented hand lengths are 150, 160, 170, 180, 190, 200, 210 and 220 mm. Find the median and the fraction in an inclusive 170–200 mm grip-fit range. Explain why a control reach and a clearance opening need different design considerations.
13. **AHL:** A sarcomere shortens from 2.5 to 2.0 micrometres while its thick-filament span stays at 1.6 micrometres. Find percentage shortening and describe Z-disc separation, overlap, A band, I band and H zone.
14. **AHL:** Explain the roles of calcium, troponin, tropomyosin, actin, myosin and ATP in cross-bridge cycling and relaxation. Predict why ATP absence does not simply release every cross-bridge.

Worked answers

1. Skull and sternum are axial; scapula, femur and pelvic girdle are appendicular. Elbow is distal to shoulder and proximal to wrist. Tibia is medial to fibula in anatomical position. The reference comparison is part of a positional answer.
2. Forward roll: sagittal plane, mediolateral axis. Cartwheel: frontal plane, anteroposterior axis. Upright spin: transverse plane, longitudinal axis. A throw also involves out-of-plane components, which one projected view may hide or distort.
3. Elbow flexion decreases its angle and extension increases it. Shoulder abduction moves the arm away from the midline; adduction returns it. Horizontal flexion brings the raised arm across the chest; horizontal extension reverses this. Rotation turns about the segment's long axis; circumduction moves its distal end around a cone through combined actions.
4. Supination brings the palm forwards in anatomical position; pronation brings it backwards. Inversion turns the sole medially and eversion laterally. Dorsiflexion brings foot towards shin; plantarflexion points it away. Protraction/retraction bring the shoulder girdle forwards/backwards; elevation/depression move it up/down. Opposition brings thumb towards fingertips; reposition returns it.
5. Tendon transmits muscle tension to bone; ligament usually joins bones and limits excessive movement. Articular cartilage provides a smooth load-bearing surface; fascia surrounds and connects structures. Active muscles stabilize a joint under changing loads, so passive structures alone cannot control every movement.
6. Fibrous joints link bones with dense connective tissue; cartilaginous joints use cartilage; synovial joints have a lubricated cavity. Examples: elbow hinge, flex-

ion/extension; proximal radioulnar pivot, rotation; shoulder ball-and-socket, multi-axis; radiocarpal condyloid, two-axis; thumb-base saddle, movements supporting opposition; intercarpal plane, gliding. These categories simplify living movement.

7. Recruitment and firing rate grade whole-muscle force; all-or-none concerns electrical activation. Type I is relatively slow, oxidative and fatigue resistant; IIa is faster with mixed capacities; IIx is fast and powerful but fatigues sooner. Greater demand generally adds units, retaining earlier ones. All use ATP; oxidative metabolism is not exclusive to type I.
8. Raising: concentric; hold: isometric; controlled lowering: eccentric elbow-flexor activity. Isokinetic means constant angular velocity under suitable resistance. Reciprocal inhibition reduces antagonist activation, but co-contraction can stabilize joints; antagonists need not be completely inactive.
9. First-, second-, then third-class. A longer racket gives greater endpoint speed at fixed angular velocity but can require more accelerating torque. Force advantage depends on perpendicular moment arms, not class alone.
10. Load moment $120(0.30) = 36$ newton metres. Effort $36/0.045 = 800$ N. Mechanical advantage $0.045/0.30 = 0.15$. Added weight moment $15(0.12) = 1.8$ newton metres, so total is 37.8 and effort is $37.8/0.045 = 840$ N. The ideal static model neglects other forces and acceleration; the joint reaction must also balance forces.
11. $180/0.50 = 360$ N and $180/1.00 = 180$ N. The longer interval halves average net force for this fixed momentum change. A force-time curve is needed for peaks; weight and other forces distinguish net force from ground reaction. Injury has further anatomical and contextual causes; do not test it by provoking impacts.
12. **AHL:** Median $(180 + 190)/2 = 185$ mm. Four of eight measurements, 170, 180, 190 and 200 mm, lie in range: 50%. A reachable control must accommodate shorter reach; clearance must accommodate larger dimensions. Fit also depends on breadth, posture, gloves and user population; a median alone cannot justify a universal grip.
13. **AHL:** Fall $2.5 - 2.0 = 0.5$ micrometres; $0.5/2.5 \times 100 = 20\%$. Z discs approach and overlap increases while filament lengths and A-band length remain unchanged. I bands and the H zone narrow. The image supports a structural comparison, not every biochemical step.
14. **AHL:** Calcium binds troponin, moving tropomyosin to expose actin sites. Myosin attaches and power strokes slide actin. ATP binding releases the head; hydrolysis re-energizes it. ATP-powered calcium uptake helps restore inhibition. Without ATP, detachment and calcium restoration are impaired; relaxation is not automatic.

Exam tips and common mistakes

Name the joint, segment and phase; give positional reference structures and perpendicular plane/axis pairs. Active lengthening is eccentric. Tendon and ligament differ; antagonists can stabilize.

Mark fulcrum, effort, load and perpendicular arms. Include supplied segment weight and state static assumptions. Separate muscle force, net force, moment and momentum, with correct units.

- **AHL:** Equipment must fit its users and task. Filaments slide without shortening; calcium regulates binding, while ATP supports cycling, detachment and restoration. Use the supplied data, not memorized example values.

B.2 · Forces, motion and movement

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

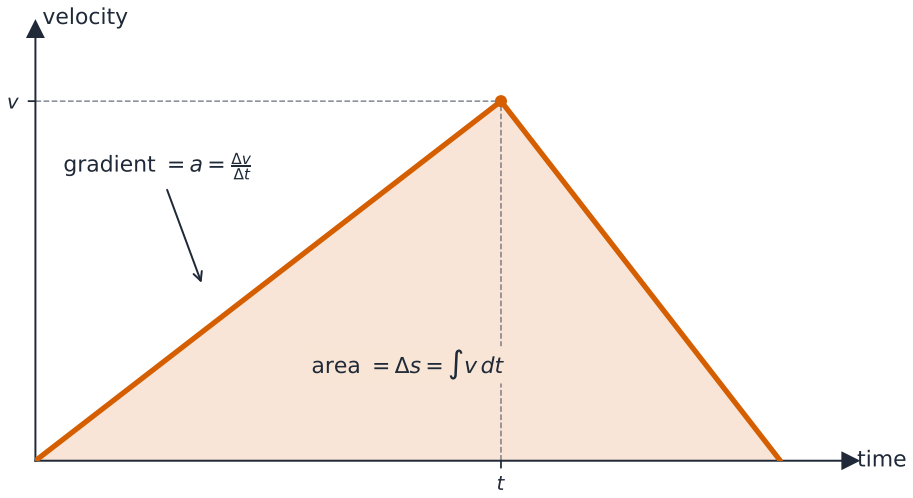
Scope and prerequisites

A player swings the racket after the ball has left it. Does that later movement add more impulse to the ball? A useful analysis separates the contact interval from what happens afterwards, chooses a positive direction and names the object whose motion is changing.

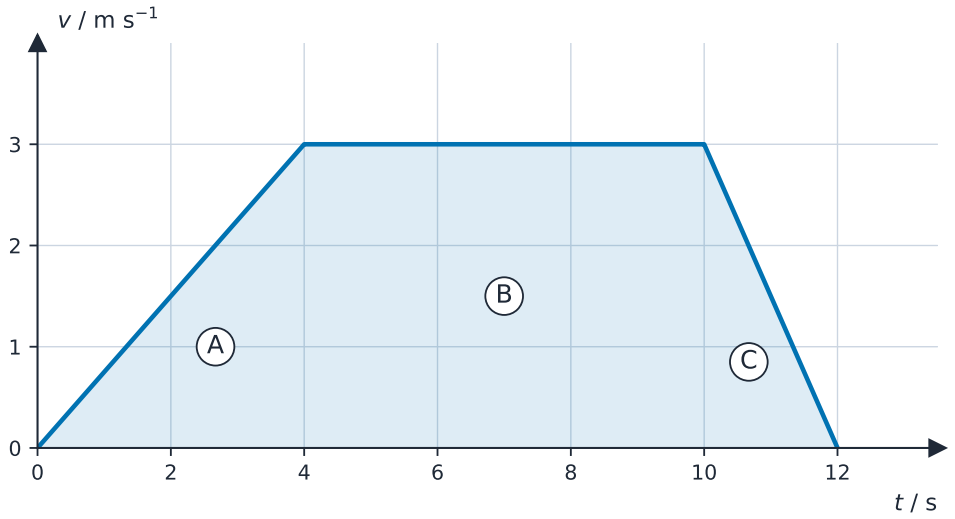
This handout covers B2: forces, motion and movement. Shared teaching includes Newton's laws, stability, coordinated movement, linear and angular motion, projectile paths and phases of movement analysis. Sections marked **AHL** are for Higher Level only. Prerequisites are the B1 descriptions of joints, muscle actions and levers, together with ratios, areas and units. All numerical datasets, force curves and schematic comparisons here are invented teaching examples. They are not observations from real athletes or examination papers. Trigonometric calculations are not required.

Describe motion before explaining its cause

Distance is the length of a path; displacement is the change in position with direction. Speed is distance per time; velocity is displacement per time, including direction. A runner completing a 400 m lap in 80 s has average speed 5 metres per second, but average velocity over the complete lap is zero because displacement is zero. Neither average tells you the runner's highest instantaneous speed.



Velocity–time graph – gradient gives acceleration, area gives displacement



Velocity–time graph of a lift: gradient gives each acceleration, the shaded area gives the distance

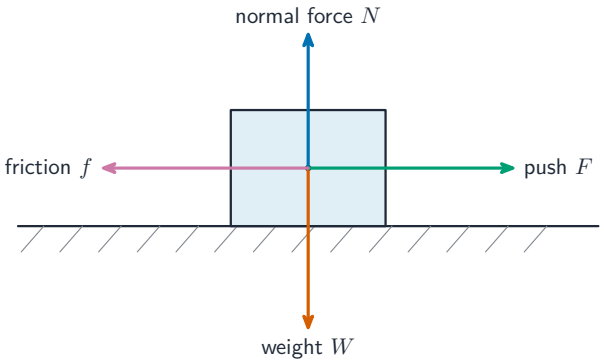
Acceleration is change in velocity per time. Choose a positive direction and use final minus initial velocity. A runner changing from +2 to +6 metres per second over 2 s has acceleration +2 metres per second squared. Slowing from +6 to +2 over 2 s gives −2. Negative acceleration is not always slowing: an object moving in the negative direction speeds up if its acceleration is also negative. Turning at constant speed also changes velocity and requires acceleration.

Angular displacement describes a change of orientation; angular velocity is its rate of change. A segment moving through 1.2 radians in 0.30 s has average angular velocity 4 radians per second. Endpoint linear speed also depends on distance from the rotation axis: at the same angular velocity, an endpoint farther from the axis moves faster. Thus two rackets can have the same angular velocity but different tip speeds. Do not compare degrees per second with radians per second without conversion.

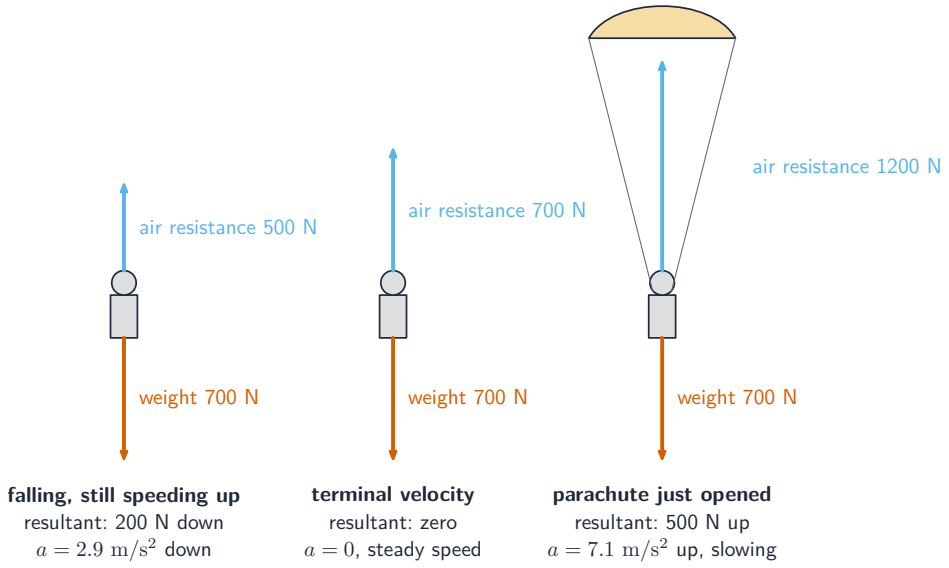
For video measurements, calibrate a length in the movement plane and know the frame rate. A displacement of 0.60 m over 15 frame intervals at 50 frames per second takes 15/50 = 0.30 s, giving average velocity 2.0 metres per second in the specified direction. There are 15 intervals between frames numbered 10 and 25, not 16. Apparent displacement from a skewed camera can be biased, and differentiating noisy positions to find acceleration magnifies measurement problems.

Newton's laws relate resultant forces to changes in motion

The first law says that velocity remains constant when resultant external force is zero. Zero resultant does not mean no forces act: weight and support can balance. An object moving at constant velocity does not require a forward resultant force simply to keep moving. In practice, a driving force may be needed to balance resistance.



A free-body diagram shows every force on the box as a labelled arrow



Arrows drawn to scale: the weight stays 700 N while the air resistance changes, so the resultant force changes

The second law relates resultant force to acceleration. For constant mass, $F_{\text{net}} = ma$. A 60 kg athlete accelerating horizontally at 2 metres per second squared has horizontal resultant 120 N. If resistance is 20 N backwards, the forward driving force must be 140 N in this simplified model. It is not legitimate to call 120 N the force of a particular muscle: several muscle, joint and contact forces contribute within and between linked segments.

Weight is gravitational force, $W = mg$; mass is not a force. At $g = 9.81$ metres per second squared, an 80 kg athlete has weight 784.8 N. A support force need not always equal weight: during upward acceleration it can be greater, and during downward acceleration it can be smaller. Draw forces on the chosen body, not a mixture of forces acting on different objects.

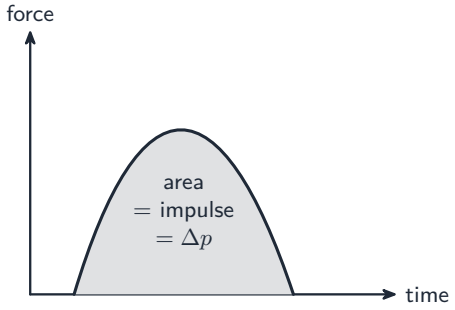
The third law concerns pairs of interaction forces on different bodies. A foot pushes the ground backwards and the ground pushes the foot forwards. These forces have equal magnitudes and opposite directions, but they do not cancel on a force diagram of the athlete because one acts on the ground. Balanced weight and ground support acting on a stationary athlete are also not a third-law pair: their interaction partners act on Earth and the supporting surface respectively.

Impulse needs a direction and a defined contact interval

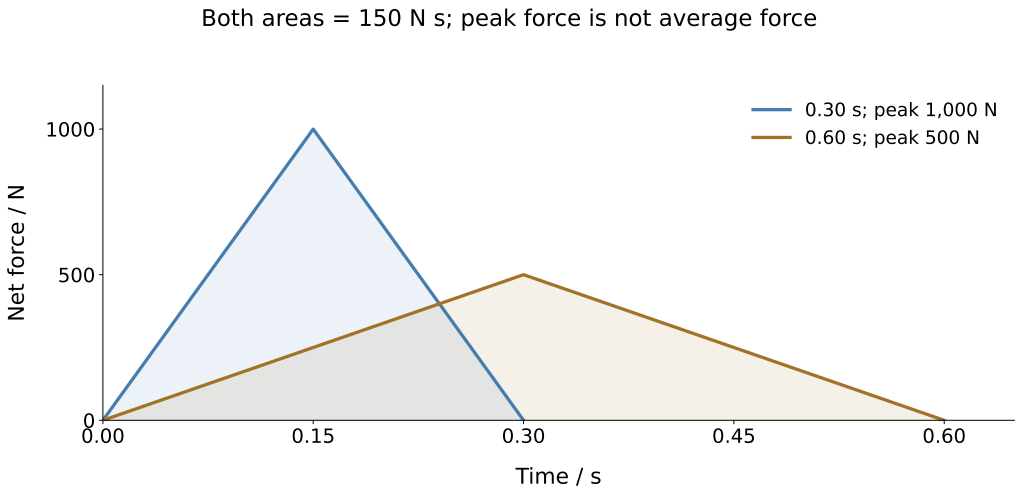
Linear momentum is mass multiplied by velocity. **Impulse** 冲量 is the integral of resultant force over time and equals momentum change. For an interval, average net force multiplied by interval duration gives the same impulse. On a force-time graph, signed area gives impulse; peak height alone does not.



A swimmer's start: the push against the block, held over a short contact time, sets the take-off velocity



Impulse is the area under a force-time graph, equal to the change in momentum



The triangular curves have areas 150 N s: half of 0.30 s times 1,000 N and half of 0.60 s times 500 N. Their peaks are twice their respective average forces.

For momentum change 150 kg metres per second, average net force magnitude is $150/0.30 = 500$ N over 0.30 s, or $150/0.60 = 250$ N over 0.60 s. These are average values, not the triangular graph's peaks. In general, doubling contact time for a fixed impulse halves average force, but it does not determine the new peak without the curve's shape.

Retain the sign through a ball calculation. An invented 0.058 kg ball slowing from +30 to +20 metres per second has momentum change $0.058(20 - 30) = -0.58$ kg metres per second. Over 0.005 s, average resultant is −116 N, opposite the chosen positive direction. Doubling the interval to 0.010 s for this same change gives −58 N. If it instead rebounds from +30 to −20, the change is $0.058(-20 - 30) = -2.90$ and average resultant over 0.005 s is −580 N. Reversal is not a speed change of only 10.

Separate contact from follow-through. Movement after racket–ball separation cannot continue applying a contact force to that ball. A coordinated follow-through can reflect a useful movement sequence and help decelerate body segments, but a later arm motion is not itself an additional ball impulse. Compare the actual contact force-time record before making claims about force or momentum transfer.

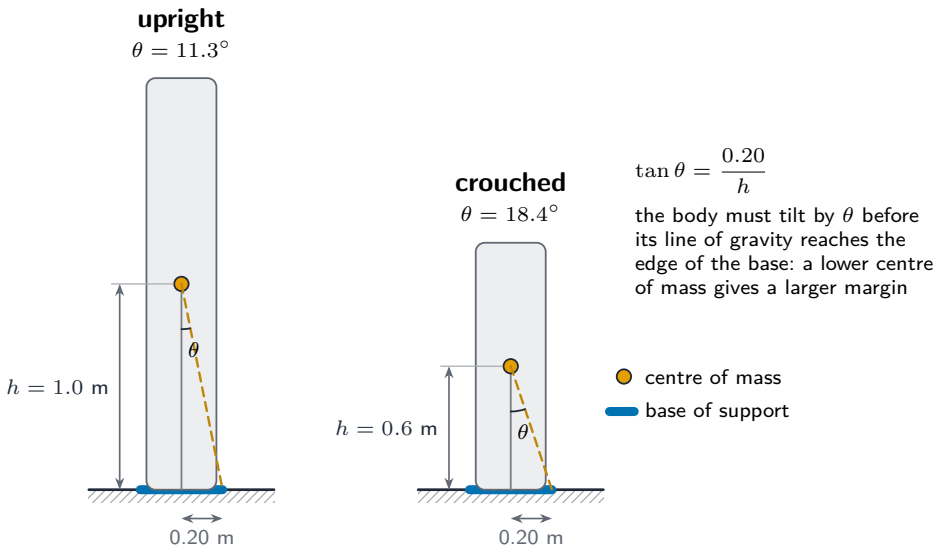
In an invented vertical take-off, an 80 kg athlete's upward momentum increases by 240 kg metres per second over 0.20 s. Average net upward force is 1,200 N. Average upward ground reaction in the simple weight-plus-support model is $1200 + 784.8 = 1984.8$ N. The 1,200 N resultant is not the total ground reaction. A 200 N average net force acting for 0.30 s gives 60 N s; a 100 N s change spread over 0.50 s gives 200 N. In every case define what other forces the "net" has already included.

Stability depends on geometry and the disturbance

The **centre of mass** 质心 is the mass-weighted mean position of a body. Its vertical projection gives the line of gravity on a level support. The **base of support** 支撑面 is the area enclosed by supporting contacts. A wider base and a lower centre of mass can increase the margin against toppling, but direction matters: widening the feet sideways helps resist some sideways disturbances more than a fore–aft push.



On a 10 cm beam every landing must bring the gymnast's centre of mass back over a tiny base of support



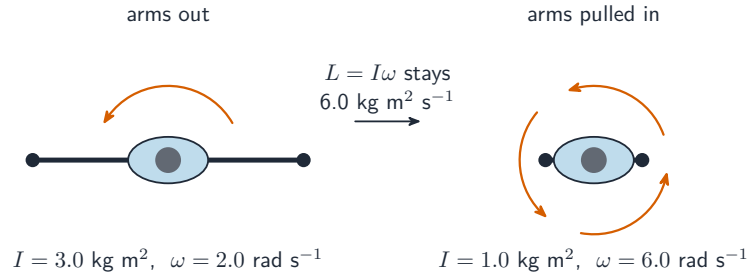
Both models have a half-base of 0.20 m. Tilting brings the line of gravity to the edge after a smaller angle in the taller model; this is a geometric comparison, not a measured fall prediction.

During static balance, the line of gravity normally lies within the base. Once it passes beyond an edge, weight can produce a toppling moment about that edge unless a step, external support or another action changes conditions. A moving runner can have the projection outside the current contact area and still maintain controlled dynamic motion through the next step; static rules are not a complete gait model.

Greater mass gives greater inertia, so the same horizontal force produces less acceleration. In a simple toppling model it can also increase a resisting weight moment. Mass alone does not guarantee stability, however: support geometry, friction, body position and the disturbance matter. Moving a centre of mass towards one edge may prepare a useful movement while reducing the margin in that direction. Coaches must balance stability with the need to move, rather than prescribing the widest possible stance for every action.

Coordinate joint actions and distinguish angular momentum from torque

Sequential actions of legs, trunk, shoulder, elbow and wrist can contribute to an implement's motion. Useful coordination depends on timing and task. "Summing joint forces" should not be treated as simply adding numerical muscle forces acting in different directions at different locations. Segment interactions, joint moments and the timing of energy transfer affect the endpoint velocity. A larger isolated muscle force does not by itself prove a faster or more accurate throw.



With no external torque, $L = I\omega$ is conserved: a smaller I means a larger ω

A **torque** 力矩 or moment is force multiplied by its perpendicular **lever arm** 力臂. A force whose line of action passes through the centre of mass can accelerate translation without a moment about that centre. An off-centre force can change both linear and angular motion. It is the perpendicular distance to the force's line of action, not simply the distance to the point where it touches, that determines the moment.

Angular momentum describes rotational motion and depends on both angular velocity and mass distribution. When net external torque about the chosen axis is negligible, angular momentum is conserved. An airborne athlete can rotate faster by bringing mass closer to the rotation axis, reducing moment of inertia; this does not create extra angular momentum. With invented $I = 0.80$ kg square metres and angular velocity 4 radians per second, $L = I\omega = 3.2$ kg square metres per second. At $I = 0.40$, the same angular momentum gives angular velocity 8 radians per second.

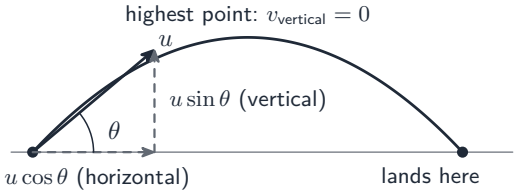
The condition is negligible external torque, not the absence of every external force. Gravity still acts during flight, but its resultant through the centre of mass has no moment about that centre in the simplified model. Air resistance and contact forces can provide external moments; angular momentum need not remain constant during take-off or landing. An athlete's shape change can alter rotation rate in flight but cannot replace the external interactions that established the initial angular momentum.

Projectile paths depend on release and fluid forces

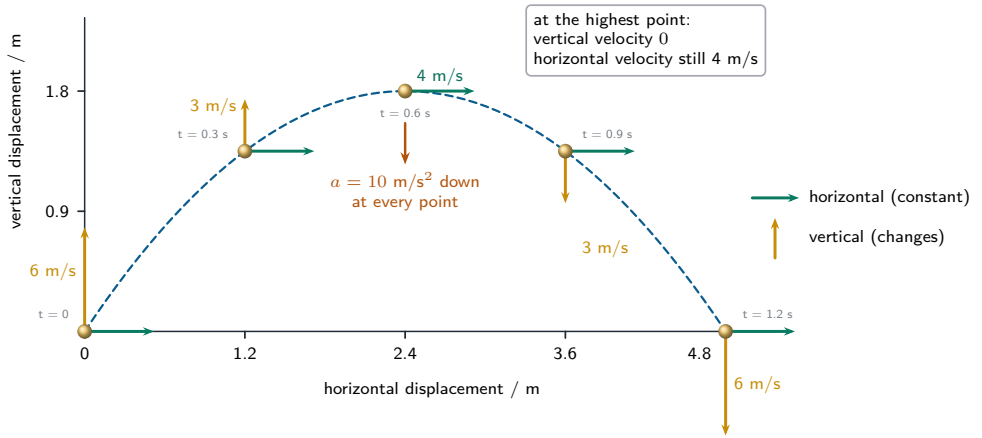
A projectile is a body moving after release; the hand or racket no longer supplies its contact force. Release speed, direction and height relative to the target help determine the path. Separate horizontal and vertical motion. In a simple no-drag model, horizontal velocity is constant and vertical acceleration is downwards. The vertical velocity is zero at the highest point, but acceleration there is still gravitational, and horizontal velocity need not be zero.



A free throw: release speed, angle and height decide the ball's path to the hoop



A projectile's launch velocity resolved into horizontal and vertical parts; at the highest point the vertical velocity is zero (reused from a_level_physics 2.1, byte copy)



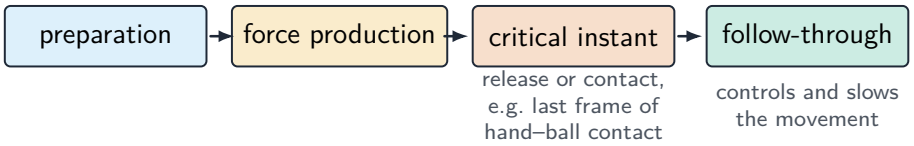
Invented model: horizontal component 4 m/s, vertical component 6 m/s and downward acceleration 10 m/s^2. Equal launch and landing heights give flight time 1.2 s and range 4.8 m.

In this model, upward velocity falls from 6 to 0 in 0.60 s, and the object returns to release height at 1.20 s. Horizontal travel is $4(1.20) = 4.8$ m. Maximum rise is 1.8 m from the model's trajectory; students need not resolve a launch velocity using trigonometry here. A higher release above a lower target generally changes flight time and the useful release direction; a 45-degree angle is not a universal optimum for every sporting task.

Air resistance can make the path asymmetric and reduce horizontal speed. A light object with a large area relative to its weight is often affected more strongly by drag than a dense compact object, under otherwise comparable conditions. A shuttlecock's rapid deceleration and a heavy compact shot's path are not well described by one identical no-drag trajectory. Spin can also produce forces that change the path. State which forces and model conditions a diagram includes before transferring its numbers to a real sport.

Movement phases turn an observation into a focused question

A discrete skill such as a throw has preparation, force production, a critical instant and follow-through. Preparation positions the body and implement; force production develops the motion towards the important event. The critical instant may be release or contact, depending on the task. Follow-through controls or decelerates subsequent movement. For continuous skills, recovery returns the body or implement into position for the next cycle.



Define each phase, and the critical instant, so observers agree

The critical instant is not the whole force-production phase. Define it operationally, for example the last frame showing hand–ball contact, so observers identify it consistently. For a swimming stroke, define propulsion and recovery boundaries rather than comparing arbitrary frames. Interpret timings alongside stroke rate, distance and phase definitions.

Analysis can identify a limited range, mistimed sequence or accessibility obstacle. An invented comparison in which moving a target closer reduces required reach supports evaluating that adjustment, not diagnosing an impairment. Match camera geometry, task and measurement methods. Use supplied records or consented low-risk activities; rehabilitation needs qualified assessment. Class work need not provoke impacts or disclose medical records.

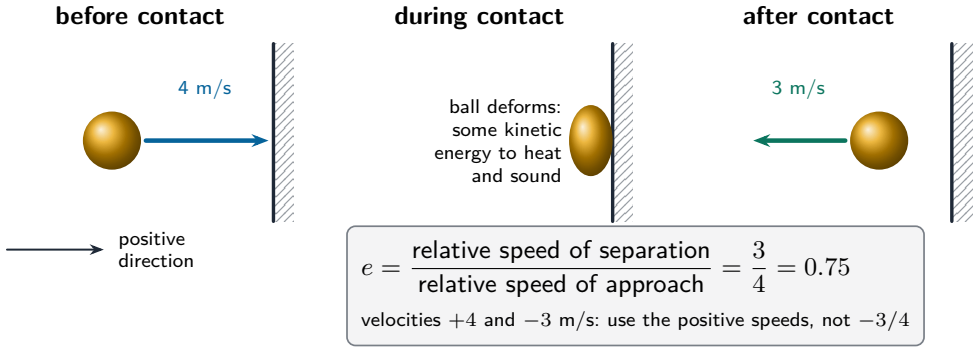
AHL: Collisions require relative speeds and system boundaries

During a short collision, interaction forces exchange momentum between bodies. Total linear momentum is conserved for a chosen system when external impulse is negligible; an individual ball's momentum is not conserved merely because the collision is short. Kinetic energy may decrease as energy transfers to deformation, thermal stores and sound. Total energy is still conserved.



A rugby tackle is a collision: what happens depends on the players' relative speed and where the system boundary is drawn

The coefficient of restitution compares relative separation speed with relative approach speed along the collision direction. For one-dimensional motion, label bodies and directions before subtracting velocities. Against an effectively fixed surface, a ball approaching at speed 4 and rebounding at speed 3 metres per second has $e = 3/4 = 0.75$. Using signed rebound velocity directly as a negative speed would give the wrong interpretation.



For the fixed-surface model, approach speed 4 m/s and separation speed 3 m/s give e = 0.75. The rebound direction is opposite; both quantities in the speed ratio are positive.

For an ideal ordinary passive collision, $e = 1$ represents elastic relative motion and $e = 0$ means zero relative separation speed immediately afterwards. Values between these describe different losses of relative kinetic energy; exceptional energy-releasing systems need additional explanation. An e value is not the percentage of total energy retained in every collision. In a fixed-surface bounce, retained translational kinetic-energy fraction is $e^2 = 0.5625$, or 56.25%, for the same mass. Temperature, material, impact speed, surface and ball construction can affect the measured coefficient.

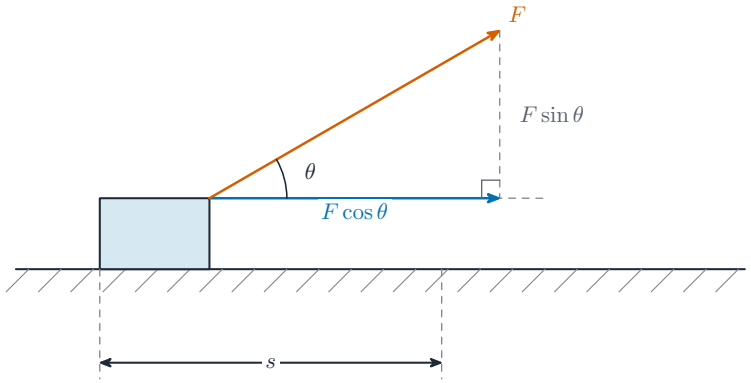
For two invented equal 0.20 kg masses, initial velocities +4 and 0 and $e = 0.50$ imply $v_1 + v_2 = 4$ from momentum conservation and $v_2 - v_1 = 2$ from restitution. Thus $v_1 = 1$ and $v_2 = 3$ metres per second. Initial kinetic energy is 1.6 J and final is $0.5(0.20)(1^2 + 3^2) = 1.0$ J, so 0.6 J, or 37.5%, has left translational kinetic energy. This differs from treating the second body as an immovable wall.

AHL: Friction, work and power describe different quantities

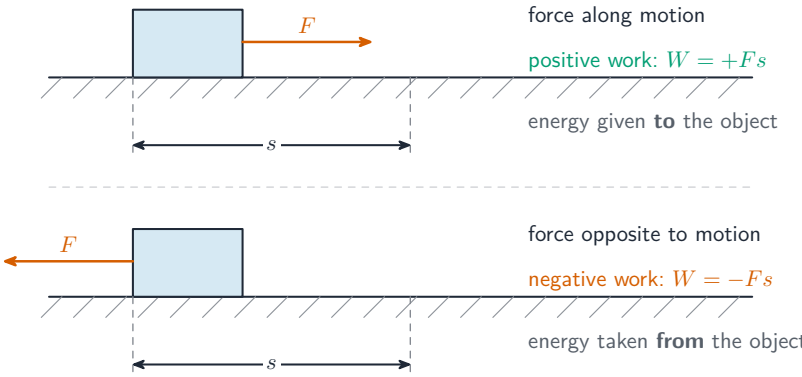
Friction acts to oppose relative sliding or its tendency at a contact. Static friction adjusts to the needed value up to a limiting value, commonly modelled as $F_{s,\max} = \mu_s N$. It is not always equal to that maximum. Sliding friction can be approximated by $F_k = \mu_k N$. The normal reaction N is perpendicular to the surface and is not always equal to weight. Coefficients depend on the materials and conditions; a single value is not a property of a shoe regardless of its surface.



A pole vaulter: kinetic energy from the run-up is stored in the bent pole, then given back as height



Only the component of the force along the displacement ($F\cos\theta$) does work



Positive work ($W = +Fs$): force along the motion (top). Negative work ($W = -Fs$): force opposite to the motion, e.g. friction (bottom)

With invented $N = 500$ N and $\mu_s = 0.60$, the limiting static friction is 300 N. A 100 N horizontal push on an otherwise stationary object is balanced by 100 N static friction, not 300 N. If sliding friction is modelled with $\mu_k = 0.40$, its magnitude is 200 N. Appropriate traction can permit acceleration or braking, while excessive grip in some turning situations can create unwanted loading. Surface preparation, tread, studs and conditions affect both performance and injury considerations; more friction is not universally better.

Work is energy transferred by a force through displacement in that force's direction. For a constant parallel force, $W = Fd$. A force opposite the displacement does negative work on the chosen body. An upward force of 300 N moving a load upward through 0.40 m does 120 J; doing it over 0.50 s gives average mechanical power $120/0.50 = 240$ W. Power is work per time, not simply a large force. The same work completed faster has greater average power.

An isometric muscle action can consume metabolic energy while doing no external mechanical work on a stationary held load. Mechanical power output and metabolic energy-use rate are different. Equipment and technique can improve useful energy transfer, reduce unwanted motion or change the force–velocity conditions; they cannot create energy. A 200 N sliding-friction force acting against travel over 2 m does −400 J on the moving object in the simple constant-force model.

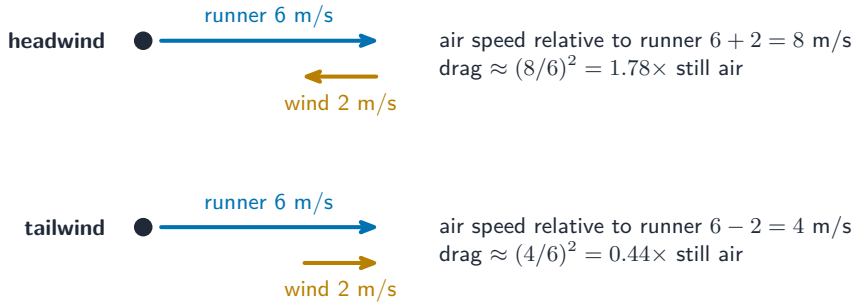
AHL: Environmental conditions alter forces in fluids

Air and water are fluids. Temperature, pressure, altitude, humidity and wind can affect air density or relative flow; temperature and salinity can affect water density and other properties. At comparable pressure, warmer air is generally less dense; higher altitude commonly means lower air pressure and density. Humid air is less dense than dry air at the same temperature and pressure because water-vapour molecules replace some heavier molecules. These statements hold other conditions fixed; do not assume every

warm or humid sporting setting has one predictable total effect.



Riders in a peloton shelter behind one another: drafting cuts the air resistance on each rider



Drag depends on air speed relative to the athlete, roughly as its square

Wind changes velocity relative to air, which matters for aerodynamic forces. A runner moving at 6 metres per second into a 2 metre per second headwind has relative air speed 8; with the same tailwind it is 4, assuming a simple collinear model. A stationary object can experience wind force despite zero ground speed. If drag is proportional to relative speed squared with other factors fixed, the headwind model's drag is $(8/6)^2 \approx 1.78$ times the no-wind value; tailwind gives $(4/6)^2 \approx 0.44$. This does not predict the exact change in running time or metabolic cost.

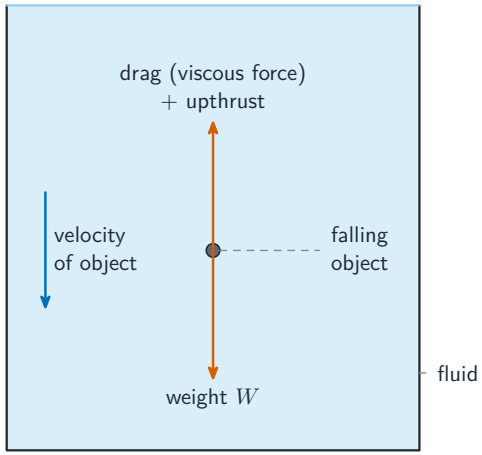
Buoyancy is the upward resultant from fluid pressure differences and equals the weight of displaced fluid: $F_b = \rho V g$. Use submerged displaced volume, not automatically total body volume. An invented displaced volume 0.060 cubic metres in water of density 1000 kg per cubic metre gives $F_b = 1000(0.060)(9.81) = 588.6$ N. This balances the weight of a 60 kg body under the stated conditions; a 65 kg body of the same submerged volume has a downward weight–buoyancy resultant of $637.65 - 588.6 = 49.05$ N before considering other forces. Denser saline water produces more buoyancy for the same displaced volume.

AHL: Lift and drag depend on flow, shape and motion

Drag acts against relative motion through the fluid. Surface or skin-friction drag relates to shear at the surface; form drag relates to pressure differences and flow separation; wave drag relates to wave generation near a water surface. A swimmer's alignment, exposed area, suit surface and depth can alter different contributions. Reducing frontal area does not necessarily remove every source of resistance. In a simplified comparison with unchanged shape and fluid properties, doubling relative speed can quadruple drag; a change from 6 N to 24 N illustrates that model, not a universal exact law at every speed.



A ski jumper's V-shaped skis and forward lean turn the body into a wing, trading drag for lift



Forces on a falling object in a fluid

Lift is a fluid-force component perpendicular to the relative flow; it need not point vertically upwards. Its magnitude and direction depend on shape, orientation, flow and conditions. Angle of attack describes the orientation relative to incoming flow. Increasing it does not always increase useful lift: separation and stall can reduce lift and increase drag. Bernoulli's principle relates pressure and speed along suitable streamlines in an idealized flow; a lower-pressure/higher-speed relation is not proof that particles on opposite sides must reunite at the same time. Real lift also involves momentum change and viscous effects.

A spinning ball can experience the Magnus effect: rotation changes the surrounding flow and pressure, producing a force transverse to relative flow and spin axis. In a conventional ball moving right through still air, topspin commonly produces a downward contribution and backspin an upward one. Side spin can curve the path sideways. The actual force depends on speed, spin, surface and flow regime; "any spinning ball must curve by the same amount" is false. A projectile's trajectory then differs from the gravity-only model.

Fluid-related design has sporting, ethical and regulatory consequences. Equipment that lowers drag or changes buoyancy can affect comparisons between competitors, cost and access. Evaluate the measured benefit, conditions, safety, accessibility and the applicable competition rules; do not infer legality from a performance improvement. Rules can change, so an imagined classroom design is not a claim that a named product is currently permitted.

Practice

1. A runner completes a 300 m lap in 60 s. Find average speed and average velocity. Explain why neither is the maximum instantaneous speed.
2. Velocity changes from +1 to +7 metres per second over 3 s. Calculate acceleration. A different object goes from −1 to −7 over the same time: find acceleration and say whether it speeds up.
3. At 40 frames per second, positions at frames 12 and 20 differ by +0.50 m. Find elapsed time and average velocity; give two measurement limitations.
4. A 50 kg athlete has horizontal acceleration 1.5 metres per second squared against 15 N resistance. Find net force and the model's forward driving force. Explain why neither is the force of one muscle.
5. Explain a foot–ground third-law pair and distinguish it from balanced weight and support on a stationary athlete.
6. A triangular net force-time pulse lasts 0.40 s with peak 600 N. Find impulse and average net force. Compare with a 0.80 s triangular pulse giving the same impulse.
7. A 0.050 kg ball changes velocity from +24 to −16 metres per second over 0.008 s. Find momentum change and average resultant. Explain why a later follow-through cannot add ball impulse after separation.
8. An athlete of mass 60 kg gains upward momentum 120 kg metres per second over 0.25 s. Find average net upward force and average upward ground reaction using $g = 9.81$ and a weight-plus-support model.
9. Explain how base width, centre-of-mass height, line of gravity and mass affect stability. Distinguish a static toppling model from running balance.
10. An airborne model has moment of inertia 0.60 kg square metres and angular velocity 5 radians per second, with negligible external torque. Find angular momentum and the new angular velocity at moment of inertia 0.30. Explain why gravity can still act.
11. A no-drag equal-height projectile has supplied horizontal speed 5 metres per second and flight time 0.80 s. Find range. Explain the velocity and acceleration at the apex, and define preparation, force production, critical instant and follow-through for a throw.
12. **AHL:** A fixed-surface bounce has approach speed 5 and rebound speed 4 metres per second. Find restitution and retained translational kinetic-energy percentage. Then solve equal-mass motion with initial velocities +6 and 0 and $e = 0.50$, assuming negligible external impulse.
13. **AHL:** At normal force 400 N and static coefficient 0.50, find limiting friction and actual friction balancing an 80 N push. Sliding coefficient is 0.30: find sliding friction and its work over 3 m. Separately, a constant parallel 250 N force moves a load 0.60 m in 0.75 s: find work and average power.
14. **AHL:** A body displaces 0.050 cubic metres of water at density 1000 kg per cubic metre. Find buoyancy at $g = 9.81$. Explain how salinity can affect it. A collinear

athlete speed is 8 metres per second with headwind 2: find relative air speed and drag ratio to still air under a squared-speed model. Compare lift, Magnus force and three forms of drag; give one equipment-evaluation limitation.

Worked answers

1. Average speed $300/60 = 5$ metres per second; lap displacement and average velocity are zero. Instantaneous speed can vary; the averages do not locate its maximum.
2. $(7 - 1)/3 = +2$ metres per second squared; $(-7 - (-1))/3 = -2$. The second object speeds up because velocity and acceleration both point negatively.
3. Eight intervals: $8/40 = 0.20$ s; velocity $0.50/0.20 = +2.5$ metres per second. Perspective, scale-plane mismatch, uncertain landmarks and event-frame identification affect measurements.
4. Net $50(1.5) = 75$ N forward; driving force $75+15 = 90$ N. Whole-body acceleration does not determine individual internal muscle forces.
5. Foot-on-ground and ground-on-foot are equal opposite interactions on different bodies. Weight and support both act on the athlete; their partners act on other bodies. They can balance without being each other's third-law partners.
6. Area $0.5(0.40)(600) = 120$ N s; average $120/0.40 = 300$ N. At 0.80 s, average is 150 N and a triangular pulse's peak is 300 N. Equal impulse does not require equal peak or duration.
7. $\Delta p = 0.050(-16 - 24) = -2.0$ kg metres per second; average resultant $-2.0/0.008 = -250$ N. Subtract signed velocities. After separation, racket contact force ceases.
8. Net upward average $120/0.25 = 480$ N; weight $60(9.81) = 588.6$ N; upward ground reaction $480 + 588.6 = 1068.6$ N. Assume other vertical forces are negligible.
9. Wider base in the disturbance direction and lower centre of mass can increase the toppling margin. Gravity's line relative to an edge determines its moment; mass affects inertia and weight moments. Friction and task matter. Running involves changing contacts and dynamic control.
10. $L = 0.60(5) = 3.0$ kg square metres per second; $\omega = 3.0/0.30 = 10$ radians per second. Gravity through the centre of mass has no moment about it. Conserved angular momentum needs negligible external torque, not zero force or constant angular velocity.
11. Range $5(0.80) = 4.0$ m. At the apex, vertical velocity is zero; horizontal velocity remains 5 and gravitational acceleration remains downwards. Preparation sets position; force production develops motion; release is the chosen critical instant; follow-through controls subsequent movement. Continuous skills use recovery for the next cycle.
12. **AHL:** $e = 4/5 = 0.80$; fixed-surface kinetic-energy fraction $e^2 = 0.64$, or 64%. For equal masses, momentum gives $v_1 + v_2 = 6$ and restitution gives $v_2 - v_1 = 3$. Therefore $v_1 = 1.5$ and $v_2 = 4.5$ metres per second. A moving second body cannot be treated as a fixed wall; state the system and external-impulse assumption.
13. **AHL:** Limit $0.50(400) = 200$ N; actual static friction balancing the push is 80 N. Sliding friction $0.30(400) = 120$ N; its work is $-120(3) = -360$ J. The separate applied-force work is $250(0.60) = 150$ J and average power $150/0.75 = 200$ W. Neither friction coefficient nor power is the total metabolic energy cost.
14. **AHL:** $F_b = 1000(0.050)(9.81) = 490.5$ N. Greater density at the same displaced volume increases buoyancy. Relative air speed $8 + 2 = 10$; drag ratio $(10/8)^2 = 1.5625$. Lift is perpendicular to flow; Magnus force arises from spin-altered flow. Surface drag concerns shear, form drag pressure/separation, wave drag surface waves. Equipment comparisons need matched conditions, user fit and applicable rules; improved performance alone does not establish legality or universal benefit.

Exam tips and common mistakes

Use signed changes and frame intervals. Distinguish average/peak force, net/ground reaction and interaction pairs/balanced forces. Angular-momentum conservation needs negligible external torque. Gravity remains at an apex; a racket cannot push a separated ball.

- **AHL:** Restitution uses relative speeds; static friction need not equal its maximum. Separate work, power and metabolic cost. Use displaced submerged volume for buoyancy and air-relative speed for aerodynamic comparisons. A named fluid principle needs its assumptions and does not automatically prove an equipment claim.

B.3 · Injury

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

A club records fewer injuries after changing its warm-up. Did the warm-up work, or did the club also play fewer matches? Injury prevention requires both a plausible explanation and a fair comparison of evidence. Counts, exposure, severity and reporting can point to different conclusions.

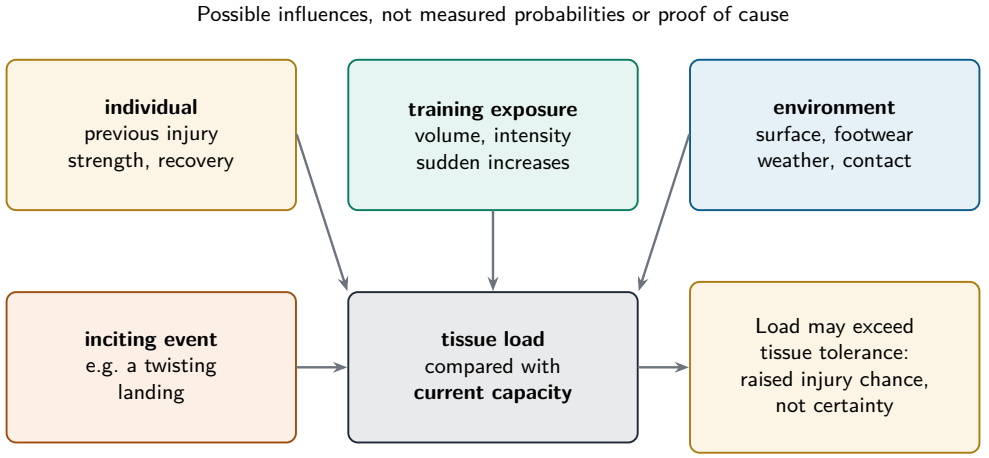
This handout covers B3: injury, including interacting risk factors, acute and cumulative trauma, prevention, treatment principles and staged concussion recovery. Sections marked **AHL** are for Higher Level only. Prerequisites are B1 tissue and joint functions, B2 forces and movement phases, and rates and percentages. All datasets and scenarios are original invented teaching examples, not real athlete records or examination papers. Use them for scientific reasoning; students do not induce injuries, diagnose classmates or decide return-to-play clearance.

Risk factors interact rather than identify one inevitable cause

A risk factor is a characteristic or exposure associated with a greater chance of an outcome in specified circumstances. A mechanism describes how an injury occurs, such as a sudden twisting load that exceeds tissue tolerance. A risk factor is not itself a diagnosis, and an observed association is not automatically a causal mechanism.

Internal factors concern the individual. Age, development, physiological sex-related differences, pregnancy, congenital characteristics, previous injury and the effects of training can change the demands or capacities relevant to a task. Their effects depend on the sport, movement, environment and person. A demographic category does not establish an individual's ability or justify assuming every member has the same risk. Previous injury may leave strength, range or control deficits; it may also be a marker of the activities and exposures that caused the earlier injury.

External factors include equipment, playing surface, weather, rules, contact with other participants and how activity is organized. Footwear that suits one surface may provide unsuitable traction on another. Protective equipment can reduce particular consequences of a collision without removing every injury mechanism. A training programme is an external exposure that interacts with the individual's current capacity and recovery.



The arrows represent possible influences, not measured probabilities or proof that one factor alone causes injury.

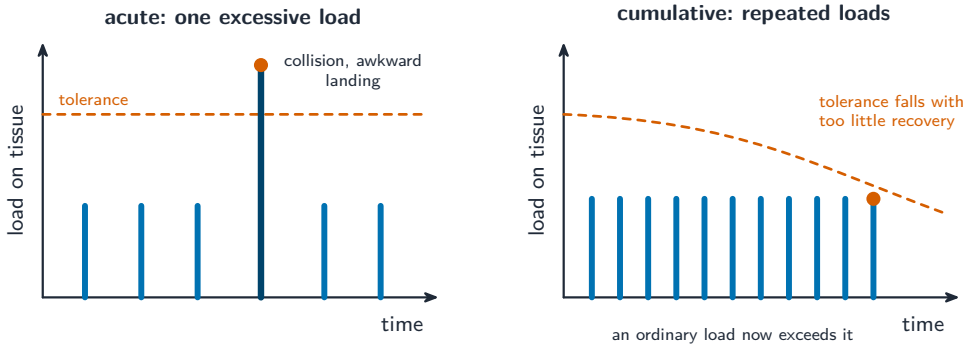
For an invented runner returning after an ankle injury, reduced strength or control, a sudden increase in running volume and an uneven surface may combine. It would be weak reasoning to attribute every later symptom only to the surface because the surface was visible in a video. Compare alternative explanations and the sequence of events. Training can improve capacity, but poorly matched loading and recovery can increase problems; "all training prevents injury" and "all training damages tissue" are both incomplete.

Acute and cumulative trauma describe loading histories

Acute trauma follows a sudden event, excessive force or unexpected force direction. A collision, an awkward landing or a rapid change of direction may impose a load that the involved tissues cannot tolerate. Cumulative trauma involves repeated loading whose combined effects exceed recovery and adaptation. An **overuse injury** 过度使用损伤 can develop without one dramatic accident. Symptoms may appear suddenly even when the preceding loading history was cumulative.



A stress fracture of the tibia on X-ray: repeated loading, not one big impact, cracked the bone



Acute injury: one load exceeds tolerance. Cumulative injury: tolerance falls until an ordinary load exceeds it

Both mechanisms can affect different tissues. A ligament sprain concerns a ligament; a muscle or tendon strain concerns those tissues. A tendon can be affected by repeated loading, and a major tendon tear can also follow an acute event. Bone injuries include acute fractures and bone stress injuries associated with repeated loading. Skin can suffer cuts, abrasions or repeated friction damage. Muscle damage can involve overstretching, a direct blow or repeated demands. Tissue type and mechanism are separate classifications; "acute" does not mean only bone and "overuse" does not mean only muscle.

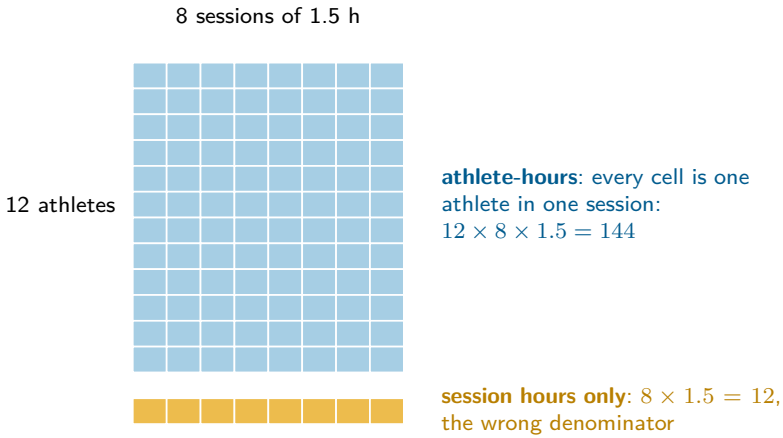
Fascia, cartilage and other connective tissues also transmit or distribute loads, so their structure and function affect the consequences of a movement. The same external force can produce different internal tissue stresses depending on geometry, contact area, joint position and tissue capacity. A net whole-body force from B2 is not a direct measurement of the force in one ligament.

For the brain, concussion involves a disturbance of function following transmitted mechanical forces. A blow or jolt to the body can transmit force to the head; a direct head impact is not required in every case. Symptoms can include headache, dizziness, balance difficulty, slowed thinking or changes in behaviour. Loss of consciousness is not required. Structural and functional injury are not identical categories: a routine scan can be normal despite concussion, while concerning signs may require urgent investigation for other or additional injury. This unit focuses on functional concussion-like injury rather than detailed structural neuropathology.

Surveillance needs a case definition and an exposure denominator

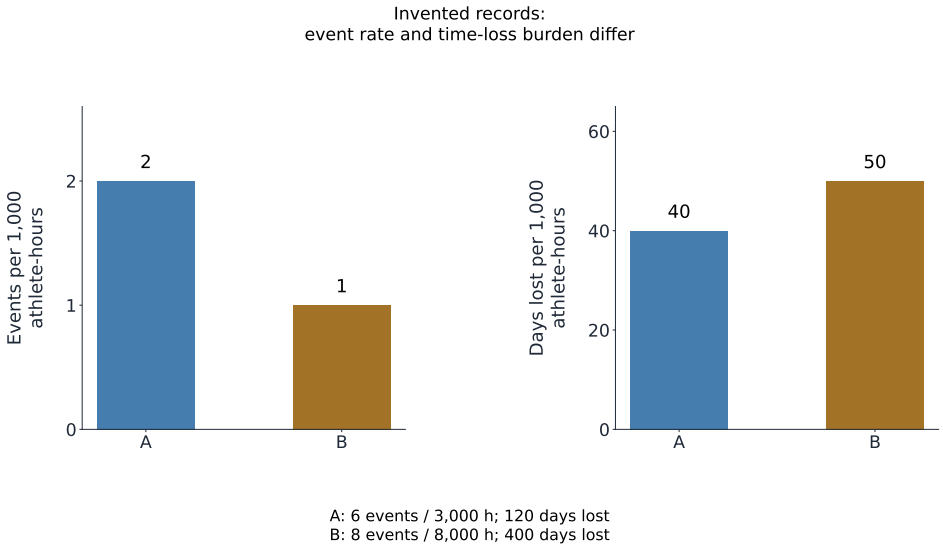
An **incidence rate** 发生率 counts new events relative to a stated exposure. An injury-surveillance record should define what counts as an injury, when it occurred, its tissue/location and mechanism where known, exposure and relevant consequences. An "any physical complaint" definition can produce a different count from a "missed training" definition. Keep the definition constant before interpreting a trend.

An athlete-hour is one participant exposed for one hour. Twelve participants each completing eight 1.5-hour sessions contribute $12(8)(1.5) = 144$ athlete-hours, assuming full participation. Counting only the session duration gives the wrong denominator. Record actual participation if athletes miss part of a session, and distinguish training from match exposure where their risks differ.



The denominator counts every athlete in every session: 144 athlete-hours, not 12

In the original invented comparison, group A records 6 injuries over 3,000 athlete-hours: $6/3000 \times 1000 = 2$ per 1,000 athlete-hours. Group B records 8 over 8,000 hours: rate 1 per 1,000. B has more events but a lower recorded rate. A further group with 9 events over 4,500 hours has rate 2. These are rates of recorded events, not percentages of all athletes or predictions that exactly two people will be injured in the next 1,000 hours.



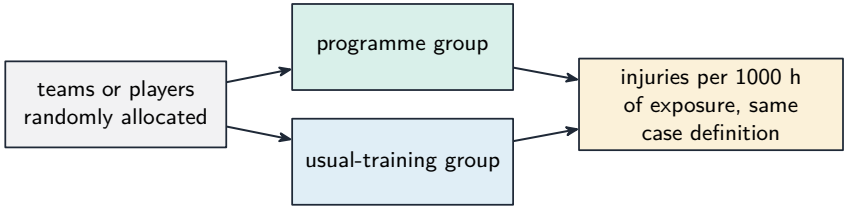
Invented records: A has 6 events/3,000 hours and 120 days lost; B has 8 events/8,000 hours and 400 days lost. B has the lower event rate but greater days-lost burden per 1,000 hours.

Severity and recurrence matter alongside frequency. If A's injuries produce 120 total days lost, burden is $120/3000 \times 1000 = 40$ days per 1,000 athlete-hours. B's 400 days give 50 per 1,000. A lower event rate can therefore coexist with greater time-loss burden. State whether time loss refers to training, competition or both and how overlapping absences are counted. A recurrent injury and continuation or aggravation of an unresolved injury also need consistent definitions.

Three events over 1,000 hours give rate 3; four over 2,000 hours give rate 2. The first group has the higher recorded rate despite fewer events. Small numbers, under-reporting, incomplete exposure and differences in participants or activity limit the comparison. Do not label every individual in the first group "riskier" from a group-level estimate.

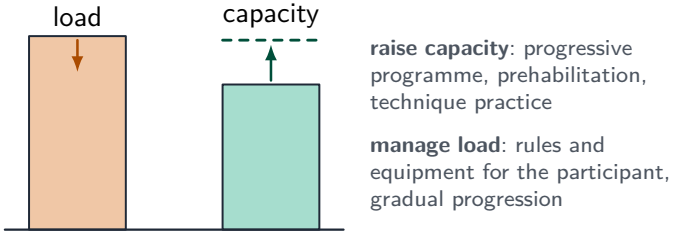
Evaluate prevention as a testable, specific intervention

A prevention explanation should connect an intervention to a load, capacity or consequence. A progressive programme can build strength, balance and control appropriate to a task. A warm-up can prepare movement and physiological responses, but it is not proof that every injury is preventable. Prehabilitation aims to develop relevant capacity and address vulnerabilities before an injury. Its content should follow the task and the individual rather than a universal routine copied from another sport.



compare rates, not raw counts; check how many actually did the programme

Testing prevention fairly



Prevention either raises capacity or manages load

Flexibility training can increase useful range for particular activities; excessive range without control is not a universal goal. Learn and practise a suitable technique and progress demands appropriately. Developmentally appropriate rules, equipment and activity reduce mismatches between participant capacity and task demands. Rules that limit dangerous contact address a different mechanism from a balance exercise: both can be relevant without being interchangeable.

Protective equipment should fit the user and the sport, be maintained and meet appropriate standards. Its padding may spread an impact over time or area; its structure may protect a vulnerable region. Anthropometry helps match dimensions and adjustment ranges. A helmet can reduce particular serious head-injury risks, but no helmet is concussion-proof, as the CDC helmet guidance explains. Equipment does not replace safe rules, coaching and recognition of injury.

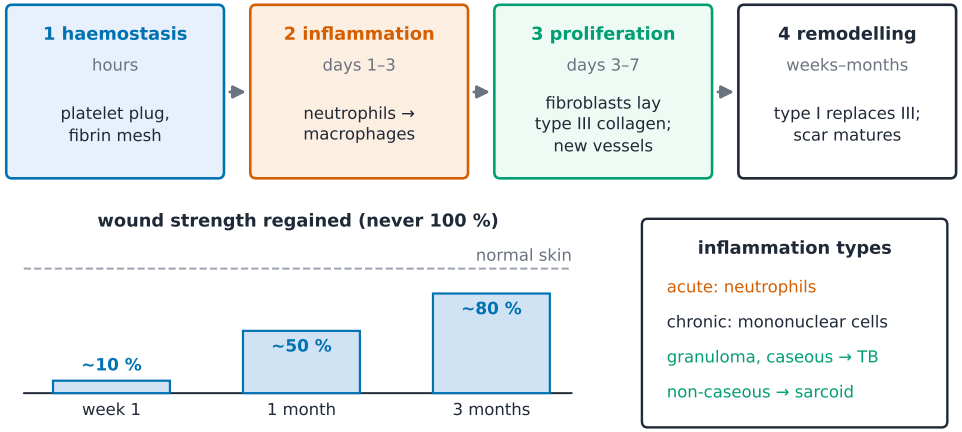
Surface and footwear should be considered together. Greater traction can support

acceleration but can also change joint loading during turns; simply maximizing friction is not a complete safety policy. Weather, visibility, space, fatigue, communication and accessible facilities affect the setting in which a technique is performed. Explain which risk a proposal addresses and what evidence would show that it helped.

A before/after comparison needs comparable exposure, participants, task, recording and time of season. Improved reporting can make recorded injury rates rise even if care and prevention improve. Where appropriate, compare groups receiving a defined intervention with comparable controls, allocate at the appropriate level, and report adherence and missing data. A large relative change based on a few events remains uncertain. A null or mixed result should lead to evaluating the intervention and measurement, not concealing unwanted records.

Treatment balances protection, healing and restoration of function

Inflammation is part of the response to tissue damage. Changes in blood flow, vascular permeability and immune activity help organize defence, removal of damaged material and repair. Swelling, heat and pain can accompany it, but inflammation is not simply a useless error to eliminate at any cost. Treatment may aim to reduce excessive symptoms while protecting the tissue and supporting repair.



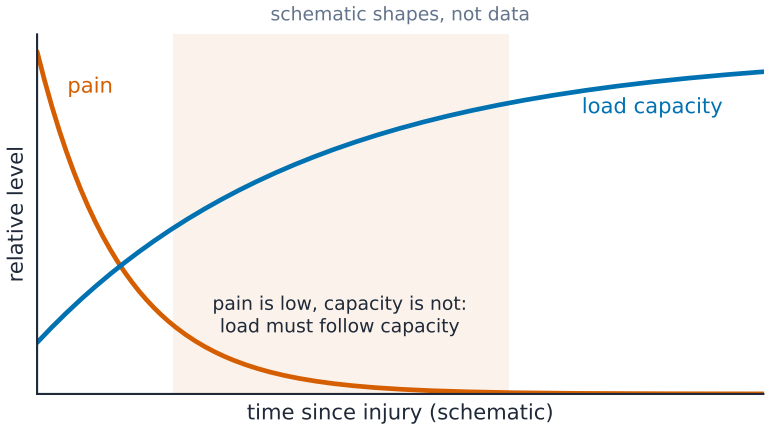
Tissue heals in overlapping phases over weeks to months, and strength returns only gradually, so loading has to follow the phase

The syllabus names compression, elevation, ice and non-steroidal anti-inflammatory drugs, or NSAIDs, as approaches used to manage inflammation or symptoms. Their suitability depends on the injury, timing and individual circumstances. Ice may reduce pain without proving that tissue repair is faster; inappropriate application can harm skin. Compression and elevation are not substitutes for assessment of a serious injury.

NSAIDs have potential adverse effects and are not suitable for everyone; medication decisions belong with qualified health professionals, not a classroom calculation or a teammate's recommendation. No doses or treatment prescriptions are inferred from these examples.

A severe fracture or complete tear may require surgical repair, depending on the structures, stability, demands and assessment. Not every injury requires surgery. After initial protection and assessment, rehabilitation can progressively restore range, strength, control and task capacity. Therapeutic modalities may assist particular goals, but the use of a device or treatment name is not itself evidence of benefit. Distinguish symptom relief, tissue healing and readiness for the demands of sport.

A person may feel less pain before full load capacity has returned. Conversely, a single imperfect performance measure does not necessarily mean healing has stopped. Qualified practitioners consider findings over time, activity demands and individual circumstances. A safe return is a managed process with review points, not simply the end of an arbitrary number of days. Students can evaluate fictional rehabilitation evidence without offering a diagnosis or clearance.



Pain settles before capacity returns, so loading follows capacity

Concussion needs recognition, assessment and staged return

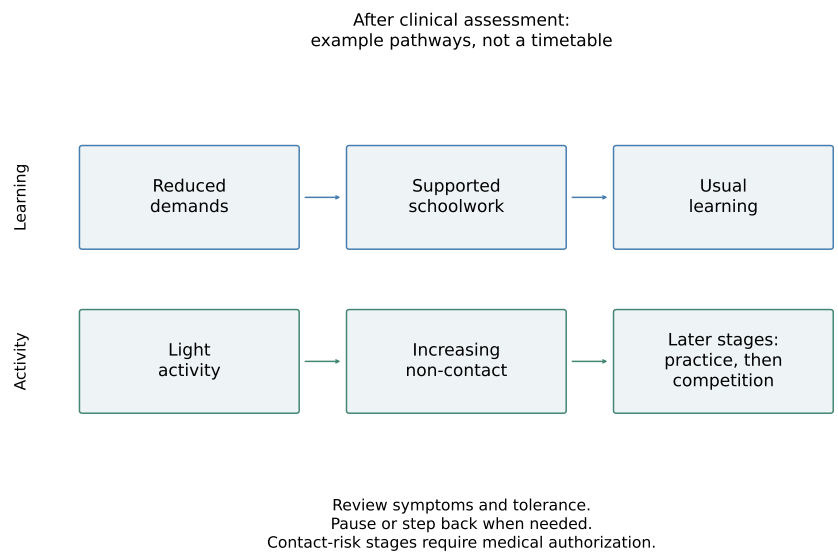
After a suspected concussion, remove the athlete from the activity and arrange appropriate medical assessment. Do not return them to sport the same day or let a classmate decide that they are "fine" because they can answer a question. Worsening headache, repeated vomiting, seizures, increasing drowsiness or new weakness after an impact are examples of danger signs needing urgent emergency assessment. The CDC response guidance distinguishes initial recognition from clinical diagnosis and clearance.



Heading the ball: repeated head impacts are one exposure that concussion surveillance has to count

Recovery can vary between people and can fluctuate. Complete isolation in a dark room until every symptom disappears is not the general recovery model. Current guidance uses a short initial period of relative rest, commonly the first 24–48 hours, with suitable daily activity and later increases in demand directed by clinical advice. Relative rest reduces excessive demands; it does not mean that all movement or all thinking must stop. The Amsterdam concussion consensus distinguishes early symptom-limited activity from later stages involving risk of contact or falling.

Learning and physical activity need coordinated support. Many students can return to school relatively early with adjustments such as breaks, shorter tasks, reduced screen demands or more time for work, according to their needs and medical advice. A return to lessons with support does not imply readiness for contact sport. Symptom changes, attendance and task tolerance help guide review; they are not a schoolmate-administered diagnostic score.



Learning support and physical progression can overlap. Medical review and symptom response guide changes; reaching one box does not automatically clear a person for contact.

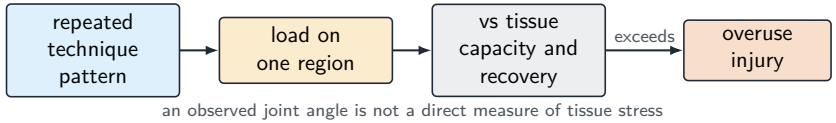
A return-to-sport progression typically moves from ordinary activity through increasing aerobic and sport-specific non-contact demands to appropriate supervised practice and competition. The CDC six-step framework starts with return to regular activities, then light aerobic, moderate, heavy non-contact, practice/full contact where appropriate, and competition. The process needs healthcare-provider approval and supervision, and ordinary non-sport activities should be restored without injury-related supports before full sporting return. Each stage usually takes at least 24 hours; this is not a six-day recovery promise. Symptoms or clinical findings can require pausing or stepping back, and later contact-risk activity needs appropriate medical authorization.

Consider an invented follow-up record with symptom ratings 3, 2, 3, 1 and 0 on successive observations using one consistent scale. The temporary rise shows why recovery is not necessarily linear. The final zero alone does not establish tolerance of schoolwork, exertion or contact. State what was measured, under which conditions, and what further assessment is needed. An athlete's wish to compete and an upcoming final do not replace the staged clinical process.

AHL: Technique changes must be linked to loading and tested fairly

Repeated technique patterns can contribute to an overuse injury when they expose tissues to demands that exceed their capacity and recovery. A biomechanical maladaptation is a movement or loading pattern that is poorly suited to the individual's task and current condition. It is not simply any technique that differs from a pre-

ferred textbook drawing. Body proportions, prior injury, equipment and constraints can change which adjustment is useful.



Overuse follows when repeated load exceeds tissue capacity and recovery

Analyse the task by phases and choose a question. For a throwing action, examine how the trunk, shoulder and arm sequence contribute to force transfer. A repeated demand concentrated on one region may be relevant, but an observed joint angle is not a direct measure of tissue stress. In running, changing one feature such as stride pattern can redistribute loads rather than remove them. An apparently smoother video does not prove every tissue is safer.

An invented side-view recording estimates a joint angle before and after coaching. If the camera position also changes, an apparent improvement may reflect projection rather than a true movement change. Use consistent landmarks, scale, frame rate, phase and camera geometry, and consider multiple views or suitable force measurements. Blinded repeated scoring can help assess observer agreement. A model should state its assumptions rather than converting every two-dimensional angle into a clinical diagnosis.

A useful intervention can combine appropriate coaching, equipment adjustment, strength/control development and load progression. Correcting a relevant maladaptation may reduce injury risk, but evidence must link the correction to outcomes. Suppose technique coaching is introduced and recorded injury rate falls from 18/6,000 hours to 12/6,000 hours: 3 to 2 per 1,000 hours, a relative fall of one third. Season, training load, reporting and participant differences remain alternative explanations without a suitable comparison.

An invented load-proxy model makes the limits visible. At 400 repetitions with a per-repetition index of 100 arbitrary units, total proxy is 40,000. At 300 repetitions and index 80 it is 24,000, a 40% fall. That is a fall in the defined proxy, not evidence that injury probability fell 40%. Nonlinear tissue responses, recovery, technique variation and the validity of the proxy matter. Measure the relevant movement and exposure, then follow outcomes with appropriate professional oversight; do not ask students to create painful repetitions to test the hypothesis.

Practice

1. Distinguish a risk factor from an injury mechanism. Give two internal and two external factors in a plausible sporting example, explaining their interaction.
2. Compare acute trauma and cumulative trauma. Explain why sudden symptom onset does not prove that all preceding loading was acute.
3. Classify ligament sprain, muscle strain, acute fracture, bone stress injury and skin abrasion by tissue and possible loading history. Explain why a whole-body net force is not one ligament's force.
4. Ten participants each complete six 1.5-hour sessions. Find athlete-hours. Eight new injuries occur over 4,000 athlete-hours: calculate rate per 1,000 and explain why it is not a percentage of participants.
5. A has 6 injuries/3,000 athlete-hours; B has 8/8,000. Compare counts and rates. A loses 120 days, B 400: calculate days-lost burdens and explain the different ranking.
6. A group records 9 injuries/4,500 athlete-hours. Another records 3/1,000 and a third 4/2,000. Calculate rates and give three reasons why these estimates cannot establish one individual's future risk.
7. Connect warm-up, strength/control work, suitable flexibility, equipment fit and developmentally appropriate rules to different prevention mechanisms. Explain why no helmet is concussion-proof.
8. Explain how a prevention study's case definition, exposure recording, reporting changes and adherence can affect its conclusion. Does fewer recorded injuries prove success?
9. Explain inflammation's roles and why symptom relief, healing and sporting readiness are different. Discuss why ice, compression, elevation, NSAIDs or surgery cannot be selected from an injury label alone.
10. Explain why concussion can occur without a direct head blow or loss of consciousness. What should happen after a suspected concussion, and why is one normal scan or one good answer insufficient clearance?
11. An invented symptom series is 3, 2, 3, 1, 0. Explain the evidence for non-linear recovery, the limits of the final zero, relative rest, school support and staged return to sport.
12. **AHL:** A side-view video shows a different landing angle after coaching, but camera position changed too. Explain what can be concluded and design a stronger movement comparison without provoking injury.
13. **AHL:** Injuries before coaching are 18 over 6,000 athlete-hours and afterwards 12 over 6,000. Calculate rates, absolute rate difference and relative reduction. Explain why the change does not alone establish a causal technique benefit.
14. **AHL:** A model changes from 400 repetitions at load-proxy index 100 to 300 at index 80. Calculate both totals, each component's percentage fall and the total percentage fall. Explain why none is automatically an injury-probability reduction.

Worked answers

1. Risk factors concern outcome probability; mechanisms explain damaging loading. Previous ankle injury/reduced control can interact with uneven ground and abrupt training increases. This suggests hypotheses, not inevitability or diagnosis.
2. Acute trauma follows a sudden event; cumulative trauma reflects repeated loading exceeding recovery/adaptation. Accumulated damage can become symptomatic suddenly, so symptom timing alone cannot establish the preceding history.
3. Sprain: ligament; strain: muscle/tendon; fracture/stress injury: bone; abrasion: skin. Acute force and repeated loading can affect different tissues. Whole-body force does not specify internal geometry or tissue-load distribution.
4. Exposure $10(6)(1.5) = 90$ athlete-hours. Rate $8/4000 \times 1000 = 2$ per 1,000 athlete-hours. The denominator is exposure time, not number of people; one person can contribute many hours and potentially more than one event.
5. A: 6 events and rate 2; B: 8 and rate 1 per 1,000 hours. Burdens: A $120/3000 \times 1000 = 40$; B $400/8000 \times 1000 = 50$ days per 1,000 hours. B has lower event frequency per exposure but greater recorded time-loss burden.
6. Rates are $9/4500 \times 1000 = 2$, $3/1000 \times 1000 = 3$ and $4/2000 \times 1000 = 2$. Small event counts, under-reporting, different activities/participants and exposure error limit comparisons. A group rate does not determine an individual's future outcome.
7. Warm-up prepares responses; strength/control improves capacity; flexibility targets useful range; fitted equipment addresses particular impacts/constraints; rules reduce inappropriate demands. No helmet removes every transmitted brain force; equipment supplements other protections.
8. Definitions alter event counts; exposure recording alters denominators; reporting changes affect ascertainment; adherence affects the intervention received. Fewer events need not mean lower risk. Comparable controls and consistent methods strengthen inference.
9. Inflammation supports defence and repair. Less pain does not establish restored capacity. Injury location, severity, timing and individual circumstances guide treatment; medicines carry risks and some severe tears/fractures need repair. Class records cannot supply prescriptions or clearance.
10. Body impacts can transmit head forces; loss of consciousness is not required. Remove from activity, arrange assessment and no same-day sporting return; danger signs need urgent assessment. A normal routine scan or one correct answer cannot establish normal function or exertional tolerance.
11. The rise $2 \rightarrow 3$ breaks a decreasing trend. Final zero is one condition-specific measure, not contact clearance. Relative rest initially reduces excessive demands; learning can resume with support. Clinically guided physical progression needs review, authorization for contact-risk stages and possible pauses or setbacks.
12. **AHL:** Changed projection confounds the angle comparison. Standardize camera geometry, landmarks, scale, frame rate, movement task and phase; repeat measurements and assess observer agreement. Additional views and appropriate force evidence can improve interpretation. A changed angle alone is not tissue stress, injury causation or clearance.
13. **AHL:** Before $18/6000 \times 1000 = 3$; after $12/6000 \times 1000 = 2$ per 1,000 hours. Absolute difference is 1 per 1,000; relative reduction $(3-2)/3 \times 100 \approx 33.3\%$. It is not 33.3 percentage points of participants. Season, load, reporting and group changes require a suitable comparison before attributing cause.
14. **AHL:** Totals $400(100) = 40000$ and $300(80) = 24000$ arbitrary proxy units. Repetitions fall 25%, per-repetition index 20%, total 40%; multiplying the remaining fractions $0.75(0.80) = 0.60$ confirms this. The proxy is not a validated injury-probability model; tissue capacity, recovery and other loads still matter.

Exam tips and common mistakes

Define the injury, denominator and outcome. Distinguish counts, exposure rates, participant percentages and time-loss burden; give units and comparison conditions. Test prevention claims against alternative explanations.

Separate loading history from tissue type, protection from zero risk, and symptom relief from healing/readiness. Concussion recovery needs staged clinical review; a class table or video cannot provide diagnosis or clearance.

- **AHL:** Separate measured motion from inferred tissue loading. Standardize camera geometry and phases, examine redistribution of loads, and test technique interventions against suitable controls. A fall in an invented load index is not the same percentage fall in injury probability.

Individual differences

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

This handout teaches C.1 Individual differences for the course first assessed in 2026: what personality is and how it is explained and measured, whether personality predicts sports performance, mental toughness and perfectionism, and how talent develops, including the relative age effect and early specialisation. It also explains how to compare people fairly using questionnaire data. Sections marked **AHL** are for Higher Level only. Personality traits, mental toughness and fair measurement are shared; social learning/personality development and the extended confidence, health and attribution material develop HL objectives. Talent-selection and participation models are explicitly identified extensions. Numerical examples and plots are invented teaching models, not real athlete records or examination-paper data.

Prerequisites: none beyond the course so far. Units C.2 to C.5 build on the idea that athletes differ in how they think, feel and learn.

Personality

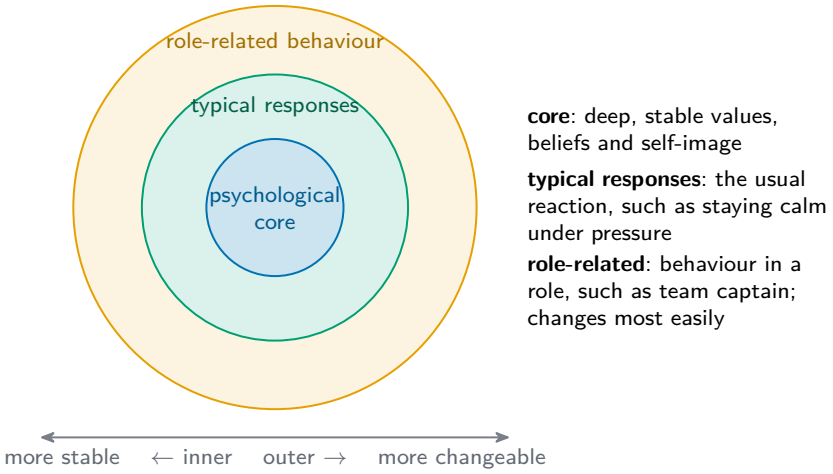
Born in January

In the invented academy used below, 48 of 120 selected players were born in January–March and 14 in October–December. Those counts describe a selected sample. To investigate selection bias, we also need the eligible population's birth distribution and the selection cut-off. Relative chronological age, biological maturity, prior coaching and selection decisions can interact, but the counts alone do not measure those mechanisms. This unit asks how we describe individual differences without turning a score or group pattern into a label or inevitable outcome.

What personality is

Personality 人格 is the set of characteristics that make a person unique and that influence how they behave across many situations. As a historical organizing model, Hollander described it in three layers; this is an extension alongside the syllabus emphasis on trait patterns and the Big Five:

- the **psychological core**: deep, stable values, beliefs and self-image;
- **typical responses**: the usual way a person reacts, such as staying calm under pressure;
- **role-related behaviour**: how a person acts in a particular situation or role, such as a team captain; this layer changes most easily.



Hollander's layers: more stable inside, more changeable outside

Trait theory

Trait theory 特质理论 describes relatively enduring patterns of thinking, feeling and behaviour. Enduring does not mean unchangeable, wholly inherited or identical behaviour in every situation. Biological inheritance and environmental experience both contribute. Trait measures summarize tendencies; they are not deterministic forecasts of a match result.



The Big Five personality traits, each a scale between two poles

Eysenck described two main dimensions:

- **Extraversion–introversion**: **extroverts** 外向者 are sociable, lively and seek

excitement; **introverts** 内向者 are quiet, reserved and prefer calm. Historical sport accounts proposed links with team/individual activities and arousal, but these are not rules for placing a particular athlete in a sport.

- **Neuroticism–stability**: higher neuroticism scores indicate a greater tendency to experience negative emotion; lower scores indicate greater emotional stability. A trait score is not a mental-health diagnosis.

The most widely used model today is the **Big Five** 大五人格:

Trait	High scorers tend to be	Possible link with sport
Openness	Curious, imaginative	Trying new sports and techniques
Conscientiousness 尽责性	Organised, hard-working, self-disciplined	Training adherence; following a rehabilitation plan
Extraversion	Sociable, energetic	Team sports; enjoying crowds
Agreeableness	Cooperative, trusting	Team cohesion; may be less aggressive
Neuroticism 神经质	Anxious, moody	Higher competitive anxiety (unit C.4)

Limitation: traits alone cannot specify behaviour in every situation. Compare context, learning history and current state rather than claiming that all trait approaches deny environmental influences.

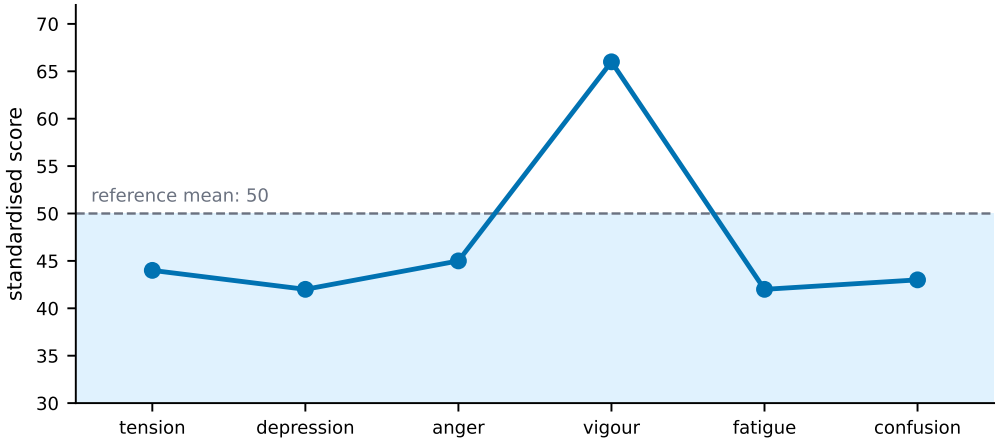
The interactionist approach

The **interactionist approach** 交互作用观 considers person and context together: behaviour depends on the person's traits **and** the situation, often written as Lewin's equation, behaviour = f(personality, environment). A normally calm player may become aggressive in a high-stakes derby when provoked. This is a useful interaction model, not a claim that one equation precisely predicts behaviour. It prompts the coach to consider the athlete, context and their interaction.

Does personality predict performance?

There are two views:

- **Credulous view**: personality does predict performance, so it could be used to select athletes.
- **Sceptical view**: personality explains only a small part of performance, and should not be used for selection.



The iceberg profile reported for some successful athletes

The **iceberg profile** 冰山剖面 is a historical mood-profile pattern: higher vigour with lower scores on several negative-mood subscales relative to a reference. The plotted numbers are invented standardized scores with reference mean 50; they are not raw observations or a selection threshold. A subscale named depression is not by itself a clinical diagnosis.

Mood is a current state and can vary with sleep, illness, workload and events. Personality concerns more enduring tendencies. Neither an iceberg-shaped trace nor one trait score determines who will win. Predictive claims need relevant samples, independent outcomes, repeated measurement and evidence of generalisation. Do not attach an unsupported exact percentage of performance explained to this sketch. Supporting an athlete's needs differs from selecting or excluding them by a profile.

Measuring personality

Method	Strengths	Limitations
Questionnaires (such as Big Five inventories)	Quick, cheap, standardised; can test many people	Answers may be dishonest or socially desirable; questions may not suit every culture or language; general, not sport-specific
Interviews	Detail; can explain answers	Time-consuming; interviewer bias; hard to compare
Observation	Real behaviour in a real setting	Observer bias; behaviour depends on the situation; slow

All results should be kept confidential, used with consent and never used to label or exclude a young athlete.

Mental toughness and perfectionism

Mental toughness

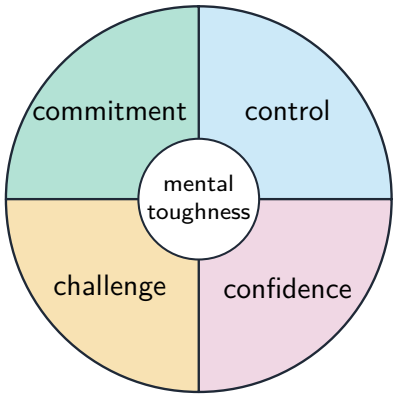
Mental toughness 心理韧性 describes qualities involved in managing demanding situations: appraisal of challenges, commitment, confidence, perceived control and resilience. Resilience concerns responding and adapting after adversity, not never experiencing distress. Performance under pressure depends on the task and context; a label does not guarantee consistency. The **4Cs model** describes four parts:

perfectionistic strivings
high personal standards and working towards them
may support effort; no guarantee

perfectionistic concerns
harsh self-judgement, fear of mistakes, others' expectations
linked to anxiety and burnout risk

the same athlete can show both; a trait label is not a diagnosis

Two sides of perfectionism



The 4Cs model of mental toughness

C	Meaning	Example
Control	Feeling in control of one's life and emotions	Staying calm after a bad call by the referee
Commitment	Sticking to goals and tasks	Completing hard winter training
Challenge	Seeing problems as opportunities	Welcoming a strong opponent
Confidence	Belief in one's ability, in skills and with others	Wanting the ball in the last minute

Mental toughness is measured with questionnaires such as the MTQ48. Individual development reflects biological and environmental influences, and supportive coaching, reflection and psychological skills can contribute to change (unit C.5). A questionnaire difference alone cannot estimate genetic influence or demonstrate that a programme caused improvement. "Toughness" should never mean ignoring injury, pain or mental health problems.

Perfectionism

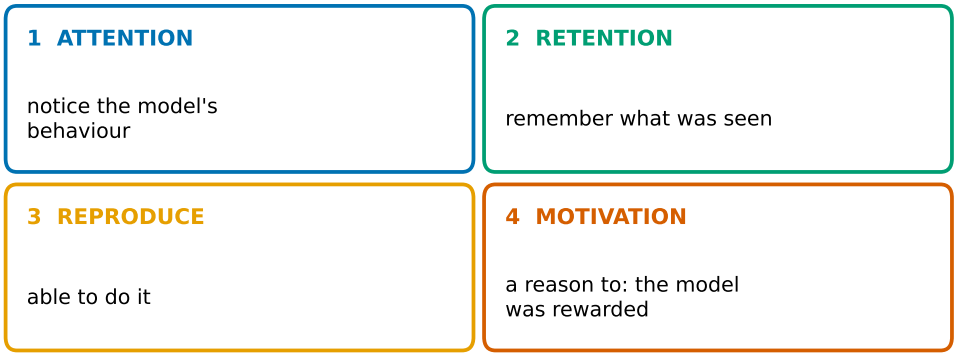
Perfectionism 完美主义 is setting extremely high standards and judging oneself harshly against them. It has two sides:

- **Perfectionistic strivings**: setting high personal standards and working towards them. This may support effort, but high standards alone do not guarantee improved performance.
- **Perfectionistic concerns**: fear of mistakes, worry about others' criticism and feeling that one is never good enough. These concerns can create difficulties in managing demands; evaluate their association with well-being and participation rather than treating them as a diagnosis or an inevitable cause of dropout.

Coaches can help by praising effort and improvement, treating mistakes as part of learning (a mastery climate, unit C.3) and avoiding comparison with others.

AHL: Social learning and personality development

Social learning theory 社会学习理论 explains learning through observing models and the consequences of behaviour. Attention concerns noticing the relevant action; retention concerns remembering it; reproduction requires the capacity to enact it; motivation affects whether it is performed. A learner may remember a model without copying it immediately. Regard for a coach or admired performer and observed rewards or disapproval can influence imitation, but the same model need not produce the same response in every observer.



the Bobo doll study: children copied the aggression they watched an adult model

Bandura's four steps of observational learning

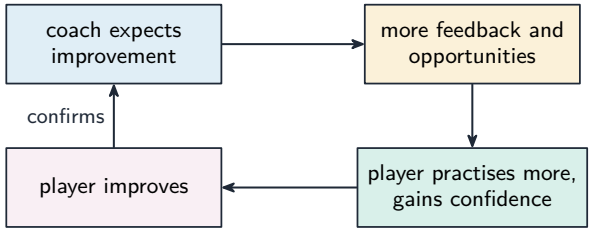
In Bandura, Ross and Ross's 1961 experiment, children exposed to aggressive adult models subsequently reproduced more modelled aggression in the experimental setting. This supports a specific observational-learning inference; it does not show that every child watching sport becomes aggressive or that inherited influences do not exist. In an original sporting example, a respected captain calmly acknowledges a mistake, and a learner adopts the same response after seeing it accepted by teammates. Explain the observed action, stored representation, ability and incentive rather than simply writing "they copy a star."

Personality can change over longer periods through experience, coaching and reflection, although traits retain some relative stability. Changing role behaviour in one session, a short-lived mood change and a durable personality change are different outcomes. Repeated validated measures and observations across contexts help evaluate development; measurement error, social desirability and life changes remain alternative explanations. There is no single personality profile that predicts every sporting result. Traits and social learning interact rather than providing an inherited-versus-learned either/or answer.

AHL: Confidence, expectations, health and attribution

Self-fulfilling expectations and learned helplessness

A self-fulfilling process occurs when an expectation changes behaviour in ways that help produce the expected outcome. A coach expecting a player to improve may provide more useful feedback and opportunities; the player may practise more and gain confidence. A negative expectation may reduce opportunities or persistence. The initial belief need not accurately measure ability. Confidence is not magic: the proposed chain runs through behaviour, opportunities and learning, and external conditions still constrain the result.



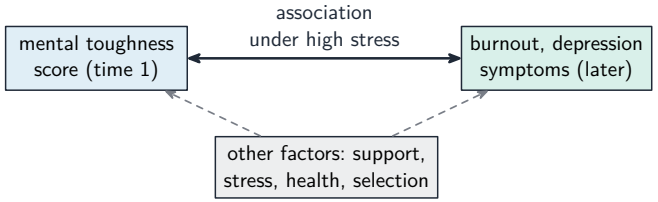
low expectations can run the same loop downwards

A self-fulfilling expectation

Learned helplessness describes a perception that actions do not influence outcomes, which can reduce attempts to change them. "Nothing I do affects selection" can discourage practice even where useful options exist. This is a theoretical explanation to evaluate, not a diagnosis of a quiet or unsuccessful teammate. Supportive feedback can identify specific, feasible actions and fair opportunities; blaming a learner for lacking toughness ignores barriers outside their control. An observation of low confidence and low performance alone cannot establish which came first.

Mental toughness and health evidence

Studies have found associations between reported mental toughness, stress responses and health-related outcomes. A prospective study of young elite athletes found that higher toughness scores were associated with fewer reported burnout and depressive symptoms under high stress; the pattern was not the same under low stress. A sleep study associated higher reported toughness with better objectively recorded sleep characteristics. These are bounded study findings, not guarantees that a high score prevents illness or that toughness training treats a disorder.



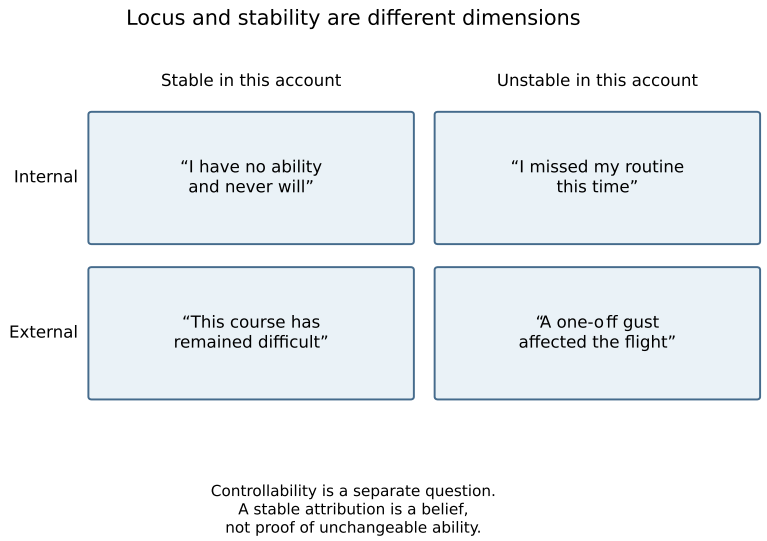
pattern differed under low stress; prospective timing helps, but is not an experiment

A prospective association, not an experiment

Temporal follow-up helps distinguish sequences but is not random allocation. Sleep, support, training stress, health and reporting can affect each other; reverse causation and confounding remain possible. Separate a questionnaire symptom score from diagnosis, and never conclude that an athlete seeking help lacks commitment. Appropriate support and care are compatible with resilience.

Attributions have more than one dimension

An attribution is an explanation for an outcome. **Locus** locates the perceived cause internally or externally; **stability** concerns whether that cause is expected to persist. **Controllability** is a separate question about whether the person can change it. An internal cause is not necessarily controllable, and external circumstances are not necessarily permanent. This distinction follows Weiner's attribution framework.



Classify the athlete's explanation. "Stable" means expected persistence in that account, not proof that a person can never develop.

Stated explanation after a missed shot	Locus and stability in this account	Possible implication to examine
"I have no ability and never will"	Internal, stable as perceived	Low expectation of improvement; test the fixed assumption
"I did not follow the planned routine this time"	Internal, unstable	A specific change may be possible if resources allow
"This course has remained unusually difficult"	External, stable over the stated comparison	Expectations may remain low without an adapted task
"A one-off gust changed the flight"	External, unstable	Outcome may be expected to differ next time; verify the explanation

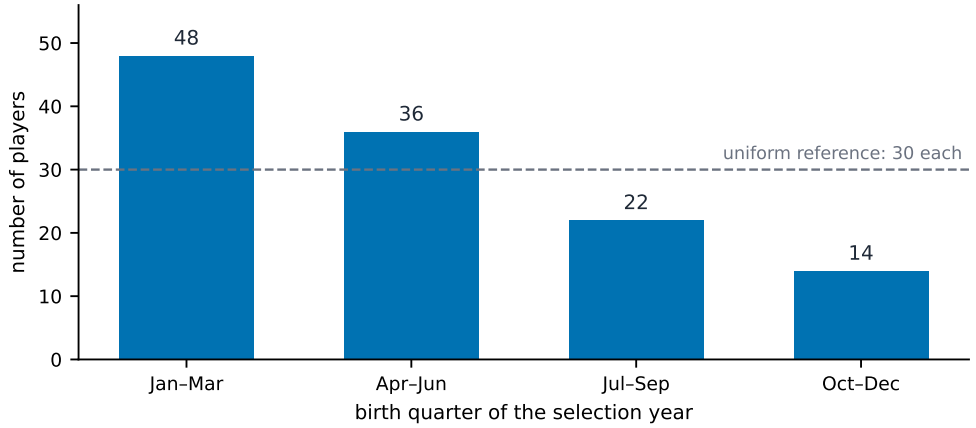
Do not mechanically classify every mention of effort as unstable or all ability as permanently fixed. Use the person's actual claim and timescale. Attributions can affect future confidence, emotion and persistence, but an encouraging explanation should still fit the evidence. A practical response identifies relevant controllable actions without denying genuine external barriers or demanding a positive story unsupported by the record.

Extension: Talent and development

Nature and nurture

Sports performance depends on both **nature** (inherited factors, such as height, muscle fibre type and how much someone responds to training) and **nurture** (environment: coaching, practice, support, money, facilities). Neither a physical measurement nor one genetic marker identifies a future champion. Coaching, opportunity, health, practice and task demands interact with individual characteristics; a current result is not a fixed ceiling on development.

The relative age effect



The relative age effect in an invented academy of 120 players



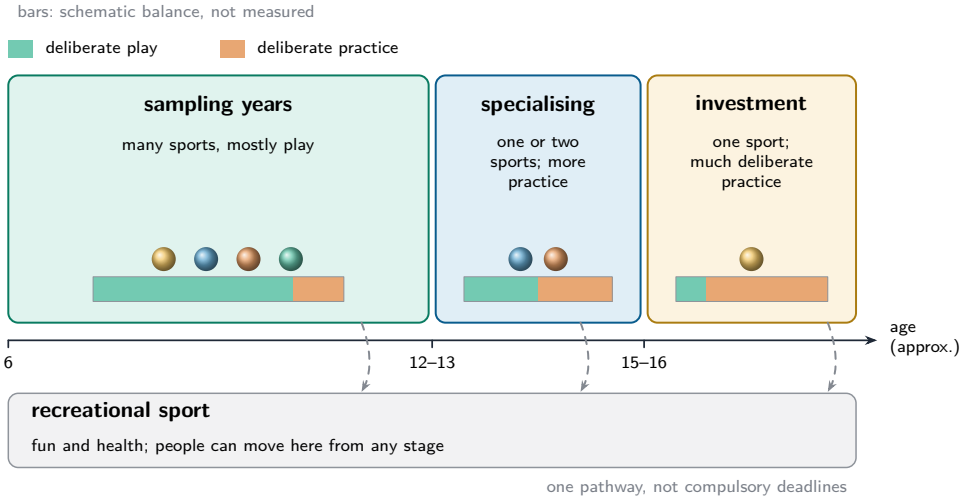
In youth teams grouped by birth year, a child born early in the year can be almost twelve months older than a teammate

The **relative age effect** 相对年龄效应 concerns differences associated with chronological age within a selection-year group. With a January cut-off, January-born children are older than December-born peers in the same annual cohort. That does not mean every older child is biologically more mature or more capable. Maturation, coaching opportunity and selection practices may interact; the relevant cut-off can differ between systems.

> **Worked example (invented).** In the academy, first-quarter share = 48/120×100 = 40%; fourth-quarter share = 14/120×100 = 11.666…%, and count ratio = 48/14 = 3.42857… . An assumed uniform reference would be 25% or 30 per quarter, but actual eligible births need not be uniform. These counts show the selected distribution, not proof that maturity caused selection. Compare eligible and selected populations, record the cut-off and examine alternative explanations.

Maturation 成熟 concerns biological development, distinct from chronological age. Grouping by relevant maturity measures, maintaining open selection opportunities, adjusting comparisons and reviewing cut-offs are possible approaches to evaluate. Each can have measurement, access and organisational trade-offs; none follows as a guaranteed solution from one bar chart. Do not assume late maturers necessarily develop superior decision-making or overtake others.

■ Early sampling or early specialisation?



The developmental model of sport participation

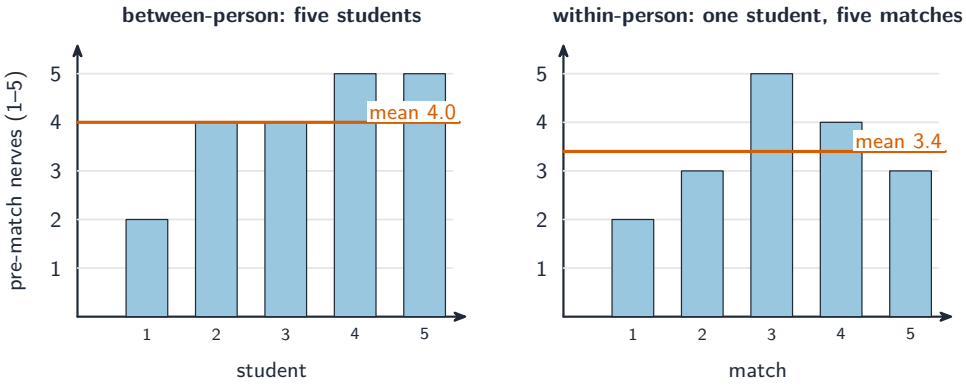
The **developmental model of sport participation** 运动参与发展模型 (Côté) offers a framework involving **sampling** several sports, play and later focused practice. Its approximate age bands describe one pathway, not compulsory deadlines. Different experiences may support varied skills and enjoyment; outcomes depend on access, demands and the individual.

Early specialisation 早期专项化, training in one sport all year from a young age, is common in sports where athletes peak young, such as gymnastics, figure skating and diving. Potential concerns include repeated loading, recovery, enjoyment and restricted opportunities. A sport where high performance can occur young does not establish that every child must specialise early or that doing so guarantees success. Compare the actual programme and participants rather than claiming a single optimal route for all sports.

Comparing individuals fairly

■ Within-person and between-person differences

A questionnaire score describes what a person reports, using the questionnaire's own scale. It does not diagnose a disorder, and it is not a perfect measure of an inner state.



A group comparison and one person's changes over time answer different questions

- **Between-person** comparisons compare different people: "Is athlete A more anxious than athlete B?"
- **Within-person** comparisons follow one person over time: "Is athlete A more anxious before finals than before league games?"

The two can give different answers. Across a team, the most anxious players might perform worst; but one player might perform best on the days when they feel most anxious. Conclusions about a group do not automatically apply to each individual.

> **Worked example.** Five students rate pre-match nerves on a 1 to 5 scale: 2, 4, 4, 5 and 5. The mean is $20 \div 5 = 4.0$. One of the students rates themselves before five matches: 2, 3, 5, 4 and 3, a mean of $17 \div 5 = 3.4$ and a range of 3. The group mean of 4.0 says nothing about how this student's nerves change from match to match, and the student's mean of 3.4 does not mean they are "less anxious than the class": the questions, time point and conditions must be the same before comparing. Report the scale, the time point and the number of people, and avoid labelling anyone.

■ Ethics of studying individual differences

- Use anonymous, voluntary questionnaires approved by the school, and allow withdrawal.
- Avoid sensitive personal questions and never share individual scores.
- Compare the same task at the same time point, and explain the limits of the scale.
- Never use results to select, exclude or label a young athlete.

Practice

Numerical records are invented; state the reference population and measurement conditions.

1. Define personality and distinguish a relatively enduring trait, a current mood and role-related behaviour. Explain Hollander's three layers as a historical organizing model.
2. Name the Big Five, describe two tendencies relevant to sport and explain why an extraversion score or iceberg-shaped mood trace cannot identify a future winner.
3. Explain a person–situation interaction. Compare questionnaire, interview and observation evidence, including reliability and validity limits.
4. Explain appraisal, commitment, confidence, control and resilience, using the 4Cs as one framework. Why does mental toughness not mean hiding injury or distress?
5. Distinguish perfectionistic strivings and concerns as an extension example. Why is a high standard not proof of better performance or a mental-health diagnosis?
6. Explain how individual characteristics and opportunities interact in development. Evaluate a claim that one physical or genetic marker identifies champions.
7. An invented January-cut-off squad contains 40 swimmers, 17 born in its first quarter and 4 in its last. Find both percentages and the count ratio. State what additional reference information is needed before inferring selection bias.
8. Suggest three possible responses to a relative-age pattern and one limitation of each. Distinguish chronological age and maturation.
9. Outline sampling, specialising and investment as a participation model. Evaluate early specialisation without treating its age bands as compulsory or any route as a guarantee.
10. Group scores 2,4,4,5,5 and one person's repeated scores 2,3,5,4,3 use a specified scale. Find both means and the second range; distinguish within-person and between-person claims. For a separate invented scale with scores 3,3,4,8,12, find mean and range.
11. Give four ethical rules for a school questionnaire and explain why one self-report score cannot establish a diagnosis or justify public ranking.
12. **AHL:** Explain attention, retention, reproduction and motivation in a sporting modelling example. Explain how personality can develop over time and why a short-lived change does not prove lasting trait change.
13. **AHL:** Explain a self-fulfilling process and learned helplessness using an expectation–behaviour–opportunity chain. Evaluate an association between toughness scores and sleep or mental-health symptoms.
14. **AHL:** Classify "I have no ability and never will", "I missed my routine this time", "this course remains difficult" and "a one-off gust affected it" by locus and stability. Distinguish controllability and explain possible effects on future confidence without pretending the classification proves cause.

Answers.

1. Personality concerns relatively enduring patterns; mood is a current state; role behaviour depends on the role and context. Hollander: core values (fair play), typical responses (usual calm response), role-related behaviour (encouraging as captain). Neither model requires identical behaviour in every situation.
2. Openness, conscientiousness, extraversion, agreeableness and neuroticism. Conscientiousness may relate to organised practice; openness to trying approaches. These are tendencies, not fixed sport assignments. Mood reflects current conditions, measurement and reference choices; neither a trait score nor a sketch determines a result.
3. The same person can respond differently to provocation, task demands or support; traits and context interact. Questionnaires permit standardized self-report but can have response bias; interviews provide detail but interviewer effects; observation records behaviour but context and observer judgement matter. Consistency does not itself prove construct validity.
4. Appraisal interprets demands; commitment concerns sustained engagement; confidence belief in relevant capacity; control perceived influence; resilience adapting after setbacks. The 4Cs organize control, commitment, challenge and confidence. Appropriate help-seeking and injury reporting support well-being and informed participation; silence is not a toughness test.
5. Strivings concern high standards; concerns involve mistakes and evaluation. Their implications depend on context and measurement. A high standard does not itself demonstrate improved results, establish a disorder or predict inevitable dropout.
6. Body characteristics, training history, practice, coaching, resources and opportunity interact. A marker or current measurement cannot capture every contributor or identify an inevitable champion. Do not infer a biological cause from one observed group difference.
7. First: $17/40\times100 = 42.5\%$; last: $4/40\times100 = 10\%$; ratio $17/4 = 4.25$, about 4.3 to one. Need the eligible population's quarter distribution, the actual cut-off, sample/selection process and uncertainty. The selected counts alone do not prove a maturity mechanism.
8. Examples: maturity-informed grouping requires reliable relevant measures; open/delayed selection needs resources and continued access; age-adjusted comparisons require suitable evidence; cut-off changes may redistribute rather than eliminate advantages. Chronological age follows birth date; maturation varies biologically within age.
9. The model describes approximate sampling/play, increasing specialisation and focused investment, with recreation possible throughout. Focused practice can develop relevant skills but narrows other opportunities and can concentrate demands. Judge load, recovery, enjoyment, access and development; no age band or programme guarantees elite performance.
10. Group mean $= 20/5 = 4.0$. Person mean $= 17/5 = 3.4$; range $= 5-2 = 3$. Across-person comparisons and one person's changes answer different questions, and conditions must match for direct comparison. Separate scale mean $= 30/5 = 6$; range $= 12-3 = 9$. No score alone establishes cause or diagnosis.
11. Voluntary informed participation/withdrawal; appropriate anonymity/confidential handling; avoid sensitive disclosures; approved low-risk questions; no selection, public ranking or labelling. State the scale, task, timing and limits. Anonymous data cannot later identify a particular pupil for withdrawal unless the procedure explicitly allows it; explain that before participation.
12. **AHL:** A learner notices a respected captain's constructive response, remembers it, can reproduce it and has reason to use it. Observed consequences and regard for the model influence imitation but do not guarantee identical behaviour. Experience, coaching and reflection can contribute to longer-term change; repeated suitable measures across contexts are needed to distinguish it from mood, role behaviour or measurement error.
13. **AHL:** Expectations can change feedback, opportunity, effort and persistence, which can affect outcomes and reinforce expectations. Perceived lack of action–outcome control may reduce attempts, but one poor result is not a diagnosis of helplessness. Associations with symptoms or sleep do not establish that toughness training causes a cure: stress, support, reverse causation, measurement and population matter. Seeking help is compatible with resilience.
14. **AHL:** In these stated accounts: internal/stable; internal/unstable; external/stable; external/unstable. Stability concerns expected persistence; locus concerns where the cause is placed. Controllability is separate. A perceived lasting cause may affect future expectation; a specific changeable action may support an improvement plan when justified. Classification does not verify the explanation, imply ability can never develop or eliminate real external barriers.

Exam tips

- Define the construct and timescale: trait, current state, reported experience and behaviour are not interchangeable.
- Apply a theory to a specific mechanism; avoid deterministic genetic, demographic or questionnaire labels.
- Show the denominator, reference distribution and unrounded working for percentages and ratios.
- Separate within-person changes from between-person patterns; explain measurement validity, consent and confidentiality.
- **AHL:** Trace observation or expectation through behaviour and context. Distinguish locus, stability and controllability. Health associations do not establish diagnosis or treatment efficacy.

Motor learning

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

This handout teaches C.2 Motor learning for the course first assessed in 2026: what skills and abilities are and how skills are classified, how performers process information and react, how movements are controlled, how people learn skills in stages, how ecological dynamics explains adaptation, how attention is controlled, and how practice, feedback and guidance should be organised. Numerical models and datasets below are invented for teaching, not measurements from a real paper. It is written for both SL and HL students.

Prerequisites: unit A.1 (the nervous system, neurons and reaction time) and unit B.1 (muscles and movement).

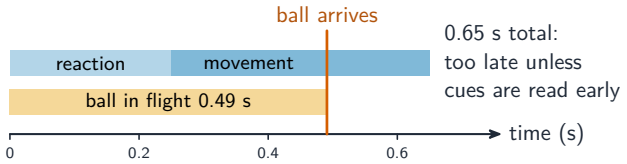
Skill and ability

Half a second to return a serve

Consider an invented serve travelling 30 m at a constant 220 km/h: speed = 220/3.6 = 61.11… m/s and flight time = 30/61.11… = 0.491 s. Real flight speed changes and the route differs between serves. If a receiver's supplied reaction and movement times total 0.65 s, waiting until this model ball is struck leaves insufficient time for that whole response. Reading early cues may help, but an incorrect anticipation can send the player the wrong way. The useful question is how a performer learns to detect relevant information and coordinate a suitable movement.



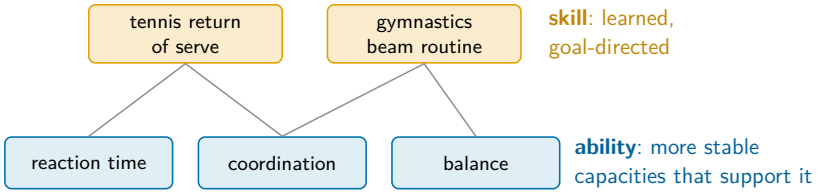
A 135 mph serve gives the receiver about half a second to detect, decide and move



The return-of-serve time budget

Skill and ability

A **motor skill** 运动技能 is a learned ability to bring about a planned result with maximum certainty and the least time and energy. Skilled movement is consistent, efficient, controlled and fits the goal, and it is learned through practice.



Abilities support skills

An **ability** 能力 is a relatively enduring capacity that supports skill, such as balance, coordination, reaction time or strength. Biological development, inherited influences and experience contribute to abilities; strength and flexibility can also be trained. Abilities are not fixed ceilings or sufficient predictions of future performance. Skills are built through suitable experience. A gymnast needs the abilities of balance, flexibility and strength to learn the skill of a handstand.

Ability type	Examples
Perceptual–motor abilities	Reaction time, coordination, manual dexterity, aiming
Physical proficiency abilities	Strength, flexibility, stamina, balance, speed

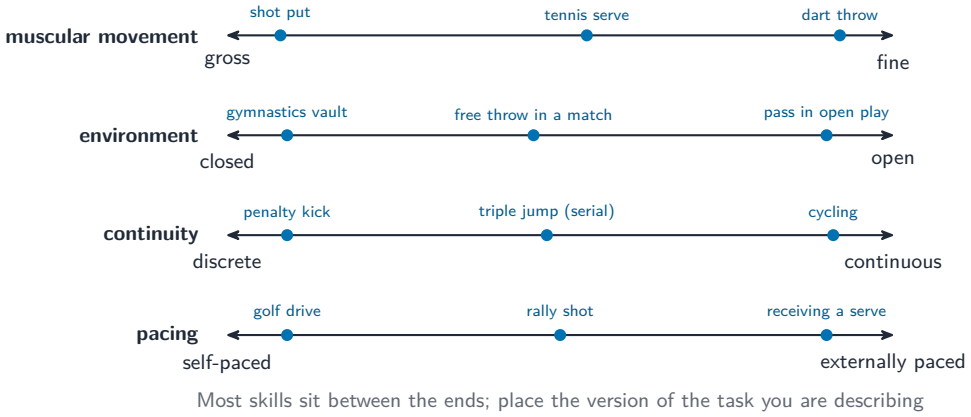
Expertise in sport needs a large amount of high-quality practice. **Deliberate practice** 刻意练习 is structured, effortful practice directed at improvement with useful feedback. It is one contributor to expertise alongside opportunity, prior experience, health and individual characteristics. Neither practice hours nor one practice label guarantees expertise.

Classifying skills

Skills are placed on **continua** (scales between two extremes), because few skills are purely one type.



Archery is a closed skill: a stable setting, and the archer chooses when to begin



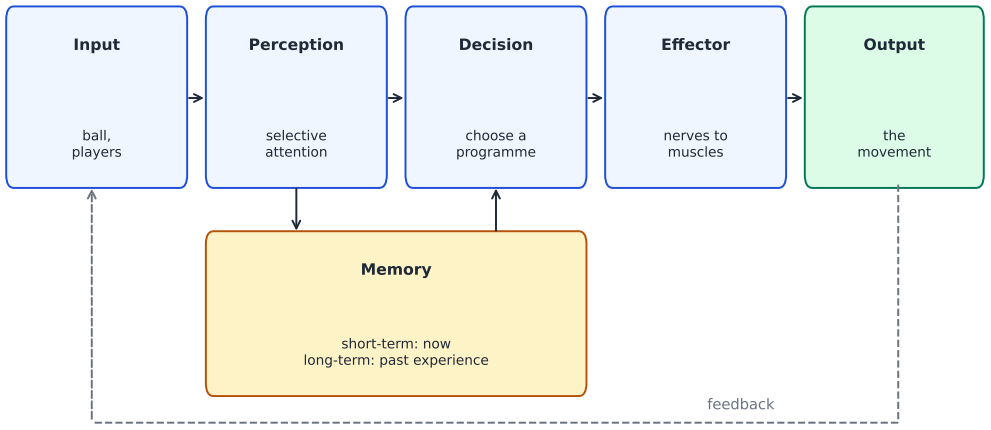
Skills sit along continua, not in boxes: classify the version of the task you are describing

Continuum	One end	Other end
Muscular movement	**Gross**: large muscle groups, such as a shot put	**Fine**: small muscle groups, precise, such as a dart throw
Environment	**Closed**: stable, predictable environment, such as a gymnastics vault	**Open**: changing, unpredictable environment, such as a football pass in a match
Continuity	**Discrete**: clear beginning and end, such as a penalty kick	**Continuous**: no clear beginning or end, such as cycling; **serial** skills link discrete skills, such as a triple jump
Pacing	**Self-paced**: the performer decides when to start, such as a golf drive	**Externally paced**: the environment decides, such as receiving a serve

The classification guides practice: repetition can help establish a movement, while varied, representative situations are needed to test adaptation. Even a free throw involves time limits and distraction; classify the specified version of the task rather than assuming a sport has one fixed label.

Information processing

The model



A simple model of information processing



A goalkeeper's dive: the whole chain from seeing the shot to moving must happen in well under a second

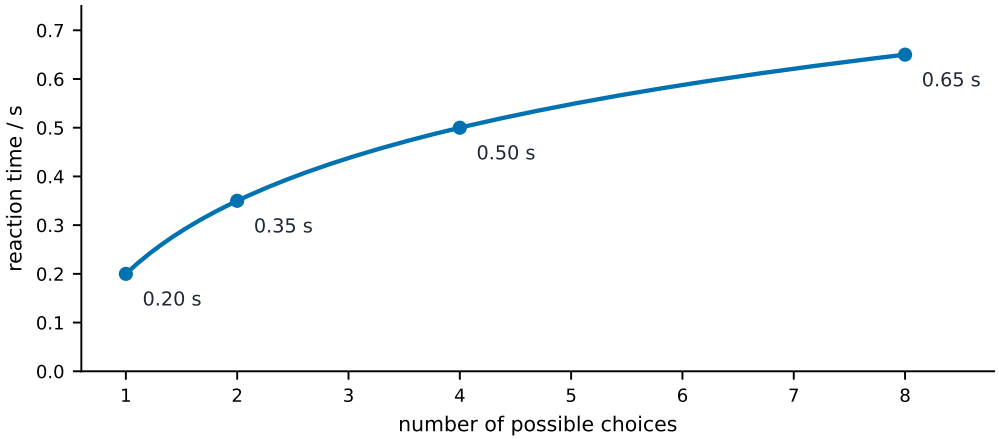
The information-processing model represents movement through linked stages. It is an explanatory model, not a literal claim that a performer is a computer:

1. **Input.** Information from the **display** (the ball, opponents, team-mates, the crowd) and from the body (proprioceptors) enters through the senses.
2. **Perception.** The brain interprets the information. **Selective attention** 选择性注意 filters out irrelevant information (the crowd) and focuses on relevant cues (the ball and the opponent's racket). This makes processing faster, because the brain can deal with only a little information at a time.
3. **Memory. Short-term memory** 短时记忆 holds the information being used now: capacity and duration depend on the task, rehearsal, chunking and interference. The historical 7 ± 2 estimate is not a universal limit on instructions or sporting cues; give a manageable number of meaningful cues and check understanding. **Long-term memory** 长时记忆 holds learned motor programmes and past experiences, over much longer periods; its contents are not always recalled accurately or promptly. The current situation is compared with past experience.
4. **Decision.** A response is chosen, and the matching **motor programme** 运动程序 is selected.
5. **Output.** Impulses travel along motor nerves (the effector mechanism) to the muscles, producing the movement.
6. **Feedback.** Information about the result returns to the start, so the next action can be adjusted.

Reaction time

Term	Meaning
Reaction time 反应时	Time from the start of a stimulus to the start of the response: the gun to the first movement
Movement time	Time from the start to the end of the movement
Response time	Reaction time + movement time

Simple reaction time is one stimulus with one possible response, such as a sprint start: about 0.15 to 0.2 s. **Choice reaction time** involves several stimuli, each with its own response, such as a goalkeeper deciding which way to dive.



An invented Hick-type model: 0.20 + 0.15 $\log_2(N)$ seconds for N equally likely choices; coefficients are supplied, not universal athlete constants

Hick's law 希克定律 states that choice reaction time increases in a straight line with the logarithm of the number of choices. Each doubling of the number of choices adds about the same amount of time. Players use this: a tennis player who can serve to many places, with disguise, makes the receiver slower.

Reaction time is affected by age, sex, fatigue, arousal, the strength of the stimulus, practice, and **anticipation** 预判. Anticipation means predicting what will happen (where the ball will go: spatial) and when (temporal), so that processing starts early. Experts anticipate better because they pick up early cues from their opponent's body.

The **psychological refractory period** 心理不应期 is the delay when a second stimulus arrives before the first has been processed. A response-selection bottleneck is one explanation (the **single-channel hypothesis**); it does not mean all sensory information is processed one item at a time. The delay depends on tasks, timing and practice. A **dummy** or feint may engage a defender in selecting or initiating one response before the real action requires another; successful deception is not guaranteed.

> **Worked example.** In an invented simplified football penalty, the ball travels 11 m at a constant 25 m/s. The following reaction and movement times are supplied assumptions.

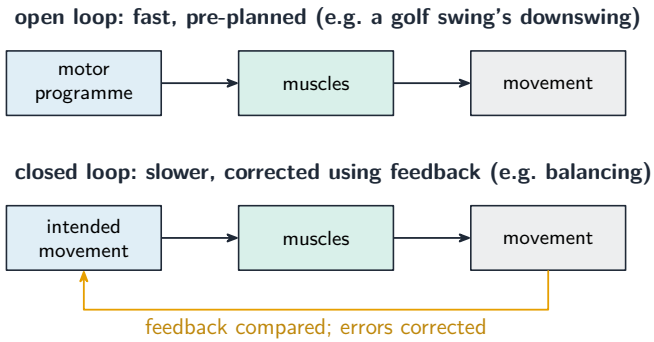
- Time for the ball to reach the goal $= 11 \div 25 = 0.44$ s.
- The goalkeeper has two main choices (left or right). With Hick's law above, reaction time ≈ 0.35 s. A full dive to the corner takes about 0.45 s of movement time.
- Response time $= 0.35 + 0.45 = 0.80$ s, which is longer than 0.44 s.

For this assumed flight and full-dive response, reacting only after the kick is too slow. Anticipation from relevant pre-kick cues could help, but an incorrect prediction can be costly. This model does not prove that every real shot requires an identical early dive or that the invented Hick coefficients predict elite goalkeepers.

Motor control

Open-loop and closed-loop control

Open-loop control	Closed-loop control
The whole movement is planned in advance as a motor programme and runs without using feedback during it	Feedback during the movement is compared with the intended movement, and errors are corrected
Fast, well-learned, discrete skills: a golf swing, a tennis serve, a punch	Slower or continuous skills: balancing on a beam, steering a bicycle, dribbling
Too fast for feedback to change the action once started	Requires time for feedback to be used

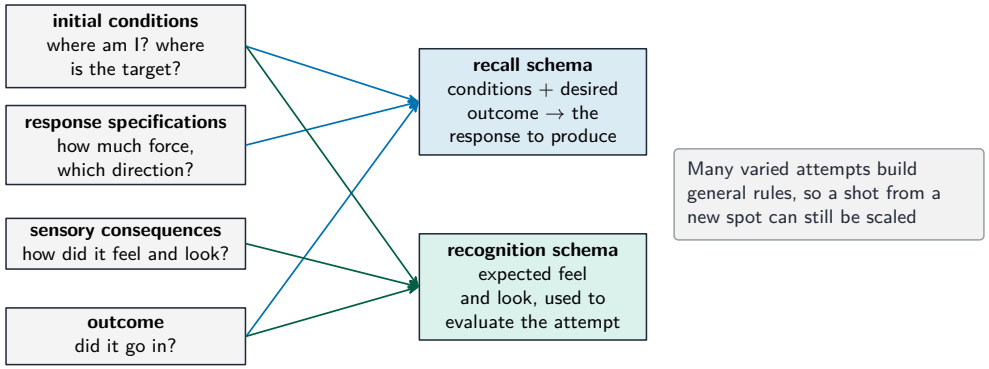


Open-loop and closed-loop control

Most sports skills combine both: the main movement runs as a programme, while slower parts are adjusted.

Schema theory

How can a basketball player shoot accurately from a place on the court where they have never shot before? **Schema theory** 图式理论 (Schmidt) says that people do not store a separate programme for every movement. Instead, from many practice attempts they build general rules, called **schemas**, linking:



Schmidt's schema theory: general rules from many attempts let a performer scale a movement to a new situation

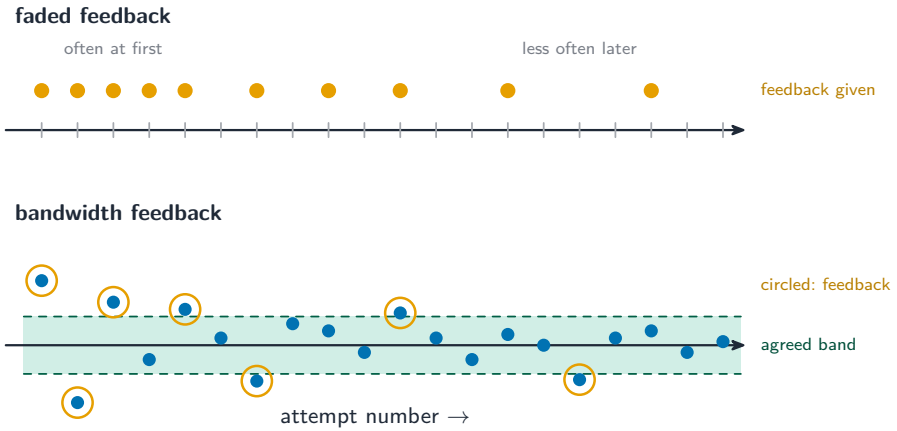
- the **initial conditions** (where am I? where is the target?);
- the **response specifications** (how much force, which direction?);
- the **sensory consequences** (what did it feel and look like?);
- the **outcome** (did it go in?).

A **recall schema** links conditions and the desired outcome to response specifications; a **recognition schema** supplies expected sensory consequences for evaluating the action and subsequent attempts. A very rapid movement can end before feedback changes it. A generalized motor pattern describes an underlying organisation, such as an overarm throw; subordinate patterns or task-specific versions adapt it to a particular implement, distance or context. Parameter changes include force and overall duration, rather than storing an unrelated programme for every attempt.

Schema theory predicts that **varied practice** can support adaptation to unpractised conditions. Treat this as a testable prediction: retained accuracy at new distances matters more than simply counting the variations offered.

Feedback

Feedback 反馈 is information about a movement and its result.



Less frequent feedback avoids dependence and lets learners detect their own errors

Faded and bandwidth schedules give less feedback over time, so learners build their own error detection

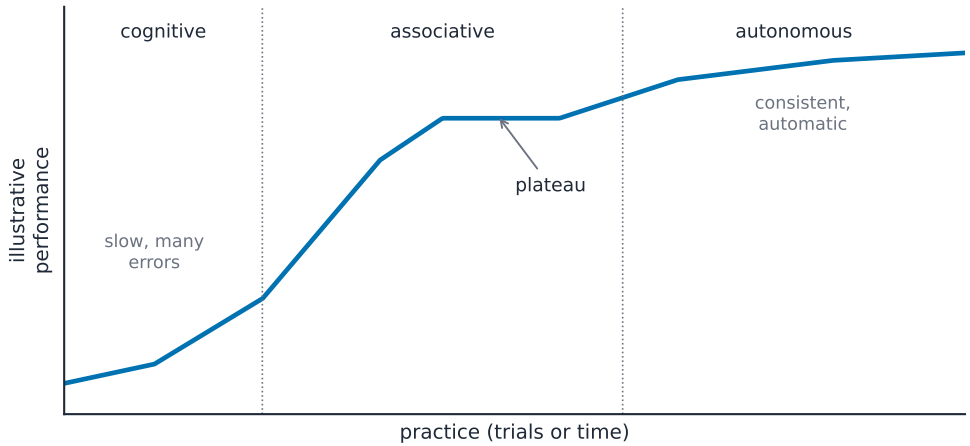
Type	Meaning	Example
Intrinsic feedback 内在反馈	From the performer's own senses, especially proprioception	Feeling a clean strike on the ball
Extrinsic (augmented) feedback 附加反馈	From an outside source: coach, video, scoreboard	The coach says, "Your elbow dropped"
Knowledge of results 结果反馈 (KR)	About the outcome	"The shot was 30 cm short"
Knowledge of performance 表现反馈 (KP)	About the quality of the movement	"Your arm was not straight at release"
Concurrent or **terminal**	During or after the movement	A rowing coach calling out stroke rate (concurrent); video after a jump (terminal)
Positive or **negative**	What was done well, or what was wrong	"Great follow-through"; "you leaned back"

Match feedback to the actual learner and task. Beginners often benefit from concise demonstrations and clear outcome information plus one actionable movement cue. Experts may use detailed video as well as intrinsic feedback. Positive should not mean inaccurate praise; useful correction describes an action without judging the learner as a person.

Too much feedback can harm learning. When feedback is given after every attempt, learners may depend on it and perform worse when it is removed (the **guidance hypothesis**). **Faded feedback** (given often at first, then less often) and **bandwidth feedback** (given only when the error is larger than an agreed amount) help learners develop their own error detection.

Stages of learning

Three stages



A schematic performance curve with an illustrative plateau; stage boundaries are not measured dates or inevitable score thresholds

Fitts and Posner described three **stages of learning** 学习阶段:

Stage	Learner	Coach should
Cognitive stage 认知阶段	Works out what to do; slow, jerky, many errors; needs to think about every part	Give demonstrations, simple instructions, guidance, and positive feedback
Associative stage 联结阶段	Practises and refines; fewer, smaller errors; begins to use intrinsic feedback	Give detailed feedback (KP), increase practice difficulty
Autonomous stage 自动化阶段	Movement is automatic, consistent and efficient; attention is free for tactics	Give occasional detailed feedback; use pressure and decision-making practice

Not every learner reaches the autonomous stage, and an expert can drop back to an earlier stage when changing their technique.

Learning curves and plateaus

A **learning curve** plots performance against practice. A **plateau** 平台期 is a period when performance stops improving despite practice. Causes include loss of motivation or boredom, fatigue, an insensitive outcome measure, inappropriate practice, and an increase in task difficulty. A plateau does not establish a permanent biological limit. Different explanations require different evidence. A coach can set new goals, vary practice, give rest and break the skill into new targets.

Learning or performance?

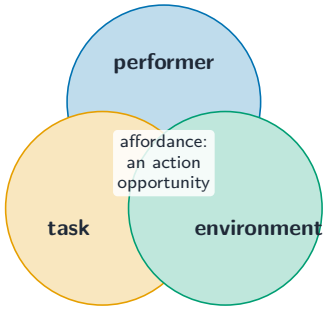
Performance is what is seen on one occasion; it can be affected by fatigue, motivation, prompts and luck. **Learning** 学习 is a relatively permanent change in the ability to perform, produced by practice. To measure learning rather than temporary performance, use:

- a **retention test** 保持测验: the skill is tested after a delay (a day or a week) without feedback or prompts;
- a **transfer test** 迁移测验: the skill is tested in a new situation, such as a different distance or under pressure.

Ecological dynamics and constraints-led learning

A different explanation of coordination

Information processing and schema theory emphasise representations, selection and stored rules. Ecological dynamics instead examines the continuously changing relationship between a performer and the environment. An **affordance** is an opportunity for action relative to the performer's capabilities: a gap may be passable for one player but not another. Detecting a gap and moving into it are coupled; movement also changes the information available.



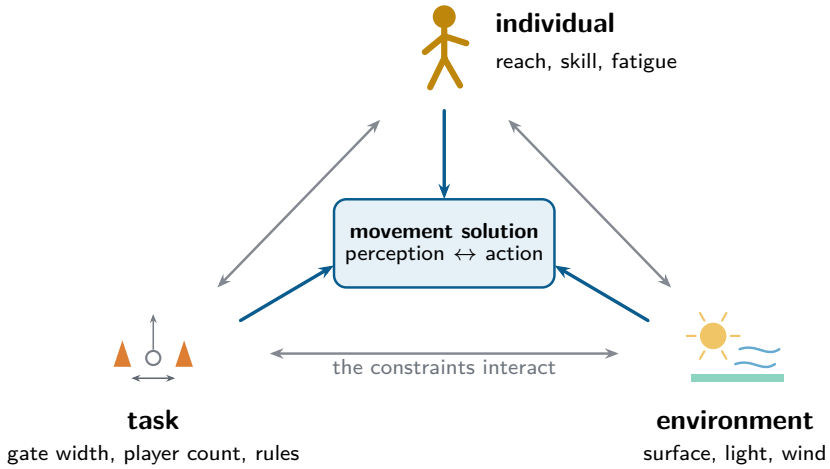
a gap a defender leaves is a passing opportunity for *this* performer, at *this* moment; coordination emerges from the changing relationship

Affordances emerge from performer, task and environment

Perception–action coupling means that perception guides action while action alters what can be perceived. In a small-sided game a defender's movement changes a passing lane, and the ball carrier's movement changes that defender's options. A cone drill can train an action, but it may remove the live information needed to decide when that action is appropriate. Representative practice preserves the important information–movement relationship; it need not reproduce every detail of a match.

A moving body has many **degrees of freedom**: joints, muscles and timing relationships that could vary. Coordination organises these possibilities into a workable movement. A beginner may initially restrict joint motion; experience can permit more adaptable coordination. **Self-organisation** describes a movement pattern emerging from interactions among the performer, task and environment, rather than every joint angle being explicitly prescribed. It does not mean absence of coaching, goals, feedback or safety boundaries.

Three interacting constraints



passing game: narrow the gate (a task constraint), observe how passes change, then judge whether the learning transfers to a match

Change a constraint, observe the response and evaluate whether learning transfers

Constraint	Practical example	What the coach can examine
Individual	Reach, strength, experience, fatigue or confidence	Whether a task offers achievable but meaningful options for this learner
Task	Court area, target size, player numbers, rules or equipment	Whether changing a rule invites a useful movement or merely rewards a shortcut
Environment	Surface, lighting, wind or nearby activity	Whether conditions change available information and safe action possibilities

For a low-risk supervised passing game, widening a target gate changes a task constraint; keeping a live defender preserves a perception–action demand. A coach might then narrow the gate as learners become more accurate. Changing gate width, defender numbers and equipment simultaneously makes it difficult to identify which change mattered. An equipment constraint can interact with individual reach: categories organise thinking rather than representing independent causes.

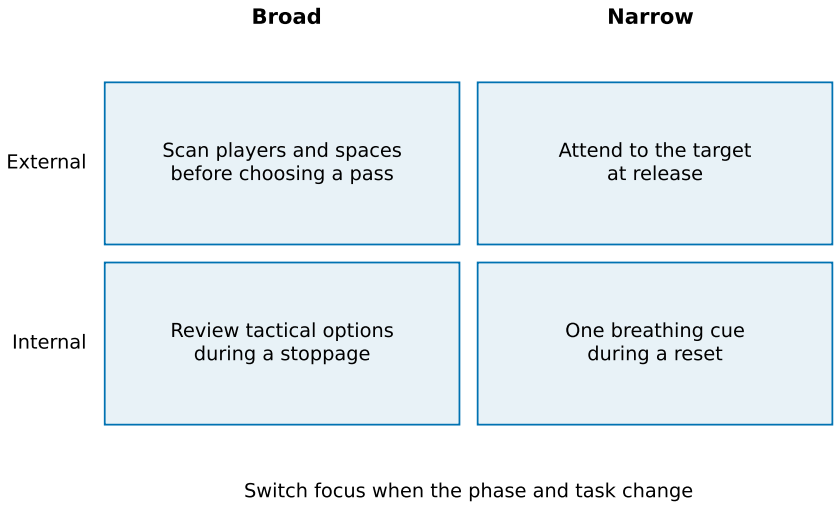
Non-linear pedagogy allows exploration of functional solutions under carefully designed constraints. A small change may produce little response until a learner discovers a new coordination pattern; progress need not be a straight line. **Performance variability** can reflect useful adaptation, random error or measurement noise. Judge whether variation achieves the goal across relevant conditions, not whether every attempt is mechanically identical. More variability is not always better, and unsafe solutions should not be encouraged.

A traditional **linear pedagogy** often uses a demonstration, an explicit movement template, sequenced practice and correction towards that template. It can give a novice clear structure. A constraints-led lesson changes meaningful opportunities and lets the learner discover suitable coordination. Real coaching can combine concise instructions, demonstration and exploration. To compare approaches fairly, define the skill, opportunity to practise and delayed/transfer outcomes; a theory's name does not establish its superiority.

Attentional control

■ Choose the direction and width of focus

Attentional control concerns directing limited attention towards information relevant to the current action. **Internal/external** describes direction; **broad/narrow** describes width. These are separate dimensions, and a performer changes focus as demands change.



The appropriate focus depends on the phase and task, not a permanently superior quadrant

Focus	Sporting example	Possible limitation if held too long
Broad external	Scan several teammates, opponents and spaces before a pass	Missing the precise cue needed at release
Narrow external	Attend to a selected target at release	Failing to notice a changing defender earlier
Broad internal	Review several tactical options before a stoppage ends	Continuing analysis when action is needed
Narrow internal	Attend to one breathing cue during a reset	Excessive conscious control during a well-learned action

External distraction can be an irrelevant sound or sight; internal distraction can be worry about a previous error or unrelated thoughts. A teammate calling useful information is external but not necessarily a distractor. Identify relevance to the task, rather than classifying every noise as harmful. Losing concentration means attention has shifted away from the relevant demand; it need not mean all attention has vanished.

High arousal can narrow attention. This may help exclude irrelevant information in one phase, yet impair a broad scan when several options matter. A player may fixate on the ball and miss a teammate. Do not claim all arousal has the same effect or that one breathing cue guarantees recovery.

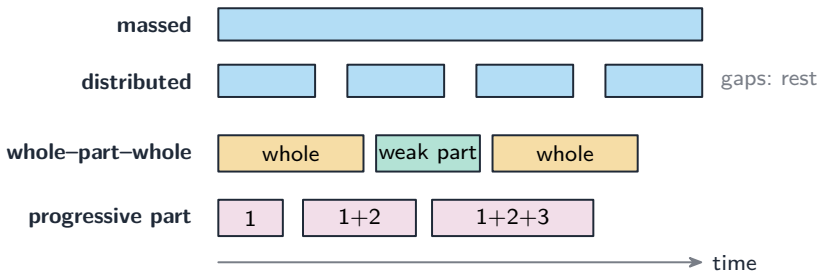
Controlled distraction introduces agreed, manageable irrelevant cues in safe practice so the performer can rehearse refocusing. For example, after establishing a target routine, add mild background sound and practise returning to the target cue. Obtain informed participation and maintain normal safety and communication signals; do not provoke distress or use startling hazards. Compare a stable task before and after, then check whether the strategy transfers without added prompts.

Task-specific **self-talk**, such as "scan, choose, pass", can cue a useful sequence. A process goal such as checking the defender before each pass directs attention to an action within the player's influence. Evaluate the cue with the performer: extra instructions may overload a novice or disrupt an automated action. Neither a mantra nor a goal replaces technical practice or guarantees the result.

Practice and teaching

Organising practice

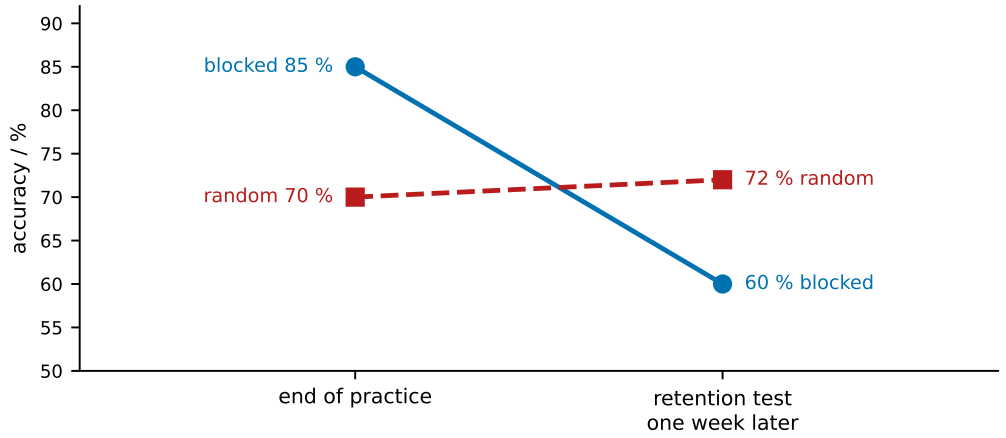
Method	Description	Best for
Whole practice	The whole skill at once	Fast, simple or continuous skills that cannot be split, such as a cartwheel
Part practice	Parts practised separately	Complex skills with separable parts, such as a swimming stroke (arms, legs)
Whole–part–whole	Try the whole, practise a weak part, put it back	Most skills; keeps the feel of the whole movement
Progressive part	Learn part 1, then parts 1 and 2 together, and so on	Serial skills, such as a gymnastics routine or the triple jump
Massed practice	Long sessions, little or no rest	Simple, discrete skills; experienced, fit performers
Distributed practice	Short sessions with rest or other activity between	Beginners, complex or tiring skills; usually better for learning
Mental practice	Imagining the skill without moving (unit C.5)	All stages, with physical practice



How practice can be arranged in time.

Fixed practice repeats the same version of a skill (good for closed skills). **Variable practice** changes the conditions (good for open skills, and supported by schema theory).

Blocked and random practice



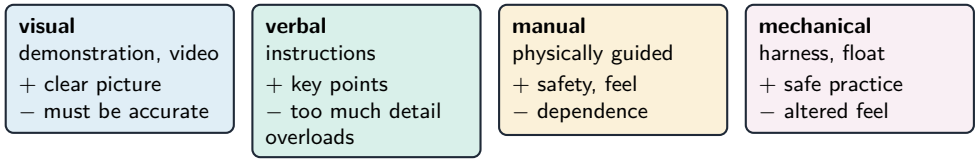
Invented scores illustrating one possible practice–retention contrast, not a guaranteed advantage of either schedule

In **blocked practice**, one skill is repeated many times before the next (20 short serves, then 20 long serves). In **random practice**, skills are mixed (short, long, short, flick...). Random practice can increase planning demands because successive tasks differ. This **contextual interference** 情境干扰 may reduce immediate scores and may aid retention or transfer in some conditions. Effects depend on skill complexity, experience, how schedules differ and the test; do not assume every sport or beginner benefits from maximum interference.

Worked example. In the figure, the blocked group fell from 85 % to 60 %, a drop of 25 percentage points, while the random group rose from 70 % to 72 %. A coach who judged by practice scores would choose blocked practice, but the delayed scores favour random practice in this invented dataset. Without baseline comparability, adequate independent participants and uncertainty, those two scores alone do not establish a causal or universal benefit. A gradual increase in variability may be appropriate when initial tasks overload learners.

Guidance

Type	Example	Strengths	Limitations
Visual guidance	Demonstrations, video, posters	Gives a clear picture; good for beginners	The demonstration must be accurate; too much detail confuses
Verbal guidance	Instructions and explanations	Can explain why; can be combined with visual	Too many words overload short-term memory
Manual guidance	The coach physically moves the learner's limbs	Gives the feel of the movement; builds confidence	Learner may come to depend on it; feel differs from real movement
Mechanical guidance	Appropriate equipment, such as a swimming float or a trampoline harness	Can support a task when correctly selected and supervised	Can create dependence

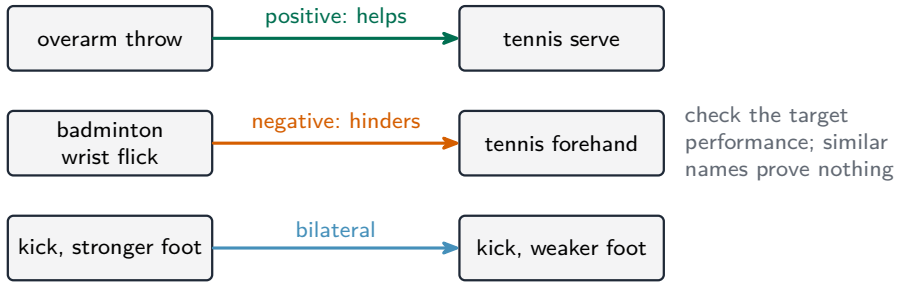


Four types of guidance

Transfer of learning

Transfer 迁移 is the effect of learning one skill on learning or performing another.

- **Positive transfer**: one skill helps another, such as a throwing action helping a tennis serve.
- **Negative transfer**: one skill hinders another, such as a badminton wrist action spoiling a tennis forehand.
- **Bilateral transfer**: from one side of the body to the other, such as learning to kick with the weaker foot.
- **Proactive transfer** (an earlier skill affects a later one) and **retroactive transfer** (a new skill affects one learned earlier).



Positive, negative and bilateral transfer: check the target performance rather than the names of the sports.

Transfer also occurs from **practice to performance**, between **abilities and skills**, from one **learning stage to another**, and from **principles to specific skills**. Representative pressure and decisions can support practice-to-match transfer; improved balance may support a new skill without automatically teaching it. Stable basic coordination can support a more autonomous version; learning the principle of creating space can guide a new passing activity. State what transfers, to which target, and what changes. Similar appearance alone does not establish a benefit or a compulsory negative effect. Compare target performance with suitable starting evidence rather than assuming transfer from the names of two sports.

Practice

All numerical cases are invented; use the supplied conditions rather than claims about actual athletes.

1. Distinguish skill and ability, classify a free throw and match dribble on three continua, and explain why a classification can depend on context.

2. Apply the information-processing model to a cricket batter. Explain selective attention and why a fixed 7-item memory limit should not be treated as a universal coaching rule.
3. Using the supplied model RT = 0.20 + 0.15 $\log_2$(N) s, find RT for 1, 2, 4 and 8 equally likely choices. Distinguish reaction, movement and response time and give one limit of applying this equation to a real goalkeeper.
4. A model ball travels 11 m at 25 m/s; the supplied reaction and dive times are 0.35 and 0.45 s. Compare times. Repeat the comparison for a 7.0 m ball flight at 30 m/s and a supplied 0.60 s response. Explain a possible benefit and cost of anticipation.
5. Explain the psychological refractory period using a feint, without claiming that the whole brain can process only one stimulus at a time.
6. Compare open-loop and closed-loop control. Explain generalized and subordinate motor patterns, the four kinds of schema information and a limitation on online correction.
7. Apply ecological dynamics to a live passing task: explain affordances, perception–action coupling, degrees of freedom, self-organisation and useful versus unhelpful variability.
8. Propose one individual, one task and one environmental constraint for that task. Explain a controlled comparison of linear and non-linear teaching and how to assess learning.
9. Classify a coach's post-attempt comment "Your take-off foot was 20 cm behind the board"; then supply genuine outcome feedback. Explain faded/bandwidth feedback and one dependence risk.
10. Describe all three learning phases with suitable coaching. Give three plausible explanations for a plateau without claiming a permanent ability ceiling.
11. Recommend practice and guidance for a beginner learning a supervised low-risk component of front crawl. Compare whole, part, distributed, fixed/variable and blocked/random decisions, including safety and dependence limits.
12. In the invented practice graph, blocked accuracy is 85% then 60% at retention; random is 70% then 72%. Calculate both changes, both between-group gaps and the blocked relative decline. State what is and is not supported.
13. Explain skill-to-skill, practice-to-performance, abilities-to-skills, bilateral, stage-to-stage and principles-to-skills transfer, giving an example and one reason transfer may fail.
14. Classify broad/narrow and internal/external attention with examples. Explain internal/external distraction, arousal-related narrowing and a safe controlled-distraction/self-talk/process-goal strategy.

Answers.

1. A skill is a learned goal-directed movement such as a free throw; an ability is a supporting capacity such as coordination, influenced by development and experience as well as inheritance. A free throw is relatively closed, discrete and self-paced within a time limit. A match dribble is relatively open, continuous/serial and externally influenced. A stationary drill and live match impose different information and timing demands; neither a trait nor a sport label fixes all performance.
2. Input includes bowler/ball/body information; perception selects relevant cues; memory supplies relevant experience; response selection chooses a shot; motor signals activate muscles; movement and sensory/outcome feedback follow. Selective attention prioritises relevant cues under limited resources, but does not guarantee a quicker correct choice in every context. Memory estimates depend on rehearsal, chunking and task; brief understandable cues need checking rather than a presumed universal seven-command allowance.
3. $\log_2$ of 1,2,4,8 is 0,1,2,3, giving 0.20,0.35,0.50,0.65 s. Reaction is stimulus to movement onset; movement time is onset to the defined endpoint; response time is their sum. Coefficients, equal probabilities and task conditions are supplied; anticipation, stimulus compatibility and changing probabilities limit direct real-match prediction.
4. First flight = 11/25 = 0.44 s; response = 0.35+0.45 = 0.80 s, exceeding flight by 0.36 s. Second flight = 7/30 = 0.2333… s; response 0.60 s exceeds it by 0.3667… s. In these models the full specified response cannot finish if started only at the strike. Early reliable cues can start a useful response sooner; deception or a wrong prediction can initiate the wrong movement. Real trajectories and required movements vary.
5. Closely timed stimuli can delay selection of a second response while the first is being handled. A feint may occupy response selection and/or initiate an action that must then change. This bottleneck account does not imply every sensory and motor process is serial, and a feint's effectiveness depends on timing and the defender's interpretation.
6. Open-loop components execute a prepared command without using feedback to change that component; closed-loop components use sensory comparison to adjust movement. A rapid strike and slower balance adjustment illustrate the difference; real skills combine them. A general throwing pattern can be parameterised into a particular implement/distance version. Schemas connect initial conditions, response specifications, sensory consequences and outcome; recall supports specification, recognition evaluation. Feedback arriving after release can inform a later throw but cannot change that released action.
7. A passing lane is an affordance relative to the player's ability and positions. Perception guides movement and movement changes the available lane information. Multiple joints/timing relationships provide degrees of freedom; coordinated solutions can self-organise through interaction with goals and constraints. Different successful passes may be functional variability; random misses or unsafe motion are not automatically desirable. A static cone task may omit the defender information essential to transfer.

8. Individual: current reach or experience; task: gate width or player numbers; environment: lighting or surface. Alter one planned constraint while holding relevant practice time, participants and outcome criteria comparable; record changes rather than assuming which constraint caused success. A linear lesson may explicitly model a sequence; a non-linear lesson may invite solutions through a meaningful gate change. Use baseline, delayed unassisted retention and a representative transfer test, adequate independent participants and uncertainty. Coaching and safety remain in both approaches.
9. The take-off-foot comment is augmented/extrinsic, terminal knowledge of performance: it describes a movement feature, not the final jump outcome. "The measured jump was 4.10 m" is knowledge of results. Feedback categories overlap. Giving every answer can encourage dependence; fading reduces frequency over time, while bandwidth feedback uses a predefined error threshold. Suitability depends on comprehension and task risk; withholding necessary safety feedback is not a learning strategy.
10. Cognitive: establishing the task and a workable pattern, with demonstration, few cues and simple feedback. Associative: refining consistency, with specific feedback and appropriate variation. Autonomous: less conscious movement control, with relevant decisions and occasional targeted feedback; experts can revisit conscious learning after a change. Fatigue suggests rest; monotonous or inappropriate practice suggests redesign; an insensitive score suggests better measurement. A plateau is an observed pattern, not proof of an unchangeable ceiling or an exact stage transition.
11. Within qualified supervision and safe water conditions, a simple component can be demonstrated, practised briefly with rest, then integrated into the whole stroke. Part practice helps only if the component can be meaningfully separated; excessive isolation can disrupt coordination. Whole–part–whole restores context. Begin with manageable conditions; add relevant variations as capability develops. Blocked repetitions can establish a task; mixed tasks may add useful demand but are not universally superior. Visual/verbal guidance should be concise. Floats or physical assistance require suitability, consent where relevant and supervision; they neither make a learner drown-proof nor eliminate dependence.
12. Blocked change = 60−85 = −25 percentage points; random = 72−70 = +2 points. Practice blocked advantage = 15 points; retention random advantage = 12 points. Blocked relative decline = 25/85×100 = 29.4118…%. The invented delayed scores favour random here and show why practice scores can mislead. Without comparable baselines, sample sizes, variability and controlled allocation they do not prove causality, universal schedule superiority or the amount of each person's learning. Learning is inferred from appropriate retained/adaptable capability, not measured directly by one percentage.
13. Skill-to-skill: an overarm throw may support a serve; practice-to-performance: live-decision passing practice may support a match; abilities-to-skills: balance may support learning a handstand; bilateral: experience on one side may help the other; stage-to-stage: a learned coordination pattern can support more autonomous execution; principles-to-skills: creating space can guide a new passing game. Specify source and target. Different timing, equipment, information or interference can limit transfer; similarity is not proof and negative effects need evidence.
14. Broad external scans players/spaces; narrow external focuses a target; broad internal reviews several tactical possibilities; narrow internal attends to one breathing cue. Internal worry and irrelevant crowd noise can distract, whereas a useful teammate call is relevant external information. Arousal-related narrowing may omit needed peripheral cues; no one focus suits all phases. Safely introduce mild agreed distraction after basic competence, practise a chosen refocusing cue and set a process goal such as scanning before a pass. Keep communication/safety cues available and assess delayed transfer; do not induce distress or promise identical effects for everyone.

Exam tips

- Apply information-processing and ecological models to a named action; explain what each contributes.
- For constraints, identify the change, intended opportunity and evidence of adaptation.
- Distinguish movement-quality feedback from outcomes, attentional width from direction, and learning from temporary performance.
- Calculate from supplied assumptions with unrounded working; identify percentage-point and relative changes correctly.
- Justify coaching by the task and learner. Use delayed unassisted retention and representative transfer evidence; phases are not age deadlines.

Motivation

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

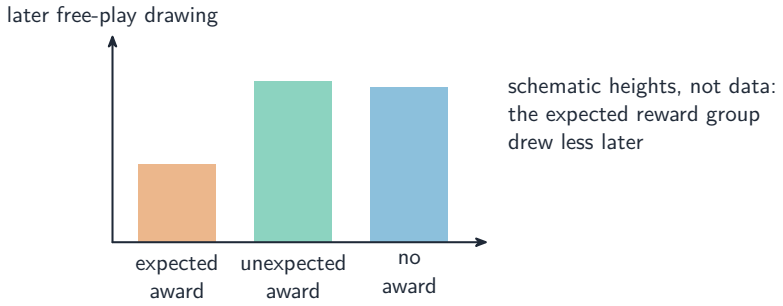
This handout teaches C.3 Motivation for the course first assessed in 2026: what motivation is, how rewards affect it, self-determination theory, achievement motivation and achievement goals, how athletes explain success and failure, self-efficacy, and why people start and stop exercising. Sections marked **AHL** are for Higher Level only. The common core covers achievement motivation, basic self-determination and motivational climate. Attribution, confidence and exercise-change examples are labelled extensions connecting this unit to other learning. Numerical cases are invented unless a named historical study is explicitly identified.

Prerequisites: unit C.1 (individual differences). Unit C.5 teaches goal setting and other skills used to build motivation.

What motivation is

Paying children to draw

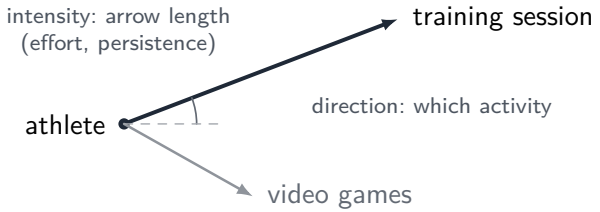
Lepper, Greene and Nisbett's 1973 field experiment compared preschool children who initially showed interest in drawing. One group expected an award, one received an unexpected award and one received no award. Subsequent free-play observations found less interest in the expected-award group than in the comparison groups. This is evidence about a particular reward arrangement and activity, not proof that every certificate harms every child or that drawing and competitive sport are interchangeable. The coaching question is what a reward communicates and how the participant experiences it.



Expected rewards and later interest

Direction and intensity

Motivation 动机 is the direction and intensity of a person's effort: which activities they choose (direction) and how hard and how long they try (intensity). It explains why people start an activity, how much effort they put in and whether they persist when it becomes difficult.



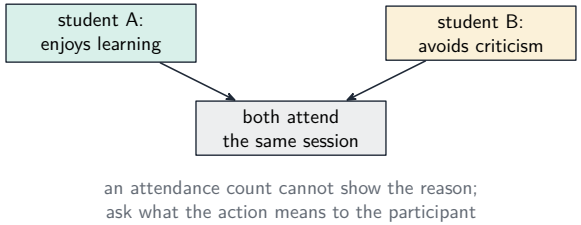
Motivation = direction (which activity) and intensity (how hard, how long)

Type	Meaning	Examples
Intrinsic motivation 内在动机	Taking part for the activity itself: enjoyment, interest, the satisfaction of improving	Loving the feeling of a perfect dive; enjoying the challenge of a hard climb
Extrinsic motivation 外在动机	Taking part for something outside the activity	Medals, money, praise, a place in the team, avoiding criticism

Extrinsic rewards can be **tangible** (trophies, prize money, scholarships) or **intangible** (praise, status, applause).

Reasons can differ for the same behaviour

Two students may attend the same session, one because they enjoy learning and the other to avoid criticism. Attendance counts alone cannot identify the reason. People can also have several reasons at once, and personally valuing a health benefit is not the same as enjoying every activity. Ask what the action means to the participant before interpreting a reward or a score.



Same behaviour, different reasons

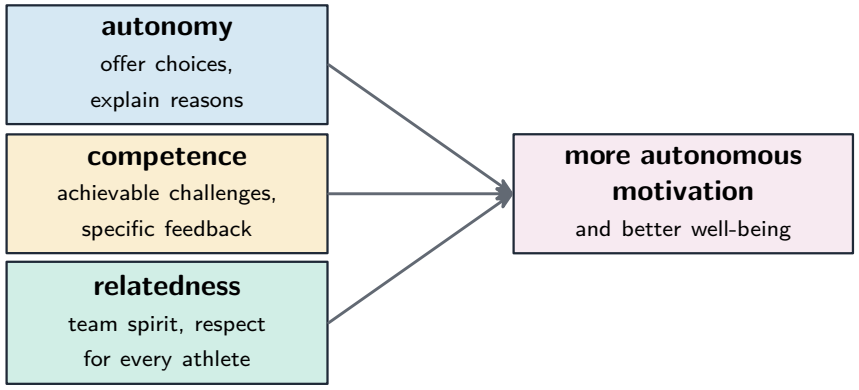
For a school investigation, use an approved, anonymous, voluntary questionnaire with non-sensitive questions and explain withdrawal arrangements before participation. State the scale, task and measurement time; avoid private disclosures or public labels. Compare different people (between-person variation) separately from repeated reports by one person (within-person variation); following one person requires a protected linking code rather than fully anonymous records. A self-report describes reported experience, not a diagnosis or a universal arousal–performance rule.

Self-determination theory

Three basic needs

Self-determination theory 自我决定理论 (Deci and Ryan) says people are most motivated, and feel best, when three **basic psychological needs** are met:

Need	Meaning	What a coach can do
Autonomy 自主	Feeling that you choose your own actions	Offer choices, explain reasons, ask for the athlete's ideas
Competence 胜任	Feeling capable and improving	Set achievable challenges, give specific feedback on improvement
Relatedness 归属	Feeling connected to and valued by others	Build team spirit, treat every athlete with respect



Self-determination theory: meet the three needs and motivation becomes more autonomous

Controlled, autonomous and absent motivation

Controlled motivation involves experienced pressure, such as obtaining approval or avoiding guilt. Autonomous motivation involves willingness and personal endorsement. Enjoyment of the activity is intrinsic; an externally separable purpose can also be personally valued. **Amotivation** 无动机 involves little intention or a perceived lack of connection between action and useful outcome. These distinctions concern the reason for behaviour, not merely whether a coach is present or a trophy exists.



Street football: children play for the enjoyment of the game itself, intrinsic motivation in its plainest form

Intrinsic motives can involve learning something new, accomplishing a challenge or experiencing stimulation. An athlete may enjoy learning a new stroke, mastering a routine or the sensations of a well-timed movement. Enjoyment and persistence are associated in research, but a motive label does not guarantee that a particular person will attend when access, illness or other demands intervene.

Support autonomy by providing meaningful choices and reasons within clear boundaries; support competence with achievable challenges and usable feedback; support relatedness with respectful inclusion. Autonomy is not abandonment, competence is not superiority over teammates, and relatedness is not compulsory agreement with every instruction.

Achievement motivation and goals

Need to achieve and need to avoid failure

Achievement motivation 成就动机 (Atkinson) depends on two personality factors:

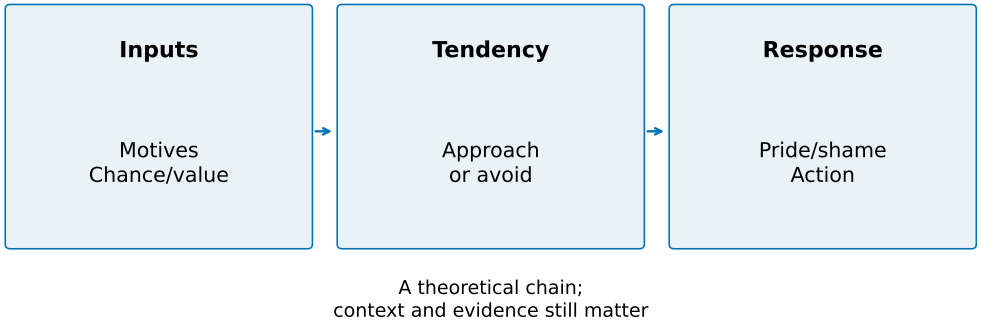
- the **need to achieve** (NAch): the wish to succeed, to take on challenges and to feel pride;

- the **need to avoid failure** (NAF): the wish to avoid the shame of failing.

High need to achieve	High need to avoid failure
Chooses realistic challenges, a moderate perceived chance of success in the simplified model	Chooses very easy tasks (certain success) or impossible ones (failure is no shame)
Enjoys being evaluated; welcomes feedback	Avoids situations where they will be judged
Persists after failure	Gives up quickly
Attributes failure to effort or strategy	Attributes failure to lack of ability

The model links person factors (approach and avoidance motives) with situation factors (perceived **probability of success** and **incentive value**). Their interaction gives a resultant tendency towards approach or avoidance; anticipated pride or shame helps explain the behaviour. These are theoretical tendencies, not a personality diagnosis from one choice.

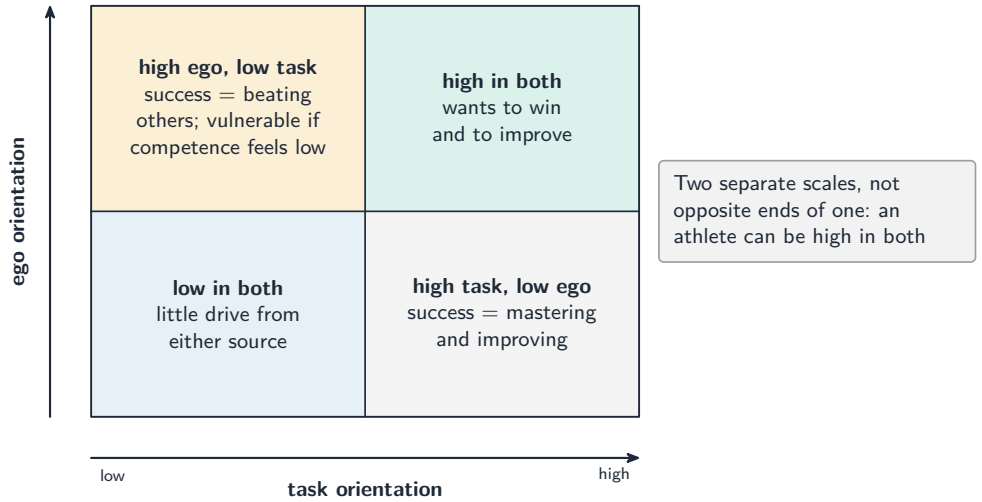
For example, a runner may avoid an unfamiliar time trial if public comparison makes failure feel humiliating. A coach can offer a suitable challenge, explain a self-referenced target and give private feedback. That changes situational demands and the meaning of evaluation; it does not guarantee confidence or change a trait instantly. A moderate challenge can balance possible success with meaningful accomplishment. The often-used 50% example belongs to a simplified model, not a universal prescription that half of every athlete's attempts should fail.



Explain the links in the specific situation; a model does not diagnose a fixed trait from one task choice

Achievement goal theory

Achievement goal theory 成就目标理论 (Nicholls) says that people judge success in two ways:



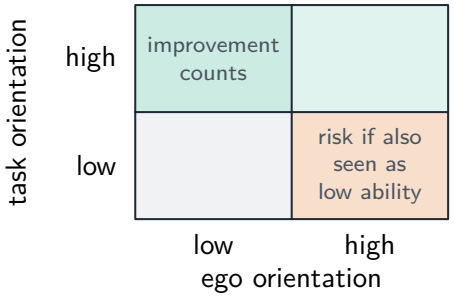
Task and ego orientation are two separate scales: an athlete can be high in both

	Task orientation 任务取向	Ego orientation 自我取向
Success means	Mastering the skill, improving, trying hard	Beating others, being the best, winning with little effort
Ability judged by	Comparing with your own past performance	Comparing with others
After failure	Tries harder; sees mistakes as part of learning	Norm-referenced success may feel threatened when perceived competence is low
Linked to	Enjoyment, persistence, fair play	Interpretation depends on perceived competence, task orientation and context

The two orientations are separate: an athlete can be high in both. Comparing with others and valuing personal improvement can coexist. A goal orientation concerns how the individual judges success; the climate concerns what the environment recognises and rewards. Neither orientation alone establishes a moral character or inevitable outcome.

AHL: Ego orientation and perceived competence

High ego orientation can become problematic when task orientation is low and the individual believes that others see their ability as low. A norm-referenced result may then threaten self-worth, encouraging anxiety, excuses, reduced effort or withdrawal as defensive responses. These are possible processes, not behaviours to assume in every losing athlete. A person who feels seen as highly capable may experience the same comparison differently.



Task and ego orientation are separate scales; the risk lies in high ego with low task orientation

Consider two invented players with similar defeat records. One sees small improvements as worthwhile and receives specific constructive feedback. The other feels that only being publicly best counts and expects others to judge every mistake as evidence of low ability. The second pattern provides a plausible mechanism for defensive avoidance, but interviews or repeated observations would be needed to test it. Actual access, injury, fatigue, discrimination and coaching conditions can also affect participation.

A coach can reduce unnecessary public ranking, offer achievable development targets and recognise cooperation and improvement. The aim is to broaden the evidence of competence and support meaningful participation, rather than demanding a positive label or guaranteeing that anxiety disappears.

Motivational climate

The coach helps create a **motivational climate** 动机氛围 through tasks, instruction, feedback and recognition; parents, peers and organisational conditions can also contribute:

- In a **mastery climate**, effort, improvement and learning are rewarded; mistakes are part of learning; everyone has an important role.
- In a **performance climate**, only winning and the best players are rewarded; mistakes are punished; players are compared with each other.

	mastery climate	performance climate
rewarded	effort, improvement, learning	winning, the best players
mistakes	part of learning	punished
comparison	with your own past	with each other

created by coaches through tasks, feedback and recognition; parents and peers add to it

The same team can feel very different depending on what the coach rewards

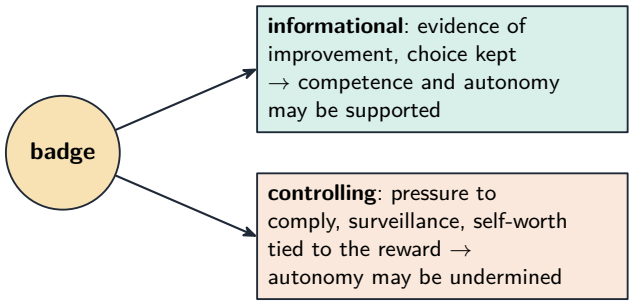
A mastery climate is linked to more enjoyment, more effort, more intrinsic motivation and less anxiety, especially for young athletes. Coaches can create one through the **TARGET** areas: the **t**asks set (varied, challenging), **a**uthority (sharing decisions), **r**ecognition (for effort and improvement, given privately), **g**rouping (mixed-ability groups), **e**valuation (against personal improvement) and **t**ime (allowing suitable opportunities to learn). TARGET is a design framework rather than a guarantee. Mixed grouping may support cooperation when thoughtfully organised, but grouping should fit the actual task, access and safety needs.

Worked comparison (invented). A club changes to private improvement feedback and cooperative tasks. Attendance rises from 18/30 to 24/30: 60% to 80%, a rise of 20 percentage points or 33.333…% relative to the starting rate. This is compatible with improved engagement, but does not establish that the climate caused it. Season, timetable, transport, membership changes and extra coaching may differ. A stronger investigation compares suitable baselines and groups, records the planned changes and follows participation and experience over time.

AHL: Six mini-theories of self-determination

■ Cognitive evaluation theory: what a reward communicates

Cognitive evaluation theory 认知评价理论 addresses intrinsic interest and how social events support or undermine perceived autonomy and competence. The same badge can communicate useful evidence of improvement or pressure to comply. Specific accurate feedback may support competence when it preserves choice; surveillance, threats or making self-worth depend on rewards may undermine autonomy. Reward effects depend on meaning, contingency and prior interest, so unexpected is not a universal instruction that every award must be a surprise.



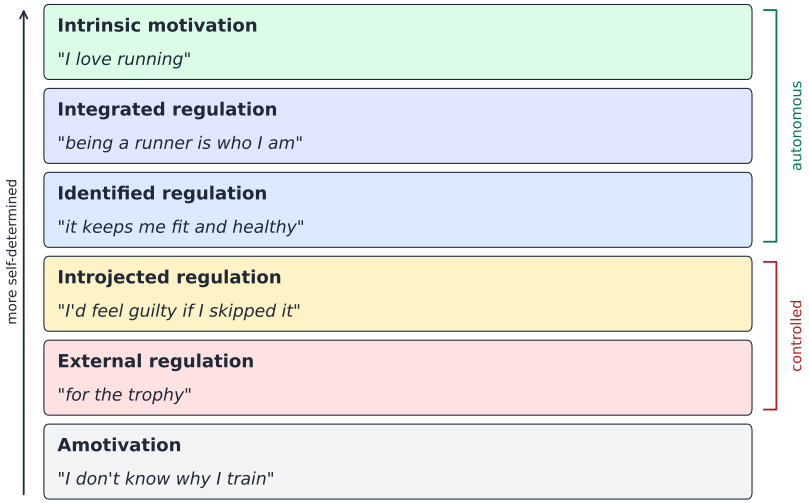
effects depend on meaning, contingency and prior interest

What a reward communicates

The drawing study above concerns an expected award for an activity children already liked. It does not measure every sporting reward, long-term professional participation or all children's motives. A useful evaluation asks who was studied, what was offered and which later behaviour was measured. Removing all recognition is not a necessary conclusion.

Organismic integration theory: internalising a purpose

Organismic integration theory explains different forms of extrinsic regulation and how a purpose can become more personally endorsed. External regulation involves reward or sanction; introjected regulation involves internal pressure such as guilt or proving worth; identified regulation involves valuing the purpose; integrated regulation fits that purpose with wider identity and values. Identified and integrated reasons remain extrinsic when the activity serves a separable outcome. They can nevertheless be autonomous. Integrated regulation is not identical to enjoying the activity itself.



Classify the stated reason, not the athlete or reward alone

Regulation	Invented reason for taking part
External	"I attend only to avoid losing a privilege"
Introjected	"I would feel ashamed of myself if I missed it"
Identified	"I value the fitness benefit, even when this session is not enjoyable"
Integrated	"This valued training supports how I choose to live"
Intrinsic	"I enjoy doing the activity itself"

People may have several reasons at once and need not progress through a fixed sequence. A coach can explain purpose, acknowledge concerns and provide meaningful choices; internalisation cannot be established simply by ordering a participant to say they want to train.

Worked scores (invented). On one supplied 1-to-7 scale, intrinsic 6.2, integrated 5.8 and identified 5.5 exceed introjected 3.1 and external 2.0; amotivation is 1.2. This describes the reported profile, not a diagnosis or a guaranteed attendance prediction. The simple mean of the three listed autonomous subscales is $17.5/3 = 5.8333\ldots$; the two controlled subscales average $5.1/2 = 2.55$. These classroom summaries are not a validated composite questionnaire score or a causal estimate.

Causality orientations theory: a tendency across contexts

Causality orientations theory examines tendencies in how people interpret situations and regulate behaviour. An autonomy orientation attends to interest and personal value; a control orientation attends to demands, rewards and approval; an impersonal or amotivated orientation involves perceived ineffectiveness or lack of con-

trol. A specific reason for one practice session is not automatically a stable orientation across all life situations. Study patterns across appropriate contexts without diagnosing a person from one absence.

Basic psychological needs theory: support and thwarting

Basic psychological needs theory examines autonomy, competence and relatedness as conditions for functioning and well-being. A technically successful session may still thwart autonomy through humiliating threats or relatedness through exclusion. Low support and active thwarting are useful distinctions: not offering a choice is not identical to coercion, and being alone for one drill does not establish lasting social exclusion. Examine the participant's experience and context rather than assuming that a winning team has met every need.

Goal contents theory: what is pursued

Goal contents theory asks what a goal is about, distinct from why the person pursues it. Personal growth, connection and contribution are intrinsic goal contents; image, status or financial recognition are extrinsic contents. A pupil might pursue a community activity willingly or under pressure, so content and regulation are separate questions. Associations with well-being should not become a claim that one stated goal diagnoses health or makes someone morally better.

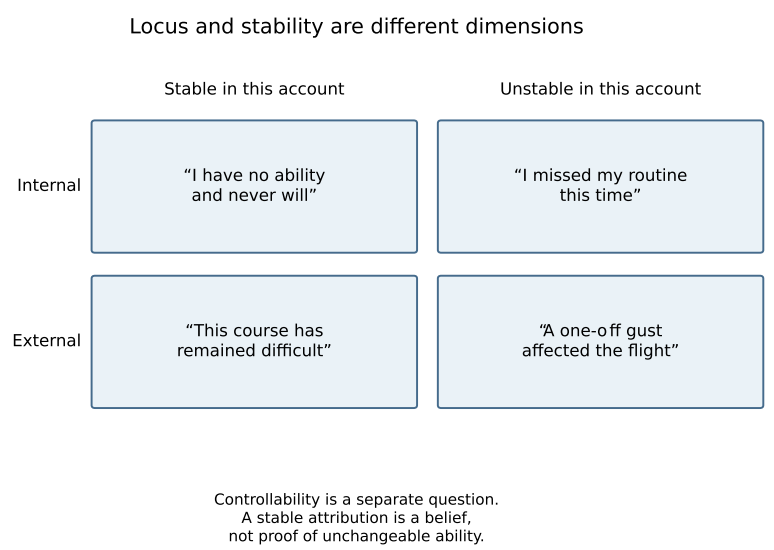
Relationships motivation theory: quality of connection

Relationships motivation theory examines how close, supportive connections contribute to functioning. A good coach–athlete or teammate relationship can support relatedness while also respecting autonomy and competence. Merely placing people in a group does not ensure supportive relationships; conditional acceptance, exclusion or pressure may frustrate needs. A practical response involves respectful listening, meaningful participation and reliable support, then evaluating the actual experience rather than counting team membership as proof.

Extension: Explaining outcomes

Explaining success and failure

Attributions 归因 are the reasons people give for their success or failure. They matter because they affect future emotion, confidence and motivation.



Illustrative attribution statements; classify the perceived explanation and timescale, not an immutable ability label

Weiner classified attributions on three dimensions:

- **Locus of causality**: internal (about the athlete: ability, effort) or external (outside the athlete: task difficulty, luck, the referee).
- **Stability**: stable (expected to persist in that explanation) or unstable (expected to differ). Ability, effort and difficulty are not permanently assigned to one cell regardless of wording or timescale.
- **Controllability**: under the athlete's control (effort, strategy) or not (luck, the opponent's skill).

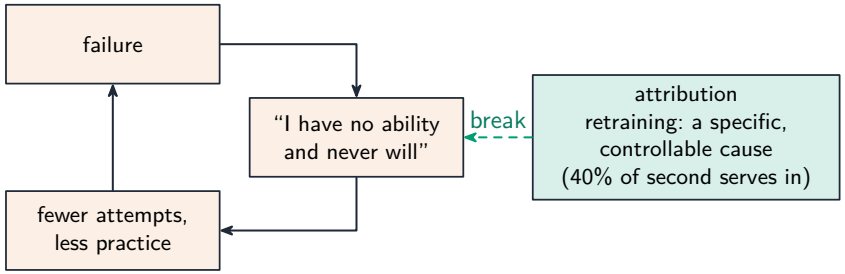
A constructive explanation remains consistent with evidence. After success, recognising a practised skill can support confidence; after failure, identifying a feasible change in preparation may support a plan. But not every failure is caused by insufficient effort. Injury, access, unfair decisions and other barriers can matter. Internal does not automatically mean controllable, and external does not automatically mean unstable. Do not invent a positive story or blame a person to fit a preferred cell.

The **self-serving bias** 自利偏差 is the common habit of taking credit for success (internal attributions) and blaming failure on external factors (the referee, the pitch). It protects self-esteem but can stop the athlete from learning from mistakes.

Learned helplessness

Learned helplessness 习得性无助 concerns a perception that actions do not influence outcomes, which can discourage further attempts. It should not be diagnosed from one comment, nor treated as inevitable after every failure. **Attribution retraining** 归因再训练 can help examine explanations and identify feasible, evidence-based

actions while acknowledging real barriers. Unit C.1 provides the syllabus connection.



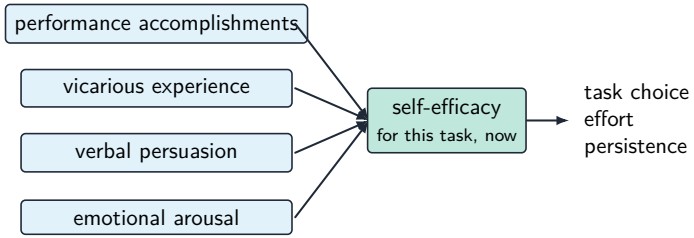
Breaking the helplessness loop

Worked interpretation (invented). After a 6–2, 6–3 loss, a player says "I have no ability and never will". This is internal and stable as stated; controllability requires a separate judgement. If 40% of second serves went in, that gives one specific performance observation, not proof of the loss's sole cause. A supervised plan can target a suitable serve action and reassess it, without guaranteeing more wins or denying the opponent's contribution.

Extension: Self-efficacy and confidence

Believing you can

Self-efficacy 自我效能 (Bandura) is a person's belief that they can successfully perform a specific task in a specific situation, for example "I can make this free throw now". It is more specific than general **self-confidence**. Self-efficacy can influence task choice, effort and persistence, while actual skill, demands and support also affect performance. Confidence does not guarantee a safe or successful attempt.



Bandura's four sources of self-efficacy

Bandura described four main sources. Relevant mastery experience is often influential, but the value of each source depends on its credibility and context:

Source	Meaning	Example
Performance accomplishments	Past success at the task	Having landed the dive many times in training
Vicarious experience 替代经验	Seeing someone similar succeed	Watching a teammate of similar ability land it
Verbal persuasion 言语说服	Encouragement from others or oneself	The coach saying, "You're ready for this"
Emotional and physiological states	How the athlete interprets their arousal	Seeing a racing heart as readiness, not fear

Imagery of success is also used as a source. Coaches build self-efficacy by offering achievable, safely supervised steps, using models of similar ability, giving honest encouragement and teaching arousal control. Interpret failure in context; no universal ranking of its impact follows from its timing alone.

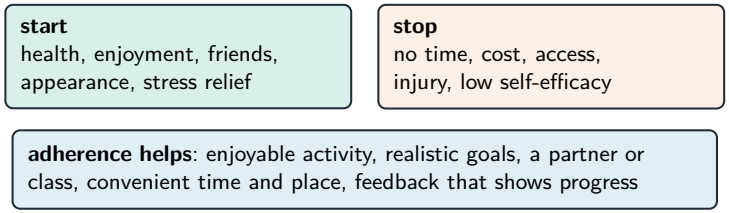
Extension: Motivation for exercise

Why people start and stop

Physical activity has strong health benefits, yet many people who start an exercise programme stop. Dropout estimates depend on the population, programme, definition and follow-up period; do not apply one universal six-month percentage. **Exercise adherence** 运动坚持 is keeping to a programme over time.



A parkrun start: free, weekly and social, it removes several common barriers to starting exercise



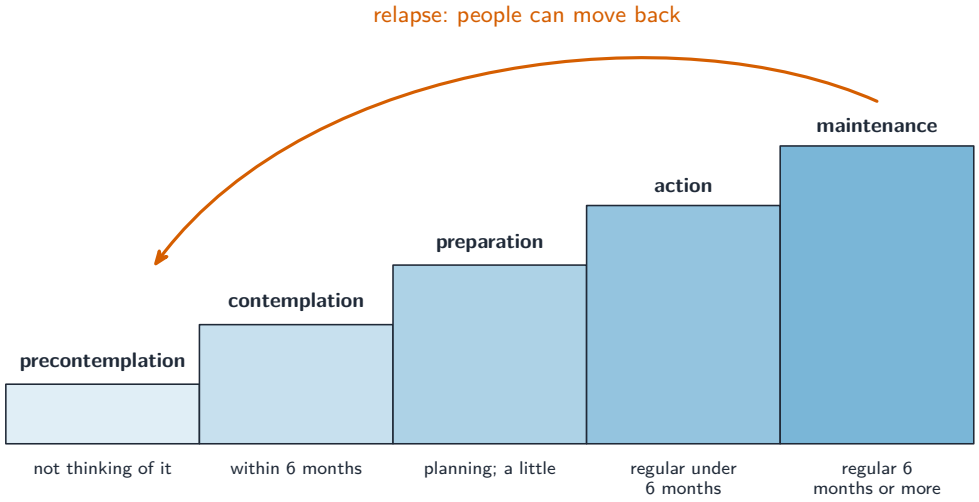
Starting, stopping and adherence

Reasons for starting	Common barriers
Health and fitness, weight control, appearance, enjoyment, friends, stress relief	Lack of time, cost, poor access to facilities, low enjoyment, injury, low self-efficacy, lack of support

Adherence is helped by enjoyable activities, realistic goals, social support (a training partner or class), convenient times and places, and feedback that shows progress.

Stages of change

The **transtheoretical model** 跨理论模型 describes stages people move through when changing behaviour:



The transtheoretical model: people climb the stages but can also slip back

1. **Precontemplation**: not thinking of exercising in the next 6 months.
2. **Contemplation**: thinking about starting within 6 months.
3. **Preparation**: planning to start soon, perhaps exercising a little.
4. **Action**: exercising regularly for less than 6 months, with duration defined from that person's behaviour change, not merely the club's calendar.
5. **Maintenance**: maintaining the defined regular behaviour for 6 months or longer in this conventional model.

People can move back as well as forward (relapse). Support should fit the stage: information about benefits for precontemplators, help to plan for those preparing, and strategies to prevent relapse for those in action.

> **Worked example.** A school gym starts a lunchtime club in September with 80 students. In December 56 still attend, and in March 44. Dropout by December $= (80 - 56) \div 80 \times 100 = 30$ %; by March $= (80 - 44) \div 80 \times 100 = 45$ %. March retention is $44/80{\times}100 = 55\%$. From December to March, a further 12 of the 56 December participants leave: $12/56{\times}100 = 21.4286\ldots\%$, a different denominator from cumulative dropout. The calendar and attendance counts do not establish each person's stage: prior exercise, exact duration and the defined regular behaviour are needed. Ask about barriers and preferences before choosing support; enjoyment, suitable access and constructive feedback can be investigated without promising identical responses.

Practice

All numerical cases are invented.

1. Define motivation by direction and intensity. Contrast intrinsic enjoyment with an instrumental purpose, and explain why identical attendance can hide different motives.
2. Explain need-achievement theory as a chain linking person factors, situation, resultant tendency, emotion and behaviour. Suggest a situational change for a learner who fears public failure.
3. Distinguish task and ego orientation from mastery and ego climate. Apply all six TARGET areas to a club without guaranteeing an outcome.
4. Explain autonomy, competence and relatedness with an appropriate coaching action and a misconception about each.
5. Distinguish controlled, autonomous and absent motivation. Give examples involving enjoyment, pressure and a personally valued benefit; explain why autonomous does not always mean intrinsically enjoyable.
6. In a club, attendance rises from 18/30 to 24/30 after a climate change. Find both rates, the percentage-point rise and relative rise; state why causation remains uncertain.
7. Describe the three conditions in the 1973 drawing study and its bounded inference. Explain why this does not establish a universal rule about sporting rewards.

8. As extension applications, classify a stated internal/stable explanation without assuming uncontrollability, and describe four sources of task-specific self-efficacy without promising successful performance.
9. A class starts with 60 people and 39 remain after three months. Find retention and dropout percentages, identify a denominator risk and suggest evidence needed to choose support.
10. The invented 80-person club retains 56 in December and 44 in March. Find cumulative December/March dropout, March retention and the relative loss from December to March. Explain why stage of change cannot be inferred from the month alone.
11. **AHL** Explain when high ego orientation may threaten motivation and why perceived evaluation, low task orientation and real barriers matter.
12. **AHL** Explain cognitive evaluation and organismic integration theories. Classify external, introjected, identified and integrated regulation, contrasting integration with intrinsic enjoyment.
13. **AHL** For intrinsic 6.2, integrated 5.8, identified 5.5, introjected 3.1 and external 2.0, find the two simple group means. State what the comparison can and cannot establish. Contrast with a second profile: intrinsic 2.5, identified 3.0, introjected 5.4, external 6.1.
14. **AHL** Apply causality orientations, basic psychological needs, goal contents and relationships motivation theories to a school team. Distinguish goal content from regulation and a state report from a cross-context tendency.

Answers.

1. Direction concerns which actions are chosen; intensity concerns effort and persistence. Enjoying the act is intrinsic; pursuing a separable result is instrumental/extrinsic. Two attendees may have different or mixed reasons. Attendance alone identifies neither their motivation nor a diagnosis.
2. Approach/avoidance motives interact with perceived chance and value of success. The resultant tendency relates to anticipated pride/shame and behaviour. A coach can replace humiliating public comparison with a suitable development target and constructive private feedback. This changes the situation's meaning and opportunities, without guaranteeing a trait change. Moderate challenge is not a universal 50% failure prescription.
3. Orientation is the individual's success criterion; climate is the environment's demands and recognition. Task orientation values improvement; ego orientation compares others. TARGET: meaningful tasks; appropriate shared authority; accurate improvement/cooperation recognition; purposeful inclusive grouping; self-referenced evaluation; suitable learning time. Match these decisions to participants and task safety; evaluate actual experience and participation rather than assuming a labelled climate caused the result.
4. Autonomy: willing endorsement, supported by meaningful choices and reasons; clear rules can remain. Competence: effective action, supported by achievable challenge and useful feedback; it does not require beating teammates. Relatedness: valued connection, supported by respect and inclusion; it is not compulsory agreement. A nominal choice or team assignment does not establish the participant's experience.
5. Controlled reasons involve approval or guilt pressure; autonomous reasons involve willingness and personal value; amotivation involves little intention or perceived useful action–outcome connection. Enjoying swimming is intrinsic. Willingly doing an uninteresting drill for a valued benefit can be autonomous but extrinsic. Reasons can coexist and do not guarantee future attendance.
6. $18/30\times100 = 60\%$; $24/30\times100 = 80\%$; rise = 20 percentage points; relative rise = $(24-18)/18\times100 = 33.333\ldots\%$. Season, access, membership or other coaching changes may differ. Comparable baselines/groups, independent participants and follow-up strengthen inference. Attendance alone identifies neither the cause nor the participant's reasons.
7. Initially interested preschool children experienced expected award, unexpected award or no award. Later free-play interest was lower after expected reward than in comparison conditions. This supports a bounded overjustification inference, not a universal reduction or direct estimate for paying young athletes. Sample, activity, reward contingency and measured outcome limit generalisation.
8. "I have no ability and never will" is internal/stable as perceived; controllability is separate and ability is not proved immutable. Relevant mastery experience, observing a credible similar model, credible persuasion and interpretation of bodily/emotional states inform self-efficacy. They replace neither actual competence nor safe supervision. A real external barrier should not be denied to force an effort explanation.
9. Retention = $39/60\times100 = 65\%$; dropout = $21/60\times100 = 35\%$. Cumulative dropout uses the original cohort, not those remaining. Define attendance and eligibility; investigate missing records, reasons, access and prior activity before choosing support. A rate alone establishes neither a change-model stage nor a motive.
10. December dropout = $24/80 = 30\%$; March dropout = $36/80 = 45\%$; March retention = $44/80 = 55\%$; interval loss = $12/56\times100 = 21.428571\ldots\%$ of December attenders. The denominators answer different questions. Stage-of-change classification needs each person's defined behaviour, intention and duration; a club anniversary does not establish regular exercise for everyone.
11. **AHL** When success is mainly defined by comparison, low task orientation leaves fewer improvement-based ways to feel successful. Believing others see one's ability as low may threaten self-worth and invite defensive excuses, anxiety or withdrawal. These are conditional theoretical processes; do not assume cheating or dropout from one orientation score. Respect real injury/access barriers and use suitable evidence. Constructive private development feedback may support participation

without guaranteeing a result.

12. **AHL** CET addresses how events/rewards affect intrinsic interest through autonomy/competence and perceived control/information. OIT addresses internalisation of instrumental purposes: external reward/sanction; introjected guilt/self-worth pressure; identified personal value; integrated fit with identity and wider values. The latter two can be autonomous yet extrinsic. Intrinsic means enjoying the activity itself. Reasons can coexist and need not advance through a fixed sequence; surprise rewards or eliminating all praise are not universal prescriptions.
13. **AHL** First simple mean = (6.2+5.8+5.5)/3 = 5.833333…; second = (3.1+2.0)/2 = 2.55. The reported profile favours listed autonomous reasons; these invented arithmetic summaries are not a validated composite, diagnosis or prediction of certain persistence. Second listed autonomous mean = (2.5+3.0)/2 = 2.75; controlled mean = (5.4+6.1)/2 = 5.75. Integrated regulation was not supplied for that profile; do not invent its value or assume directly comparable composite constructs. Conditions, instrument evidence and follow-up matter.
14. **AHL** COT asks about autonomy-, control- or impersonal-oriented tendencies across contexts; one reluctant session does not establish an enduring orientation. BPNT examines support/thwarting of autonomy, competence and relatedness, which winning does not establish. GCT distinguishes what is pursued, such as growth/connection versus image/status, from why it is pursued; the same community goal can be chosen willingly or under pressure. RMT examines supportive relationship quality, including respect for autonomy and competence as well as belonging; mere team membership does not ensure it. Apply each to the actual experiences and outcomes without diagnosing or assuming a universal causal effect.

Exam tips

- Distinguish motives, orientation, climate and observed behaviour.
- State denominators; treat scores as evidence, never diagnoses.
- **AHL** Distinguish the six mini-theories, especially goal content versus regulation and integrated extrinsic reasons versus intrinsic enjoyment.

Stress and coping

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

This handout teaches C.4 Stress and coping for the course first assessed in 2026: what stress is and how athletes appraise it, how the body responds, how arousal and anxiety affect performance, how anxiety is measured, and how athletes cope with stress and avoid burnout. Sections marked **AHL** are for Higher Level only. The common core covers arousal/anxiety models, measurement and coping categories. Numerical cases below are invented teaching examples, not real examination data or diagnostic thresholds.

Prerequisites: unit A.1 (the nervous and endocrine systems) and unit C.1 (individual differences). Unit C.5 teaches the psychological skills used to manage stress.

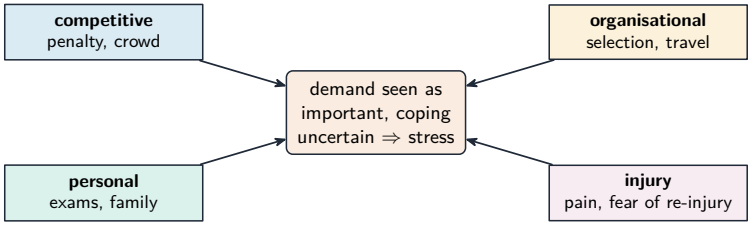
Stress and appraisal

The greatest gymnast stops

At the Tokyo Olympics in July 2021, Simone Biles withdrew during the team final. USA Gymnastics' annual report describes her difficulty with the "twisties" and the health-and-safety reasons for stopping. She returned to win balance-beam bronze on 3 August. These dated events show why safe participation and support matter even in elite sport; they do not establish one psychological cause or let a classroom observer diagnose an athlete. Stepping away from an unsafe action is different from assuming that any withdrawal is poor coping (USA Gymnastics report; beam result).

What stress is

Stress 压力 is the response to a situation that the person sees as demanding, when they are not sure they can cope and the result matters to them. A **stressor** 压力源 is the situation or event that causes it.



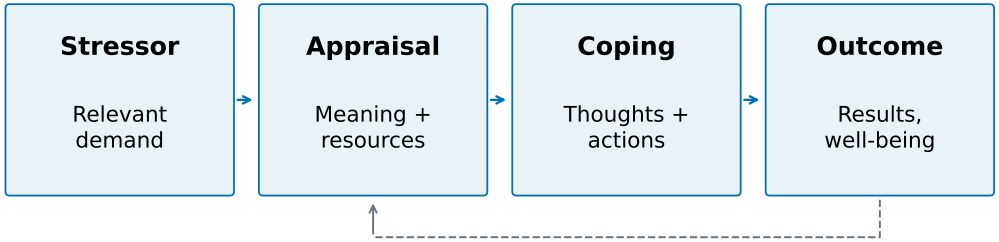
eustress: experienced as challenge distress: experienced as strain

Sources of stressors

Source	Examples
Competitive	An important match, a penalty, the crowd, a strong opponent, being evaluated
Organisational	Selection, coaching style, travel, money, team conflict
Personal	School exams, relationships, family expectations, social media
Injury	Pain, fear of re-injury, losing a place in the team

Stress is not always harmful. **Eustress** 良性压力 is a positively experienced challenge that may support focus and effort. **Distress** 不良压力 is a negatively experienced demand associated with strain or difficulty coping.

The transactional model



Appraisal, action and feedback form a changing process, not a fixed either/or classification

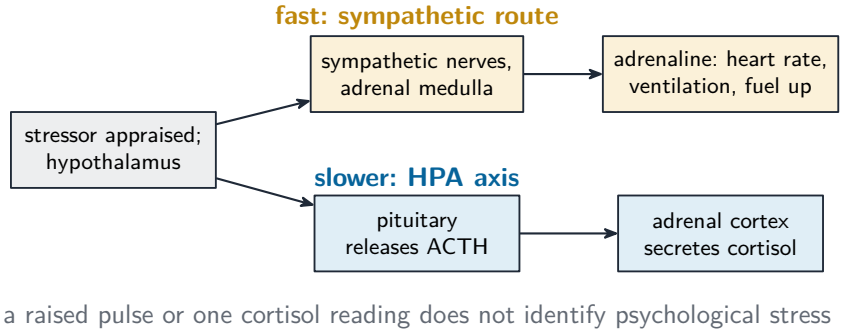
In the **transactional model** 交互模型 of Lazarus and Folkman, stress depends on how a person **appraises** 评估 the situation, not only on the situation itself:

- **Primary appraisal**: is this irrelevant to me, a challenge (a chance to gain) or a threat (a chance of harm or loss)?
- **Secondary appraisal**: do I have the resources (skill, fitness, support, time) to cope?

Perceived demands and resources contribute to challenge or threat appraisals. Challenge and threat can coexist or change as information changes; primary and secondary appraisal are related processes rather than a guaranteed single-file sequence. Two players can interpret the same penalty differently, and the same player can reappraise it after new feedback. Actual resources and demands matter alongside interpretation: changing a belief does not remove a genuine injury or an impossible timetable.

The body's stress response

- The **sympathetic nervous system** and adrenaline can increase heart rate, ventilation and fuel availability rapidly. Exercise, posture and temperature also affect these measurements, so a raised pulse alone does not identify psychological stress.
- The HPA axis links hypothalamic signals to pituitary ACTH and the adrenal cortex, which secretes **cortisol** 皮质醇. Cortisol has normal regulatory functions; prolonged dysregulation can affect sleep and immune functioning. One concentration is not a diagnosis or a direct reading of a person's coping capacity.
- Selye's **general adaptation syndrome** 一般适应综合征 describes **alarm**, **resistance** and **exhaustion** as a historical model of response to sustained demands. It does not supply inevitable dates, a literal fuel gauge or a rule that every prolonged demand must end in burnout. Recovery, context and individual responses vary.



The fast sympathetic route and the slower HPA axis

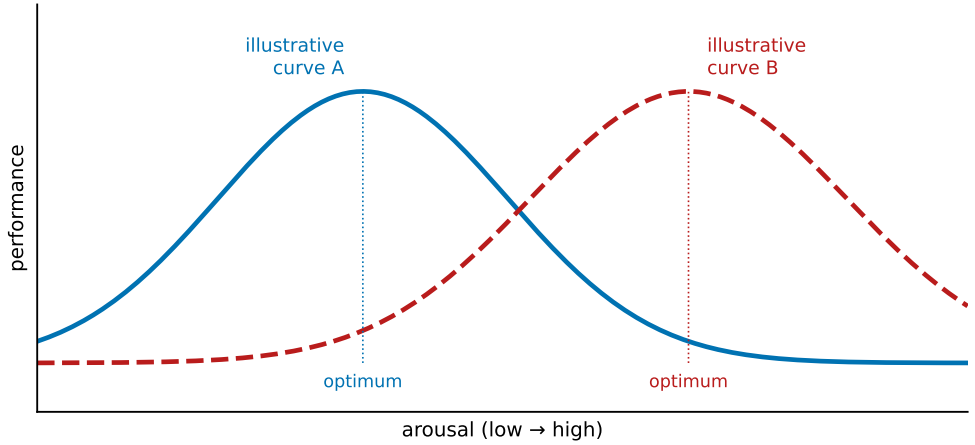
Arousal and performance

What arousal is

Arousal 唤醒 is how physically and mentally activated a person is, from deep sleep to extreme excitement. It is neither positive nor negative in itself. Signs include heart rate, sweating and muscle tension (physiological), and alertness and thoughts (psychological).

Theories of arousal and performance

Drive theory 驱力理论 proposes that arousal strengthens the dominant response. If a well-learned dominant action is appropriate, this may help; if the likely action is an error, it may hinder. An expert can still have an unsuitable dominant response, and increasing arousal does not guarantee a better result. The theory alone does not explain all sudden performance losses.



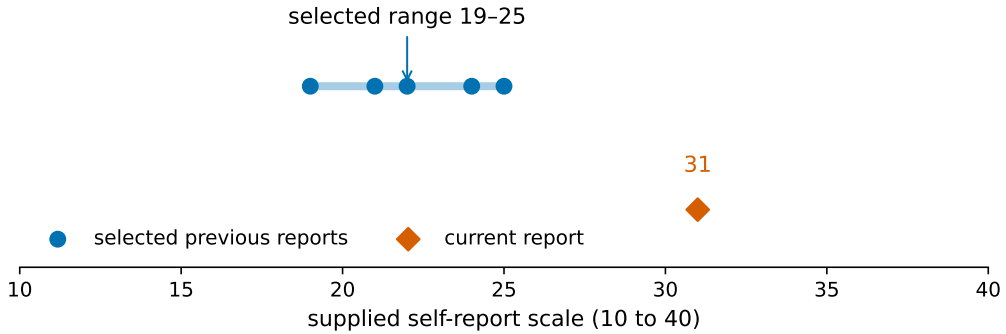
Illustrative curves, not measured task-specific optima or coaching thresholds

The **inverted-U hypothesis** proposes an increase in performance up to a context-dependent optimum, followed by decline. It is a model to examine, not a universal symmetrical law. Precision, force, attention, experience and the performer's interpretation can influence the relevant relationship. A golf putt and a powerful action have different demands, but that does not make all powerful skills simple or establish a fixed arousal prescription for a rugby player, expert or extrovert.

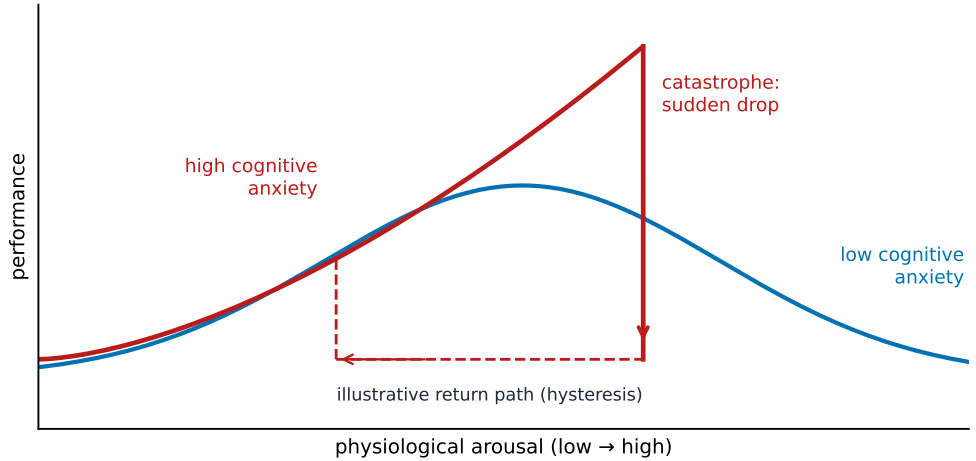
The model combines activation into one dimension and often sketches a smooth curve. Real data may be noisy, asymmetric or show sudden transitions, and activation is not identical to worry. To investigate an optimum, define a comparable outcome, measure relevant states consistently and consider repeated within-person evidence rather than assigning a value from a sport label.

Individual zones of optimal functioning 最佳功能区 (IZOF), associated with Hanin, emphasise individual patterns of emotions and functioning. A useful zone is a range rather than one universal score. The content and interpretation of emotions, task and person matter; a group average does not specify every individual's optimal state.

> **Worked example (invented).** A swimmer selects five of her best previous races and reports pre-race ratings 19,21,22,24,25 on a supplied 10-to-40 scale. The selected range is 19–25, width 6; the mean is $111/5 = 22.2$. Today's rating 31 is above those five reports. This is a descriptive comparison, not a validated optimal zone or a diagnosis: all other races, outcomes, conditions and measurement error are missing. Do not infer that lowering the score must improve her next race or prescribe an intervention from it alone.



Selected reports are not a validated intervention threshold



Different model paths at the same activation illustrate hysteresis, not a proven recovery treatment

Catastrophe theory 突变理论 (Hardy and Fazey) distinguishes physiological arousal from **cognitive anxiety**. In a simplified account, high worry combined with increasing physiological activation can produce an abrupt rather than gradual performance drop. A different return path is called **hysteresis**: merely reversing activation a little need not retrace the outward path.

These are model predictions, not an explanation of every mistake or a prescription for how long an athlete must recover. One sudden loss of performance could involve fatigue, technical error, distraction, injury or measurement issues. The sketch neither establishes a universal trigger value nor proves that a particular calming technique causes recovery.

Anxiety

Types of anxiety

Anxiety 焦虑 is an unpleasant emotional state of worry, nervousness and apprehension, with activation of the body.



A penalty kick: a skill practised a thousand times, now performed under the pressure of the moment

	cognitive (worry)	somatic (body)
trait stable tendency	tends to worry before most competitions	usually feels tense and jittery before events
state right now	"I'm going to miss this putt" on the 18th green	racing heart and sweaty hands over the last putt

Trait relates to state, but appraisal and context decide the moment

Two pairs of anxiety types: how stable it is (trait or state) and where it shows (mind or body)

Pair	First type	Second type
Trait or state	**Trait anxiety** 特质焦虑: a stable, general tendency to see situations as threatening (part of personality)	**State anxiety** 状态焦虑: anxiety felt at a particular moment, which changes from minute to minute
Cognitive or somatic	**Cognitive anxiety** 认知焦虑: worry, negative thoughts, fear of failure, poor concentration	**Somatic anxiety** 躯体焦虑: the bodily signs, such as a racing heart, butterflies, sweaty hands and muscle tension

Trait measures may relate to state responses, but task appraisal and context also matter; neither determines the other for every occasion. A golfer, for example, may feel little anxiety in practice rounds but a lot before the last putt of a major. Patterns over time vary. Some performers report worry well before an event and bodily activation nearer the start, but a fixed universal timeline should not be assumed.

Multidimensional anxiety theory

Multidimensional anxiety theory 多维焦虑理论 (Martens and colleagues) predicts that:

- cognitive anxiety harms performance in a straight line: more worry, worse performance;
- somatic anxiety has an inverted-U relationship with performance: a moderate level helps;
- self-confidence improves performance in a straight line.

These are theoretical predictions, not universal individual laws. Repeated evidence may differ with task, experience and interpretation; a self-report score alone does not establish the shape or cause of a performance relationship.

Is anxiety always bad?

Distinguish anxiety **intensity** from its interpreted **direction**. Two athletes with the same anxiety score may interpret it differently: one sees a racing heart as **facilitative** ("I'm ready"), the other as **debilitative** ("I'm going to fail"). Interpretation can differ within the same athlete across events. Reframing (unit C.5) may help examine meaning, but does not remove genuine hazards or guarantee improved performance.

Measuring anxiety

Method	What it measures	Strengths	Limitations
Sport Competition Anxiety Test (SCAT)	Trait anxiety: 15 items (10 scored), total 10 to 30	Quick, standardised, compares athletes	General trait only, not how the athlete feels on the day
Competitive State Anxiety Inventory-2 (original CSAI-2)	State anxiety: 27 items; cognitive anxiety, somatic anxiety and self-confidence, 9 items each, each scored 9 to 36	Separates the three parts; can be used before each event	Self-report: athletes may hide anxiety or give answers they think the coach wants
Physiological measures	Heart rate, blood pressure, galvanic skin response/sweating; cortisol or muscle tension in suitable protocols	Instrument readings do not rely only on self-report	Indirect, non-specific indicators; exercise, heat, timing and other influences require control
Observation	Behaviour such as fidgeting, yawning, repeated toilet visits	Real setting	Observer bias; behaviour differs between people

Use the correct version and scoring instructions. The original CSAI-2 has three 9-item subscales; revised CSAI-2R has a different 17-item structure and should not inherit the original raw totals blindly. A standardised format aids consistency but does not establish validity for every language, age, purpose or setting. A questionnaire reports experience under specified conditions; physiological measurements are proxies, not direct proof of an inner state.

Worked interpretation (invented). A supplied original-format profile is cognitive 30, somatic 16 and confidence 14, each on a 9–36 range. The values describe different dimensions; do not add them into one undifferentiated anxiety total, or call 16 a clinical "moderate" threshold without validated interpretation. The profile invites a conversation about worry, bodily experience, task demands and support; it does not diagnose a disorder, establish a cause or select a guaranteed treatment.



The worked profile: three separate dimensions on the same 9–36 scale, never one total

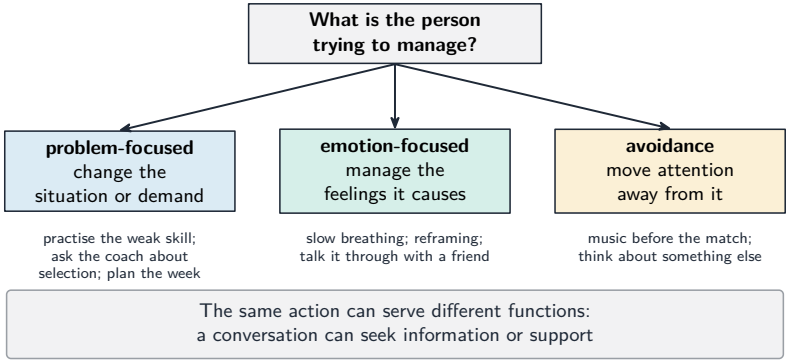
Worked arithmetic (invented classroom items). Nine 1-to-4 ratings are 2,3,4,2,3,2,4,3,3: sum 26, mean $26/9 = 2.888\ldots$. A second set 1,2,2,1,2,2,1,2,2 sums to 15; a third 3,2,3,2,3,2,3,2,3 sums to 23. These invented ratings demonstrate separate subscale arithmetic; they are not the actual questionnaire items, a validated substitute or diagnostic cut-offs.

For a class investigation, use school-approved low-risk tasks and non-sensitive voluntary measures. Explain consent, confidentiality and withdrawal arrangements. Do not induce distress, expose private results or ask pupils to diagnose classmates. A recognition concern should lead to appropriate support; the IOC distinguishes recognition and clinical assessment rather than treating a positive screen as a diagnosis (IOC tool development).

Coping

Coping strategies

Coping 应对 is the thoughts and actions a person uses to manage demands that they see as stressful.



Classify coping by what it is trying to manage, not by the activity itself

Strategy	Aim	Examples
Problem-focused coping 问题导向应对	Change the situation or the demands	Make a plan, practise the weak skill, manage time, talk to the coach about selection
Emotion-focused coping 情绪导向应对	Manage the feelings the situation causes	Relaxation, reframing, positive self-talk, seeking emotional support, humour
Avoidance coping 回避应对	Move attention away from the stressor	Listening to music before a match, thinking about something else, leaving the situation

Classify coping by its function. Seeking information about a timetable can be problem-focused; discussing feelings with a trusted person can be emotion-focused. A short music break that helps someone regulate feelings differs from repeatedly avoiding a necessary conversation. Ignoring pain or delaying appropriate help should not be presented as a useful default strategy. Leaving an unsafe or harmful situation can be an appropriate protective action.

Social support 社会支持 can provide care, information or practical help. The same conversation can have more than one function. Do not infer that talking is always emotion-focused or that physical activity is always problem-focused; explain what the person is trying to manage.

Simple self-talk can guide an action ("scan, choose, pass"), recall a helpful past experience, or use an agreed acronym for a routine. It can also be unintentional and discouraging. Choose a concise cue related to the task, practise it in suitable conditions and evaluate its effect with the performer. More positive words do not automatically improve a technical action or resolve a real barrier.

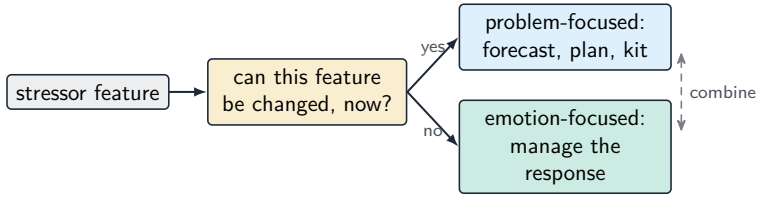
Relaxation skills can help some performers manage activation and attention. A comfortable familiar breathing or muscle-relaxation routine should remain voluntary and suitable to the person; it is not a universal treatment or proof that all bodily activation is harmful. Do not infer efficacy from a pulse change without controlling for ordinary rest, posture and activity.

Worked comparison (invented). In a seated low-risk classroom illustration, pulse changes from 72 to 66 beats/min: a fall of 6 beats/min or $6/72 \times 100 = 8.333\ldots\%$. This does not establish reduced anxiety, improved sport performance or an effect caused by a particular routine. A comparable rest condition, consistent measurement and the participant's experience would improve interpretation.

AHL: Controllability and context-specific coping

Separate what can and cannot be changed

Controllability concerns a particular feature and timescale. A player cannot change tomorrow's wind, but can obtain forecasts, choose permitted suitable clothing and plan a safe response. The stressor is not simply one indivisible "uncontrollable" label. A pupil may negotiate a timetable even when the examination date is fixed. Actual resources, authority and access affect what is feasible.

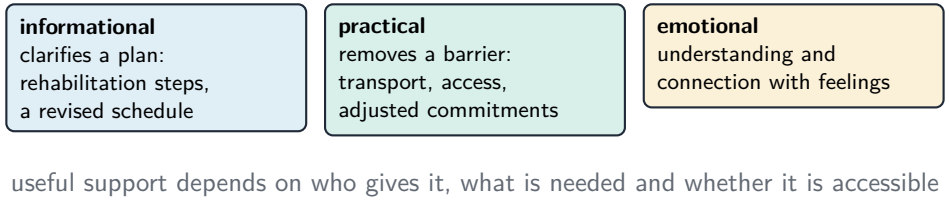


Match the coping strategy to what can be changed

Problem-focused strategies are often appropriate when a relevant demand can be changed; emotion-focused strategies can help manage the response when the demand cannot be changed directly. They can be combined. Appraising a stressor as controllable does not mean the athlete is to blame for it, and a suggestion is not feasible merely because the coach finds it simple.

Match the support to its function

Informational support may clarify a rehabilitation or scheduling plan; practical support may improve transport or access; emotional support may provide understanding and connection. The course highlights support seeking as particularly effective in athlete coping, while requiring attention to the individual and situation. It is an important resource, not a sign of insufficient toughness. Its usefulness depends on who provides it, what is needed and whether it is accessible and safe. No single source or strategy is most effective for every athlete and situation.



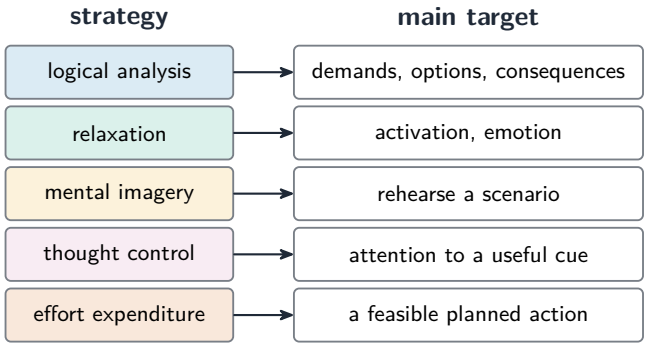
Match the support to the need

In an invented school–sport conflict, the athlete, coach and teachers can discuss actual commitments and feasible adjustments. A supportive friend can help with feelings

while practical planning addresses demands. Do not promise that reframing removes an incompatible schedule, or prescribe a training reduction without considering the individual plan and appropriate supervision.

Evaluate strategies rather than prescribing a slogan

Logical analysis examines demands, options and consequences. Relaxation targets activation or emotional regulation. Mental imagery can rehearse an appropriate scenario; thought control can redirect attention towards a useful cue; effort expenditure can support a feasible planned action. Their effectiveness depends on the person, task, timing and implementation. Imagery and psychological skills receive further treatment in C.5.



effect depends on person, task, timing and implementation; rest, reporting injury or seeking help are not failures to cope

Coping strategies and what each targets

A brief distraction may regulate emotion and help return to a task, but is not evidence that the underlying barrier has been resolved. Persistent disengagement, unproductive venting or self-blame may leave demands unaddressed or worsen experience. Distinguish these from taking necessary rest, reporting injury, seeking help or leaving an unsafe setting. Evaluate purpose and consequences rather than calling every pause or withdrawal maladaptive.

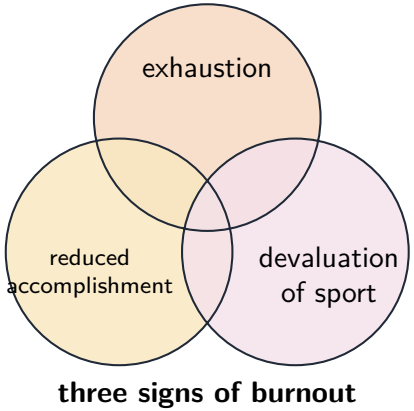
A suitable investigation defines the strategy, participants, comparison and outcomes. Record both experience and relevant performance over appropriate follow-up, consider expectancy and measurement effects, and avoid treating a group association as a guaranteed individual result. A lower anxiety score is not automatically the only successful outcome; better access, a workable plan or safe participation may be the relevant aim.

Well-being and support

Burnout and mental health

Burnout 倦怠 can follow long-term stress, often when high training demands meet low recovery and little enjoyment. Raedeke described three signs:

1. **Physical and emotional exhaustion** from training and competition.
2. **Reduced sense of accomplishment**: feeling that one is not improving or achieving.
3. **Devaluation of sport**: no longer caring about the sport, and possibly dropping out.



Raedeke's three signs of burnout

Possible interacting contributors include concentrated sporting demands, inadequate recovery, perfectionistic concerns, pressure and limited support. These associations do not diagnose burnout or make any single pathway inevitable. Prevention includes time off, variety, involving athletes in decisions, a focus on enjoyment and mastery rather than only winning, and early support.

Athletes can have mental health problems such as anxiety disorders, depression and eating disorders, like anyone else. The IOC published a mental-health toolkit in 2021, but athlete mental-health needs and support did not begin in that year. A questionnaire in class can describe how people report feeling, but it never diagnoses a disorder: anyone worried about themselves or a friend should talk to a trusted adult or a professional.

Practice

All numerical cases are invented. No class score below supplies a diagnostic threshold or treatment recommendation.

1. Distinguish stressor, appraisal, eustress and distress. Explain how two athletes can interpret the same demand differently without assuming only one can experience strain.
2. Outline rapid autonomic and HPA responses and the historical general adaptation syndrome. Explain why one pulse or cortisol value does not establish a diagnosis or an inevitable exhaustion stage.
3. Compare drive theory and the inverted-U hypothesis. Explain why calling a sport powerful, an athlete expert or a person extroverted does not establish an individual optimal arousal score.
4. For selected previous reports 19,21,22,24,25, calculate mean and range width and locate a current score 31. Repeat the descriptive comparison for 14,15,17,18,19 and current 11. State why neither proves an optimal zone or a need to calm down/psych up.
5. Explain how a catastrophe model differs from a smooth inverted U and what hysteresis means. Give two reasons not to infer a universal recovery time or treatment from a sketch.
6. Distinguish trait/state anxiety, cognitive/somatic anxiety and intensity/direction of interpretation. Explain why equal intensity scores may have different meanings.
7. Compare self-report and physiological indicators. State the original CSAI-2 subscale structure, distinguish the revised form and give controls needed in a low-risk class study.
8. For the three invented 9-item response sets in the text, find each sum and mean. Interpret a separate supplied original-format profile 30,16,14 without adding it into a clinical total or assuming an intervention.
9. Classify problem-focused, emotion-focused and avoidance coping by function, giving examples and distinguishing a brief regulating break from persistent avoidance of a necessary action.
10. Explain three practical self-talk forms and a suitable relaxation investigation. For pulse 72→66 beats/min, calculate absolute and relative changes and explain why neither establishes improved anxiety or sporting performance.
11. Describe the three burnout dimensions and a constructive support response. Explain why a classroom questionnaire, one absence or safe withdrawal does not establish a disorder or failed coping.
12. **AHL** Analyse controllable and uncontrollable elements in a wind-affected event or a school–sport scheduling conflict. Justify a combination of strategies with their limits.
13. **AHL** Distinguish informational, practical and emotional support. Explain why seeking support may be useful without claiming one provider or strategy is best in every situation.
14. **AHL** Evaluate logical analysis, relaxation, imagery, thought control, effort expenditure and distraction for a specific task. Distinguish disengagement/self-blame from appropriate rest or leaving danger, and propose evidence to test effectiveness.

Answers.

1. A stressor is a relevant demand/event; appraisal concerns its meaning and perceived coping resources. Eustress describes a positively experienced challenge; distress describes negatively experienced strain. Appraisals can differ between people and change within a person as conditions or information change. Challenge and threat may coexist; a positive interpretation does not remove a real injury, demand or barrier.
2. Sympathetic activation and adrenaline can rapidly change pulse, ventilation and fuel availability. HPA signalling links hypothalamus, pituitary ACTH and cortisol secretion by the adrenal cortex. The historical alarm–resistance–exhaustion model organises sustained responses; it does not predict inevitable dates or a literal empty resource tank. Exercise, posture, temperature, timing and other influences affect readings; one value neither identifies a psychological cause nor diagnoses health or coping capacity.
3. Drive theory strengthens the dominant response, which may help or hinder depending on whether that response suits the task. The inverted U proposes improvement to an optimum followed by decline. These are models with limits, not universal individual laws. Complex coordination can occur in powerful actions, experts can have unsuitable dominant responses, and personality or sport labels do not supply a measured optimum. Define the task and examine suitable repeated evidence.
4. First sum = 111; mean = 22.2; range = 25−19 = 6; 31 lies above the selected 19–25 reports. Second sum = 83; mean = 16.6; range = 19−14 = 5; 11 lies below 14–19. These selected successful-event reports omit other outcomes, contexts and error. Anxiety ratings do not directly measure all activation; neither range is a validated optimal band or intervention threshold. Seek relevant evidence and the performer's interpretation instead of automatically prescribing psyching up or calming down.
5. The catastrophe account adds an interaction with cognitive anxiety and permits a sudden rather than smooth decline as physiological activation changes. Hysteresis means the return path can differ from the outward path at comparable activation. The schematic supplies neither universal numerical triggers nor recovery minutes. A sudden drop may also involve fatigue, technique, distraction or injury; it does not prove which strategy would cause recovery.
6. Trait describes a relatively enduring tendency; state describes a current report. Cognitive concerns worry/thoughts; somatic concerns bodily experience. Intensity concerns how much is reported; direction concerns whether the person interprets it as helpful or harmful. Two equal intensities may have different interpretations

and outcomes, without proving interpretation alone caused the result. These dimensions neither diagnose a disorder nor determine every event.

7. Self-report accesses reported experience but depends on comprehension, context and response bias. Instrument measures such as pulse, blood pressure and galvanic skin response are indirect and non-specific; standardise task, posture, timing and environment. Original CSAI-2 has 27 items, three 9-item subscales, each raw 9–36; revised CSAI-2R uses a different 17-item structure. Use correct instructions and relevant validity evidence. Class tasks need low risk, informed voluntary participation, confidentiality and explained withdrawal limits, without induced distress or public labelling.
8. Sums are 26,15,23; means are $26/9 = 2.888\ldots$, $15/9 = 1.666\ldots$ and $23/9 = 2.555\ldots$. The invented items demonstrate arithmetic, not a validated questionnaire. Supplied cognitive 30, somatic 16 and confidence 14 describe distinct original-format dimensions; confidence must not be added as if it were the same anxiety construct. Clinical high/moderate labels need suitable validated interpretation. Discuss experience, conditions and support rather than diagnose or prescribe from raw scores.
9. Problem-focused action addresses a demand, such as obtaining timetable information; emotion-focused action regulates feelings, such as seeking understanding or using a familiar reset cue; avoidance distances the person from the stressor. A short regulating music break can support return, while repeatedly postponing a necessary conversation leaves it unresolved. Classify by function and context. Reporting injury or leaving danger can be protective rather than evidence of poor coping.
10. Self-talk may recall a useful past experience, use an agreed acronym for a routine or cue a physical action briefly. Rehearse a suitable cue without overloading the performer. Pulse falls 6 beats/min; relative fall $= 6/72 \times 100 = 8.333\ldots\%$. Ordinary rest, posture, timing or measurement could explain it. Compare suitable conditions and examine reported experience and relevant performance; a lower pulse is not proof of lower anxiety, treatment efficacy or better sport performance.
11. Burnout descriptions include physical/emotional exhaustion, reduced accomplishment and devaluation of sport. Listen respectfully, examine demands, recovery, access and support, and involve appropriate trusted adults/professionals when needed. These patterns need context and appropriate assessment. A class score or absence does not diagnose a disorder. Stopping an unsafe action, seeking help or taking appropriate rest should not be treated as a toughness failure.
12. **AHL** Wind itself may be unchangeable while access to forecasts, permitted equipment and a safe plan may be changeable. An exam date can be fixed while some scheduling decisions remain negotiable. Problem-focused actions address feasible demands; emotion-focused strategies can manage responses to remaining conditions. Combine them when appropriate, acknowledging authority, resources and safety rather than blaming the athlete or promising that reframing removes the barrier.
13. **AHL** Informational support clarifies options or a plan; practical support provides resources such as transport; emotional support offers care and understanding. One interaction may serve several functions. Seeking support can improve available resources and connection, but credibility, accessibility, the provider's role and the individual situation affect usefulness. It does not replace clinical assessment where needed or prove one source is universally best.
14. **AHL** Logical analysis clarifies options; relaxation may regulate activation; imagery rehearses a relevant scenario; thought control redirects attention; effort expenditure implements a feasible plan; brief distraction may regulate emotion before re-engagement. Persistent disengagement, unproductive venting or self-blame may leave demands unresolved. These differ from necessary rest, safe withdrawal and appropriate help seeking. Specify the strategy, comparable opportunity, experience and relevant follow-up outcomes; consider expectancy, measurement and real barriers instead of declaring effectiveness from one lower score.

Exam tips

- State the model's prediction and its limits; avoid fixed sport/personality prescriptions.
- Distinguish arousal, anxiety dimensions, interpretation and clinical diagnosis.
- Retain unrounded working; selected successful reports do not validate an optimal zone.
- Explain coping by its function and judge outcomes in context.
- **AHL** Separate controllability, feasible support and evidence of strategy effectiveness.

Psychological skills

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

This handout teaches C.5 Psychological skills for the course first assessed in 2026: goal types, their effects on attention and motivation, individual differences and the evaluation of a psychological skills programme. Self-talk, regulation and routines extend the C.2/C.4 connections. Sections marked **AHL** are for Higher Level only. Numerical examples and training plans below are invented teaching cases, not prescribed programmes.

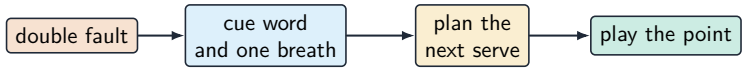
Prerequisites: unit C.3 (motivation) and unit C.4 (stress, anxiety and arousal), which explain the problems these skills are used to solve.

Psychological skills training

Results and explanations

Michael Phelps won the Beijing 2008 men's 200 m butterfly in **1:52.03**, the world record at that time. The dated result is documented in USA Swimming's 2009 record tables. It establishes his performance, not the separate contribution of confidence, rehearsal, technique or physical preparation. An account of a champion's preparation can suggest a question; it does not isolate a cause.

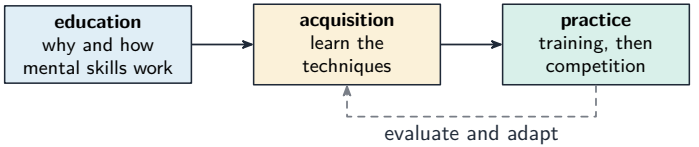
Consider instead an invented school tennis player who loses focus after a double fault. A short practised reset might give attention a useful next action. To judge it, measure comparable serves and the player's experience, including days without the reset. The question is which method helps this person with this task, and how good the evidence is.



A practised reset after an error (invented example)

Skills that can be learned

Psychological skills training 心理技能训练 (PST) is the planned, regular practice of mental skills to improve performance, enjoyment and well-being. Practice can develop these skills, but effects depend on the technique, person, task and opportunities to use it. A programme is not a guarantee of improved results.



The three phases of psychological skills training

- A **psychological skill** is a quality the athlete wants, such as confidence, concentration or control of arousal.
- A **psychological technique** is a method used to develop it, such as goal setting, imagery, self-talk or relaxation.

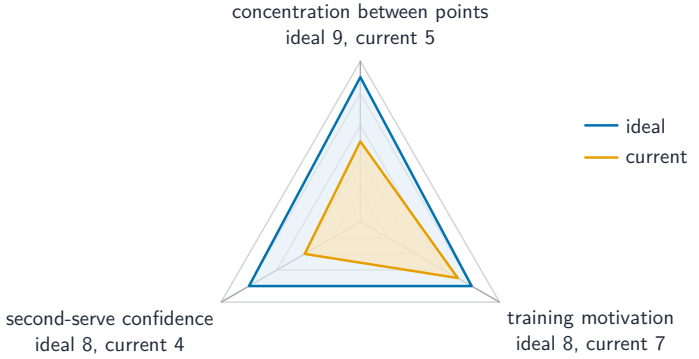
A PST programme usually has three phases:

1. **Education.** The athlete learns why mental skills matter and how they work.
2. **Acquisition.** The athlete learns the techniques, often with a sport psychologist.
3. **Practice.** The athlete uses them in training and then in suitable competition situations, evaluating and adapting their use.

Mental skills are not only for elite athletes or for "fixing problems". Beginners, young athletes and injured athletes may have relevant goals too. Transfer to a different setting must be examined rather than assumed; the athlete should help choose and evaluate the programme.

Finding out what to work on

In a **performance profile** 表现剖面图, the athlete lists the qualities that matter in their sport, rates the ideal level (usually out of 10) and their current level, and discusses the gaps with a suitable coach or practitioner. Ratings are subjective and depend on the meaning of the scale and the situation.



The tennis player's performance profile

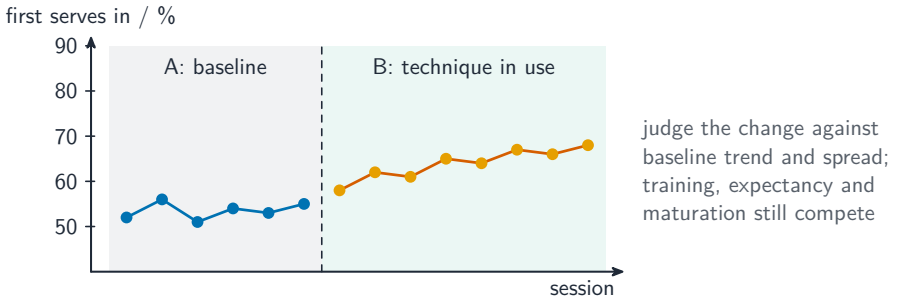
Worked example. A tennis player rates three qualities:

Quality	Ideal	Current	Gap
Concentration between points	9	5	4
Confidence on the second serve	8	4	4
Motivation in training	8	7	1

The two gaps of 4 identify possible discussion points, not automatic priorities or clinical diagnoses. Importance to the task, the athlete's wishes, available resources and whether the rating is meaningful also matter. Repeating the same profile after eight weeks shows a change in reported gaps; use comparable performance and experience measures before concluding that a skill improved or that PST caused it.

Judging whether PST works

- Define the intended outcome: a useful attentional action, reported experience, participation or a comparable performance measure. A questionnaire measures responses under specified conditions, not direct access to a person's inner state.
- In a **single-case design** 单一个案设计, collect repeated baseline measurements before introducing a specified technique, then continue measurement during use and at follow-up. Baseline trend and variability matter: one good day after a poor day may be ordinary variation.
- A **multiple-baseline design** introduces a technique at different times across participants or settings. A repeated change aligned with those starts can strengthen the inference, but starting times should not be chosen merely to favour a result. Physical training, maturation, expectancy, feedback, changed equipment and other simultaneous changes remain possible explanations.
- Standardise task difficulty, scoring and testing conditions as far as feasible. Record whether the technique was actually used. Consider a suitable comparison and independent scoring; repeated improvement alone does not prove causation or universal effectiveness.



A single-case AB design (invented data)

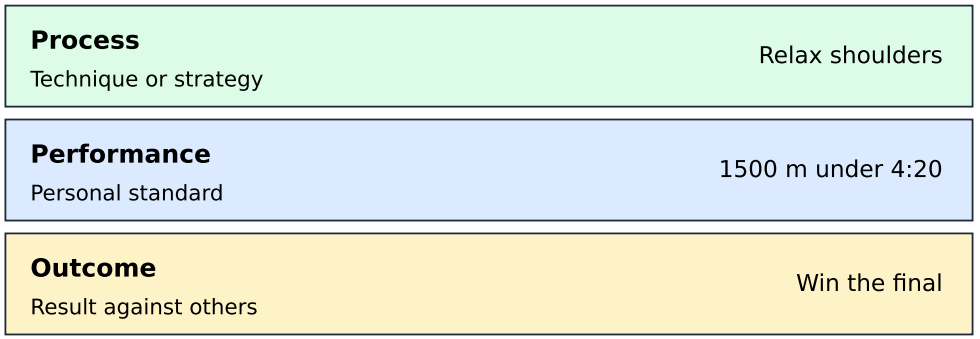
Use voluntary low-risk school tasks, protect personal reports and allow withdrawal. Do not induce distress or ask classmates to diagnose or treat one another. A practical programme should be feasible and acceptable, not just produce a lower questionnaire number.

Goal setting

Why goals work

Goal setting 目标设定 is setting a target to work towards. Goals can influence performance by helping to:

- direct attention to what matters;
- increase effort;
- increase persistence when things get hard;
- encourage the athlete to develop new strategies.



Different targets; none guarantees control or benefit.

Goal types describe the target, not a guarantee of control or benefit.

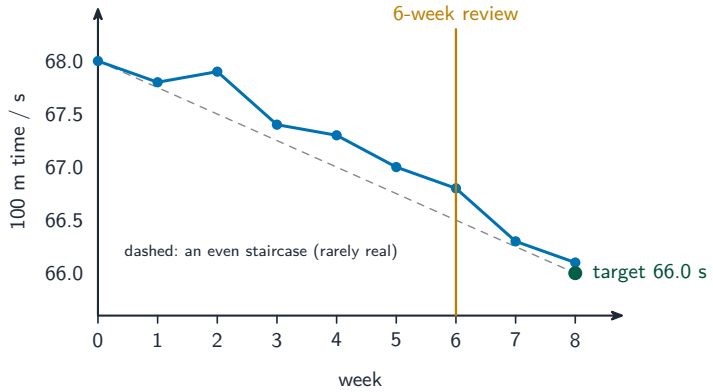
Type	Reference	Example and limitation
Outcome goal 结果目标	Norm-referenced: result against others	Win the county final; opponents and event conditions also influence placing
Performance goal 表现目标	Self-referenced, measurable standard	Run 1500 m under 4:20; weather, health and measurement still matter
Process goal 过程目标	Technique or strategy used to perform	Attend to relaxed shoulders on the final lap; fatigue, injury and the suitability of the cue still matter

An outcome target may provide direction; a performance target can monitor a personal standard; a process target can direct attention to a useful action. They can be combined, but using all three is not automatically the best plan. Too many simultaneous cues can overload attention; an athlete may benefit from one clear focus. A technically appropriate process goal is often more directly actionable than a placing, **not fully controllable**.

Achievement motivation matters. A performer who welcomes a challenging target may increase effort and persist; another may interpret the same public comparison as threat or become preoccupied with avoiding failure. Discuss the athlete's experience, perceived competence and resources. Neither a high need for achievement nor a history of success determines every response to a goal.

SMART goals

Letter	Meaning	Example
Specific	Clear and precise	"Improve my first-serve percentage"
Measurable	Can be checked with numbers	From 52 % to 60 %
Achievable	Plausible given the starting point and evidence	Discuss whether 60 % is feasible; the number alone cannot establish this
Realistic	Fits resources, recovery and other commitments	Agree suitable opportunities to practise
Time-bound	Has a deadline	By the end of the season, with a check after 6 weeks



A SMART goal names the measure, the target and the date; real progress is rarely an even staircase

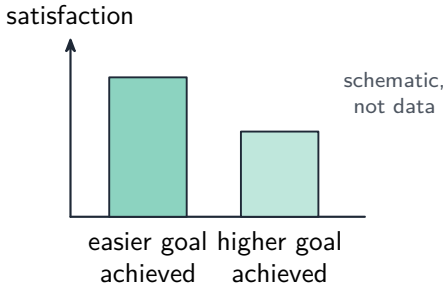
SMART is a planning checklist, not evidence that a target is feasible or beneficial. A challenging goal can organise effort, while an unrealistic or imposed target may discourage engagement. Easier tasks can also support learning or recovery. Agree the goal, relevant feedback and review points; revise it when circumstances change. Progress need not form an even staircase.

> **Worked example.** "I want to get better at swimming" is a vague goal. A SMART version: "Over the next 8 weeks, lower my 100 m freestyle time from 68.0 s to 66.0 s by completing three technique sessions a week, with a test every 2 weeks." Four two-week intervals would divide the proposed 2.0 s reduction into **0.5 s per interval**: 67.5, 67.0, 66.5 and 66.0 s. That is an arithmetic planning line, not a prediction of physiological adaptation. Decide feasibility from the individual and conditions, not from the neat numbers.

Common problems: setting too many goals at once, setting only outcome goals, setting goals without the athlete's involvement, and never reviewing them.

AHL: Goal adjustment and the goal-setting paradox

The **goal-setting paradox** in syllabus C.5.1.2 describes elite athletes sometimes feeling **less satisfied after achieving a higher goal than after achieving an easier one**, with post-success deflation offered as an explanation. The size of the achievement and the satisfaction it brings need not rise together. This is an account to examine, not an inevitable response of all elite athletes or a clinical diagnosis. Immediately adopting an even harder target may also leave little room to recognise success, but escalating targets alone do not define the syllabus comparison. A medal or personal best does not reveal the athlete's experience by itself.



The goal-setting paradox (schematic, not data)

Goal adjustment means revising, disengaging from or replacing a target when demands, resources or priorities change. A runner recovering from injury may replace a time goal with an agreed participation or learning goal. This is a reasoned response to evidence, not automatically weak commitment. Review what was learned and recognise progress instead of treating every achieved target only as a launch point for a

harder one.

Specific goals are not always preferable. A **do-your-best goal** encourages effort without a fixed performance threshold. An **open goal**, such as "see how many accurate passes you can make comfortably in this task", invites exploration without prescribing the exact achievement. These can reduce fixation on an arbitrary pass/fail boundary for some people. They still need a suitable task, clear safety conditions and useful feedback; "open" does not mean unlimited exertion.

For a new skill, uncertainty about a sensible target may favour exploration before a numerical goal is agreed. For a familiar measured task, a self-referenced target may organise practice. Compare engagement, experience, learning and follow-up rather than assuming that either SMART or open goals win in every context. A small randomized walking pilot examined open and specific goals in healthy adults; feasibility and similar activity increases in that setting do not establish effects for every elite sport or age group.

AHL: Imagery, purpose and perspective

Training in the mind

Imagery 表象 is creating or re-creating an experience without the corresponding actual perception. It may combine relevant visual, auditory, kinaesthetic and other sensory information with emotions; it need not include every sense or be equally vivid for every person. Imagery used to practise a skill without moving is often called **mental rehearsal** 心理演练.

Athletes use imagery to:

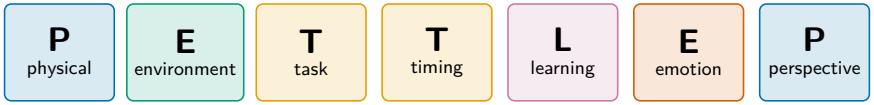
- learn and refine skills (rehearsing a gymnastics routine);
- plan and rehearse tactics (a set play in football);
- control arousal and anxiety (imagining a calm place, or a powerful start);
- build confidence (rehearsing a feasible response to an interruption);
- rehearse appropriate task information during an interruption to physical practice, where suitable. This does not replace rehabilitation or physical practice.

Perspective	Description	Possible use, not a universal rule
Internal imagery 内部表象	First person: seeing through your own eyes, feeling the movement	Exploring timing and rhythm
External imagery 外部表象	Third person: watching yourself as if on video	Checking body shape and form, such as in gymnastics

Kinaesthetic imagery 动觉表象, feeling the movement in the muscles, can be added to either perspective.

Making imagery effective: PETTLEP

The **PETTLEP model** proposes functional similarity between imagery and performance across seven features. It is a framework for planning, not a guaranteed treatment or a fixed daily dose. Holmes and Collins introduced the model in 2001. Adapt it to the task, learning stage, preferences and safe practical conditions:



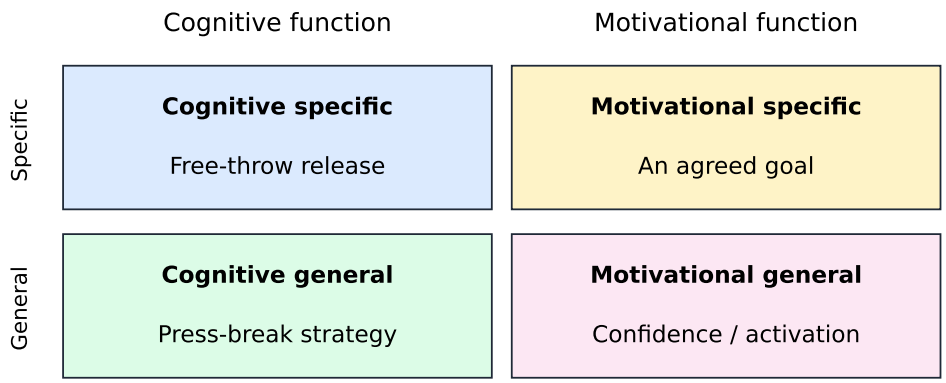
make imagery functionally similar to the real performance; a planning framework, not a fixed dose

The seven PETTLEP features

Letter	Meaning	Example for a penalty taker
Physical	Relevant posture, bodily sensations and equipment	Stand in boots, holding the ball
Environment	Relevant setting cues, directly or through suitable representations	Imagine the stadium noise
Task	The athlete's own skill level	Their own run-up, not a star's
Timing	Timing suited to the purpose; real-time rehearsal may fit an execution task	Rehearse the intended run-up rhythm
Learning	Change the imagery as the skill develops	Add a new disguise later
Emotion	Include the real feelings	Pressure, then confidence
Perspective	Internal or external, as suits the task	Choose and evaluate the useful view

Paivio's framework: what is the imagery for?

Paivio's framework distinguishes **cognitive** and **motivational** functions, each at **specific** and **general** levels. Classify the intended purpose rather than merely whether an image is vivid or pleasant.



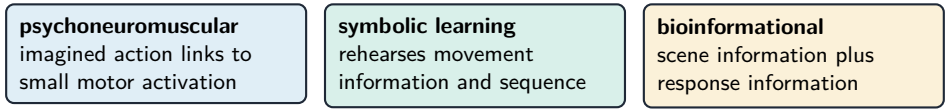
The four cells are functions; one sequence may serve more than one.

Function	Invented basketball example	What to evaluate
Cognitive specific	Rehearse the release of a free throw	Appropriate movement information and later execution
Cognitive general	Rehearse options in a press-break play	Understanding and adapting a strategy
Motivational specific	Imagine reaching an agreed season goal	Whether the goal remains meaningful and feasible
Motivational general	Rehearse handling pressure with confidence and useful activation	Reported experience and relevant behaviour in context

Later distinctions within motivational-general imagery include mastery/confidence and arousal-related experience. Do not confuse purpose with perspective: a first-person image can serve a cognitive or motivational function. Watching an imagined successful shot need not establish which function the athlete intended.

■ Mechanisms and evaluation

Psychoneuromuscular accounts propose links between imagined action and motor activation; observing small muscle signals would not by itself prove that a motor programme was strengthened or that performance improved. Symbolic-learning accounts propose rehearsal of movement information and sequences. Bioinformational accounts emphasise scene information and response information. These are proposed explanations with different predictions, not interchangeable confirmed causes.



proposed explanations with different predictions;
a fair test equalises physical practice across conditions

Three proposed imagery mechanisms

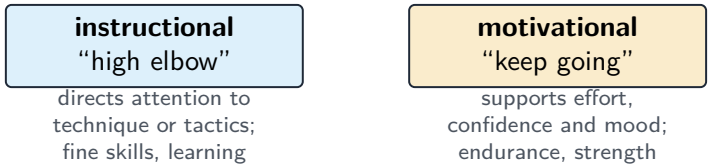
A fair investigation specifies imagery content, delivery, adherence, physical practice and comparison conditions, with suitable performance and experience measures. Equalise physical practice if investigating the additional contribution of imagery. Improvement after imagery could also reflect practice, expectation or other coaching. Neither an appealing explanation nor one successful athlete establishes a universal benefit, an optimal perspective or a daily-minute prescription.

Self-talk

These techniques extend C.2 attention and C.4 coping into a practical programme. Their labels do not establish an effect for every athlete; connect each action to a purpose and evaluate it.

■ Talking to yourself on purpose

Self-talk 自我对话 is what athletes say to themselves, aloud or silently. It can be spontaneous or deliberately planned; a useful programme may develop a manageable cue.



Instructional and motivational self-talk serve different purposes

Type	Intended purpose	Example	Possible application
Instructional self-talk 指导性自我对话	Directs attention to technique or tactics	"High elbow", "watch the ball"	Fine, precise skills; learning
Motivational self-talk 激励性自我对话	Raises effort, confidence and mood	"Keep pushing", "I've got this"	Strength, power and endurance tasks

A statement such as "I always miss" may distract or discourage a particular performer, but its wording alone does not establish a fixed psychological effect. Ask how it is experienced and what action it prompts.

- **Thought stopping** 思维阻断 is a historical label for interrupting an unhelpful train of thought. A classroom application can notice the thought and redirect to an agreed cue; do not prescribe pain, snapping wristbands or forced suppression. Unwanted thoughts can recur without meaning that the athlete failed.
- **Reframing** 认知重构 examines a more accurate and useful interpretation: "One missed penalty does not determine the next action; I can reset for the next phase." Do not invent a factual excuse, promise success or deny an actual problem.

Short **cue words** 提示语 ("smooth", "explode") are easier to use in a fast game than long sentences. Try a suitable cue in training and check its usefulness under realistic conditions. A weightlifter may need a technical cue as well as encouragement; a darts player may need confidence as well as instruction. Sport labels alone do not choose the best words.

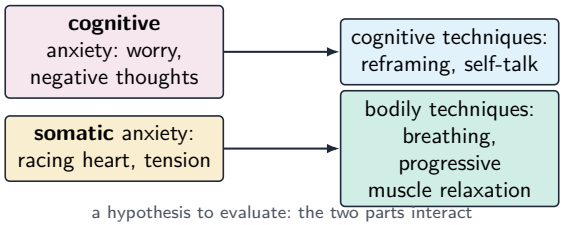
Relaxation and arousal regulation

Matching the technique to the problem

Unit C.4 compares models of arousal and performance, and that anxiety has a **cognitive** part (worry, negative thoughts) and a **somatic** part (racing heart, muscle tension, butterflies). The **matching hypothesis** 匹配假说 proposes relating a technique to the main reported difficulty. Cognitive and bodily experiences interact; this is a hypothesis for discussion, not a rule that a classroom label prescribes treatment.



A yoga class: slow breathing and muscle relaxation lower arousal when it is too high



The matching hypothesis pairs the technique with the main difficulty

- **Breathing awareness/control:** explore a comfortable familiar voluntary method; avoid forced pacing, breath-holds or hyperventilation.
- **Progressive muscle relaxation** 渐进式肌肉放松: learn the contrast between tension and release with appropriate guidance; avoid painful or injured areas and forced contractions.
- **Biofeedback** 生物反馈: a device supplies information about pulse or muscle activity; a changed signal alone does not establish reduced anxiety or better performance.
- **Mindfulness and meditation** 正念: notice present experience without automatically judging it. Effects and acceptability vary. Autogenic training uses taught relaxation-related self-statements; self-talk may instead cue attention or motivation.

Develop and evaluate a technique in suitable practice before relying on it in a pressure situation. No fixed number of weeks guarantees a quick effect. If an athlete has a concerning health issue, use appropriate support rather than treating a classroom

exercise as clinical care.

Psyching up

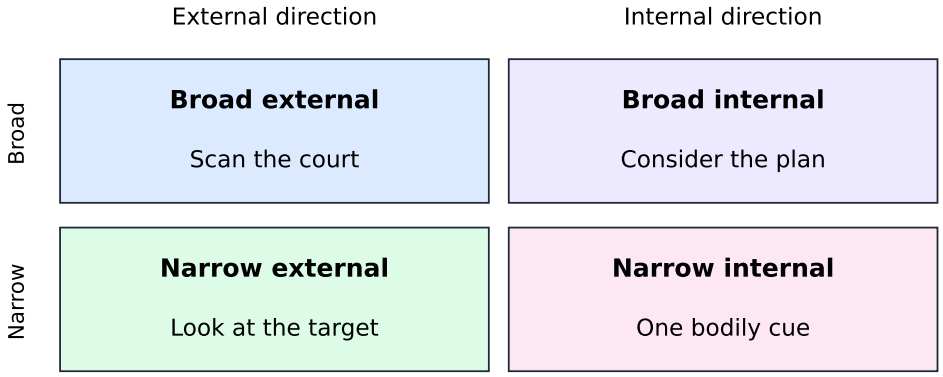
Feeling flat can suggest a need to examine activation, sleep, recovery, task demands and motivation; it does not identify one cause. Familiar music, ordinary warm-up movements or an agreed motivational cue may help some athletes prepare. Do not prescribe rapid short breaths or equate greater arousal with better performance.

A powerful movement can still require precise coordination, and a precision task can involve substantial activation. Evaluate the individual and the task rather than assigning every lifter a high optimum and every golfer a low one.

Concentration and routines

Attention

Concentration 专注 is focusing on the relevant cues and keeping that focus. Distractions can be **external** (crowd noise, an opponent's taunts, the scoreboard) or **internal** (worry, fatigue, thinking about past mistakes).



Shift attention with the task; these are examples.

Nideffer's attentional styles

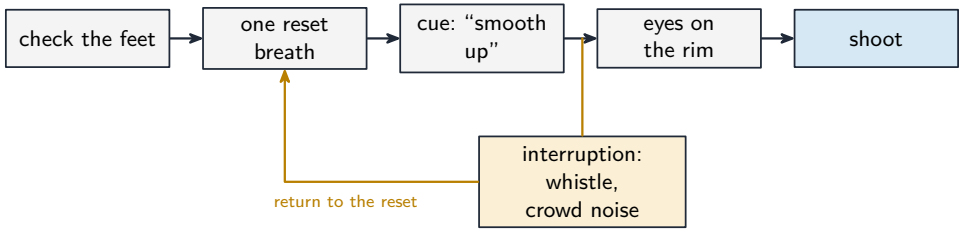
Nideffer described attention along two dimensions: **width** (broad, many cues; or narrow, one or two cues) and **direction** (external; or internal). Good performers shift between styles as the situation changes. A golfer uses broad external to read the wind and the green, broad internal to choose the club, narrow internal for one bodily cue, and narrow external to focus on the ball.

Pre-performance routines

A **pre-performance routine** 赛前常规 is a practised sequence of task-relevant thoughts and actions before a skill. An invented free-throw routine might check the feet, use one comfortable reset, choose a concise cue and look at the target. It can give attention a useful sequence and a familiar starting point; it does not eliminate distraction or guarantee the desired arousal or score.



At the free-throw line, a fixed pre-performance routine steadies attention before every shot



A routine gives attention a sequence; it does not guarantee the score

A routine gives attention a familiar sequence and a way back after an interruption

Consistency can support learning, but a useful routine is adaptable to interruptions, rules and actual safety needs. Being unable to perform an exact ritual need not mean failure. A supposedly lucky object has no established direct mechanical effect on ball flight, although a belief about it could affect experience; test the claimed mechanism rather than dismissing or validating every ritual by name.

Choking 发挥失常 describes a marked performance decrement under pressure relative

to capability or expectation. Proposed explanations include distraction and excessive conscious monitoring of normally fluent actions. A single error can also reflect ordinary variability, fatigue, technique or injury and does not diagnose choking. Process cues and routines may be evaluated as possible supports, not guaranteed prevention.

Practice

1. Distinguish a psychological skill from a technique. Outline education, acquisition and practice in a suitable programme.
2. A hockey profile gives ideal/current ratings: decision making 9/6, aggression control 7/6, confidence 9/5. Calculate the gaps and explain how to choose a priority without treating the profile as a diagnosis.
3. Evaluate one before–after test against repeated baseline and staggered intervention measurements. Name two remaining alternative explanations.
4. Classify "win the final", "beat my previous time" and "attend to my release cue". Explain why none is fully controllable and how achievement motivation may affect the response.
5. Improve "get better at swimming" using the 68.0→66.0 s, eight-week example. Calculate the four equally spaced two-week targets and explain the limit of that plan.
6. A runner proposes 58.0→56.0 s over ten weeks, testing every two weeks. Calculate the even improvement per interval, all five targets and the total percentage time reduction.
7. An invented basketball goal is to raise free-throw success from 60 % to 70 %. Find the percentage-point and relative increases. Give two conditions needed to judge a fair comparison and discuss feasibility.
8. A footballer misses a penalty and thinks "I always fail". Give an instructional cue, a motivational cue and an accurate reframe. Explain why sport labels alone do not select the technique.
9. Explain the matching hypothesis and one limitation. Describe a safe interpretation of relaxation or psych-up without giving a fixed treatment dose.
10. Use broad/narrow and internal/external attention in an invented free-throw routine. Explain how to adapt it after an interruption and why one miss does not prove choking.
11. Plan a feasible evaluation of a chosen goal or routine: intended outcome, participant choice, comparison, repeated measurement, adherence and follow-up.
12. **AHL** Explain the goal-setting paradox and goal adjustment. Compare a specific target, a do-your-best goal and an open goal for a novice learning an unfamiliar task.
13. **AHL** Give all four cells of Paivio's framework with basketball examples. Distinguish function from internal/external perspective and kinaesthetic information.
14. **AHL** Apply all seven PETTLEP features to a swimmer. Outline two proposed mechanisms and explain why imagery plus extra physical practice would be an unfair test of imagery alone.

Answers.

1. Confidence or concentration is a skill; goal setting or a relevant self-talk cue is a technique. Education explains the purpose and limits, acquisition teaches a suitable method, and practice applies and reviews it in progressively relevant conditions. Neither access to a technique nor repetition guarantees benefit.
2. Ideal minus current gives **3, 1 and 4**. Confidence has the largest reported gap, but discuss task importance, meaning of the ratings, wishes and available resources before choosing it. Repeat comparable reports alongside behaviour/performance measures; a changed gap alone proves neither a clinical condition nor a causal effect.
3. A single pair of results is vulnerable to ordinary variation and regression towards typical performance. Repeated baseline helps identify trends and variability; changes aligned with staggered starts across cases can strengthen an inference. Physical training and expectancy are two alternatives; maturation, changed scoring or simultaneous coaching are also possible. Record implementation and use suitable comparisons rather than claiming all alternatives are eliminated.
4. These are outcome, performance and process goals respectively. Placing depends on opponents; personal time on health/weather; executing a cue on fatigue, suitability and opportunity. A target may direct attention and effort, but excessive cues or fear of failure may hinder engagement. An achievement-motivation label does not determine the response.
5. Agree a measured 100 m target, appropriate practice opportunities, an eight-week review and comparable two-week checks. There are four intervals: $\mathbf{2.0/4 = 0.5\ s}$ each; **67.5, 67.0, 66.5, 66.0 s**. The straight line is invented planning arithmetic. Feasibility requires individual evidence; progress may be uneven and the target may need revision.
6. Five intervals give $\mathbf{2.0/5 = 0.4\ s}$ each: **57.6, 57.2, 56.8, 56.4, 56.0 s**. Relative time reduction uses the initial 58.0 s: $\mathbf{2/58 \times 100 = 3.448...\ \%}$. This is a proposed reduction in time, not an equal percentage increase in speed or a prediction of adaptation.
7. **10 percentage points**; relative increase $\mathbf{10/60 \times 100 = 16.666...\ \%}$. Compare similar difficulty and sufficient attempts, using consistent scoring and conditions. Clarify current variability, resources and the athlete's agreement; the numbers and deadline alone do not show that 70 % is feasible.
8. Instructional: "scan for the next pass"; motivational: "keep contributing"; reframe: "one miss does not settle the next phase". These are examples to agree and test, not guaranteed remedies. Do not invent a goalkeeper save or use pain to interrupt a thought. Technical and motivational needs can occur in any sport.

9. The hypothesis relates a predominantly bodily or cognitive difficulty to a suitable technique. These dimensions interact, and a label does not establish an effective treatment. A familiar comfortable breathing method or appropriately taught tension–release exercise may be explored voluntarily; avoid painful contractions or forced breathing. Familiar music or ordinary warm-up can be considered without assuming higher activation always helps.
10. Broad external: assess relevant court conditions; broad internal: consider the plan; narrow internal: one bodily cue; narrow external: the target. Not every routine needs all four at each attempt. After an interruption, reset within the rules and attend to the next useful action. A miss may reflect ordinary variability or technique; monitoring and distraction are proposed choking mechanisms, not diagnoses from one outcome.
11. Choose a specific relevant outcome with the athlete, for example an observed reset action plus experience and comparable success rate. Collect repeated baseline, describe the method and suitable comparison, record adherence and cointerventions, and follow up. Protect voluntary participation and reports. Evaluate feasibility and uncertainty; better scores alone do not prove universal efficacy.
12. **AHL** The syllabus paradox compares lower satisfaction after a higher achievement with greater satisfaction after an easier one; post-success deflation is a proposed explanation, not an inevitable response. Escalating targets can compound dissatisfaction but are not the comparison itself. Review achievement and adjust, replace or disengage from an unsuitable goal. A novice may lack a sensible threshold: best-effort encourages effort; an open goal invites exploration. Compare learning, experience and engagement. Neither removes safety limits nor guarantees superiority.
13. **AHL** Cognitive specific: free-throw release; cognitive general: press-break strategy; motivational specific: an agreed season goal; motivational general: confidence or useful activation. A sequence may serve several functions. First/third person are viewpoints; kinaesthetic information is movement sensation and can accompany either.
14. **AHL** Physical: posture/sensations; environment: pool cues; task: own technique; timing: appropriate rhythm; learning: update with skill; emotion: relevant experience without imposed distress; perspective: evaluate a useful view. Motor-activation accounts and symbolic rehearsal accounts propose mechanisms, not proof. Equalise physical practice: extra practice in the imagery group confounds the comparison. Record implementation and comparable outcomes.

Exam tips

- Classify the target and its reference; connect attention and motivation to the person and task. A SMART checklist does not prove feasibility, causation or full control.
- Show the reference and units in calculations, then discuss design and measurement limits. Distinguish a changed report from an established mechanism or diagnosis.
- **AHL** Distinguish goal adjustment from giving up without reason, imagery function from perspective, and a PETTLEP planning feature from proof of effectiveness.

Experimental programme

International Baccalaureate · IB Diploma · Sports, Exercise and Health Science · HL

Scope and prerequisites

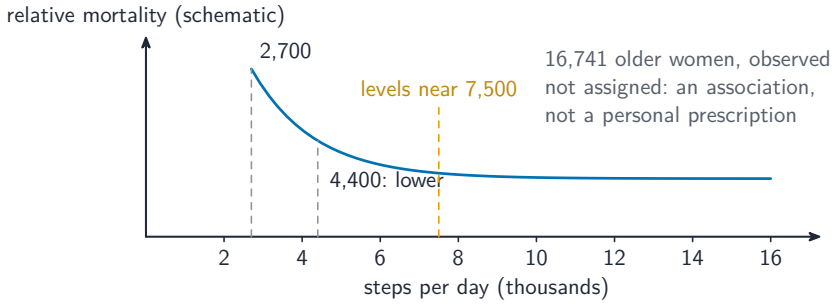
This handout teaches the experimental programme for the course first assessed in 2026: how to plan a safe and ethical investigation in sport and exercise science, how to choose valid and reliable tests, how to handle uncertainty, how to analyse and present data, and how to evaluate a study. It also explains the scientific investigation, the internal assessment worth 24 % of the final grade, and the collaborative sciences project. The experimental skills taught here are common to SL and HL. Numerical data and proposed methods are invented teaching cases unless a published source is explicitly named. A classroom example is not permission to carry out a physical intervention.

Prerequisites: the units A.1 to C.5, which give the topics you will investigate, and basic statistics (mean, percentage and graphs).

Planning an investigation

A population association is not a personal prescription

A 2019 cohort study by Lee and colleagues followed 16,741 older women after measuring step activity. Approximately 4,400 steps/day was associated with lower mortality than approximately 2,700, and the observed association levelled near 7,500. Participants were not randomly assigned to those step counts. Health, selection and other differences may contribute despite adjustment.

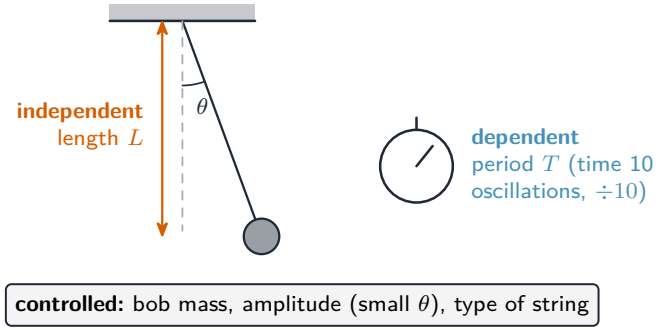


The shape of the steps association (schematic)

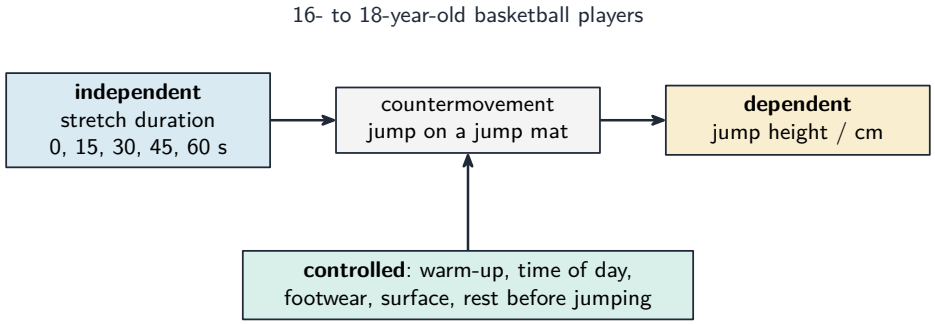
These results do not establish a universal threshold, prove that changing one person's steps causes that outcome, or prescribe exercise for a school student. A useful investigation identifies the population, exposure, measurement and design before interpreting a number. This unit develops the same discipline with low-risk school tasks and invented data.

Research question and variables

A good **research question** 研究问题 is focused: it names what you change, what you measure and who you measure. For example: "What is the effect of the duration of static stretching (0, 15, 30, 45 and 60 s) on countermovement jump height (cm) in 16- to 18-year-old basketball players?"



The pendulum investigation: change L, measure T, keep the rest the same.



Change one thing, measure one thing, and hold the rest as steady as you can

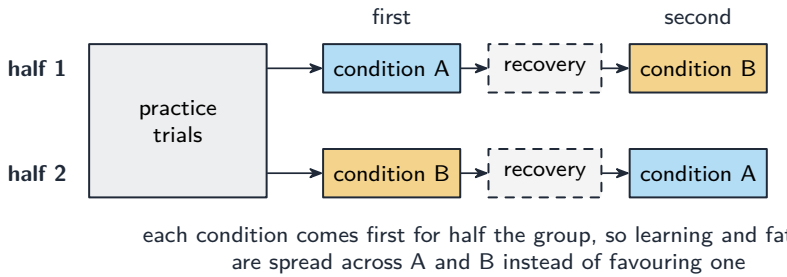
Variable	Meaning	Example
Independent variable 自变量	The one you change or compare	Stretch duration: 0, 15, 30, 45, 60 s
Dependent variable 因变量	The one you measure	Jump height in cm, from a jump mat
Controlled variables 控制变量	Standardised as far as feasible to reduce alternative explanations	Warm-up, time of day, footwear, surface, rest before jumping

Some influences, such as recent activity, sleep or motivation, are difficult to standardise. Collect only relevant information that participants can appropriately and voluntarily provide; do not demand sensitive health disclosures. Record feasible controls and remaining limitations. In an observational study an explanatory variable is measured rather than manipulated, so "effect" requires particular caution.

A **hypothesis** 假设 is a testable prediction with a scientific reason: "For this defined protocol, longer stretching may be associated with lower subsequent jump height; a possible explanation involves changed muscle–tendon behaviour." This predicts an outcome rather than establishing one universal mechanism. The **null hypothesis** 零假设 states that there is no effect or no difference; a preselected statistical test can assess how compatible the data are with a specified null model, subject to its assumptions. Failure to reject is not proof of no effect.

Designing a fair test

- **Sample.** A larger appropriate sample can improve precision, but does not repair selection bias or poor measurement. Describe the relevant population and recruitment; justify the number by feasibility, variability and the question, rather than a magic minimum.
- **Familiarisation.** People improve at a new test with practice, a **learning effect** 学习效应. Use suitable familiarisation to reduce learning effects; it does not guarantee their complete removal.
- **Counterbalancing** 平衡设计. When every participant does every condition, change the order (half do A then B, half do B then A), to distribute order effects rather than systematically align one condition with being first. With several conditions, use an appropriate balanced/randomised schedule and consider carry-over and sufficient recovery; balance does not eliminate every effect.
- **Randomisation.** When comparing two groups, random allocation reduces systematic allocation bias and balances differences in expectation; small groups can still differ. Random sampling concerns who enters the sample and is a separate process.
- **Repeats.** Take several trials per condition and predefine whether to use a mean or best according to a justified protocol. Several trials from one participant do not become several independent participants.
- **Pilot study** 预实验. A short trial run finds problems with the method before the real data collection.



Counterbalancing: each condition comes first for half the group, so order effects are spread rather than favouring one condition.

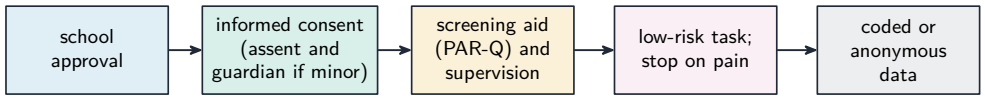
In published research, a **double-blind** 双盲 design hides from both the participants and the testers who received the real treatment and who received a **placebo** 安慰剂, to reduce expectation-related bias. Blinding can fail, cannot always be implemented and does not eliminate every source of bias. State who is blinded rather than relying on the label alone. A placebo comparison in a published study does not authorise supplement or deception experiments in school.

Safety and ethics

- Obtain school approval and appropriate **informed consent** 知情同意 before collecting data. Explain the task, risks, data use and withdrawal arrangements. For minors, follow the school's parent/guardian consent and student-assent requirements; consent must be voluntary rather than linked to team selection or grades.
- Use the school's approved screening and supervision arrangements. A Physical Activity Readiness Questionnaire (PAR-Q) is a screening aid, not medical clearance or a classroom diagnosis. A relevant concern requires an appropriate decision by the responsible adult or qualified professional, with an accessible alternative where feasible.
- Choose low-risk tasks, appropriate equipment, supervision and suitable preparation/recovery. Do not induce exhaustion, restrict food or drink, give supplements/caffeine or continue through pain to obtain data. Use an approved non-exercise task or secondary data when that better fits the question and participants.
- **Anonymous** 匿名 data cannot reasonably be linked to a person. Codes such as P 1/P 2 with a retained name key are **pseudonymised**, not fully anonymous: protect the key separately, limit access and collect only necessary information. Explain the

point after which genuinely unlinked data cannot practically be withdrawn.

- Never diagnose a health condition from a class measurement or publish personal labels. Record a safety-related stop without pressuring a participant to complete a trial. Consider environmental effects and avoid unnecessary waste.



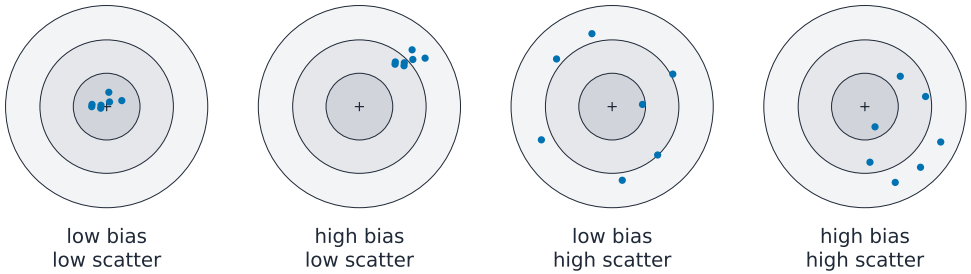
voluntary: never tied to selection or grades; withdrawal explained in advance

Ethics before data collection

Validity and reliability of tests

Two different questions

- **Validity** 效度 asks: does the test measure what it claims to measure? A sit-and-reach score reflects a specific reaching task influenced by flexibility, body proportions and technique; it is not a direct measure of every joint or whole-body flexibility.
- **Reliability** 信度 asks: how consistent are results under suitably repeated conditions, allowing for genuine change and measurement variation? **Test–retest reliability** compares two sessions a few days apart.



Accuracy around a reference and repeatability are useful analogies; construct validity requires evidence about the intended interpretation.

Type of validity	Question	Example
Criterion validity	How well does the result agree with a suitable reference for the intended use?	Multistage fitness test level compared with VO_2max measured in a laboratory
Internal validity 内部效度	Did the independent variable cause the change, not something else?	Was the warm-up the same in every condition?
External validity 外部效度	Can the results be applied to other people or settings?	Results from 17-year-old swimmers may not apply to older runners
Ecological validity 生态效度	Is the test like real sport?	A reaction-time test on a computer is less like a goalkeeper facing a penalty

A repeatable result may still miss the intended construct. Substantial unreliability limits what an individual score can support, but validity concerns the evidence for a particular interpretation and use, not a badge proved by a target picture. A scattered group mean near a reference does not establish validity of each individual result.

Common fitness tests

Component	Field test	Laboratory test
Aerobic endurance	Multistage fitness test (beep test), Cooper 12-minute run	VO_2max on a treadmill with gas analysis
Muscular strength	Hand-grip dynamometer	Isokinetic dynamometer
Power	Vertical jump, standing long jump	Force plate
Speed	20 m or 30 m sprint with timing gates	
Change-of-direction speed	Illinois course, T-test	These planned courses do not by themselves test reactive agility
Flexibility	Sit-and-reach	Goniometer measurement of joint angles
Muscular endurance	A justified repeated submaximal task	Define the endpoint and avoid an exhausting school protocol
Balance	An approved, standardised stable-surface stance	Define support, duration, scoring and safe stopping conditions
Reaction	A defined desktop response task	Separate stimulus detection and response measures
Coordination	A suitable standardised alternating-hand task	Define accuracy, timing and relevant task demands
Body composition	Skinfolds, waist circumference	Dual-energy X-ray absorptiometry



Measuring a vertical jump: the dependent variable must be measured the same way, with the same equipment, on every trial



A handgrip dynamometer: a simple, reliable field test of grip strength

field test	laboratory test
beep test, sit-and-reach, sprint gates: cheap, many at once, sport-like	gas analysis, force plate, isokinetic: more valid and reliable, costly, one at a time

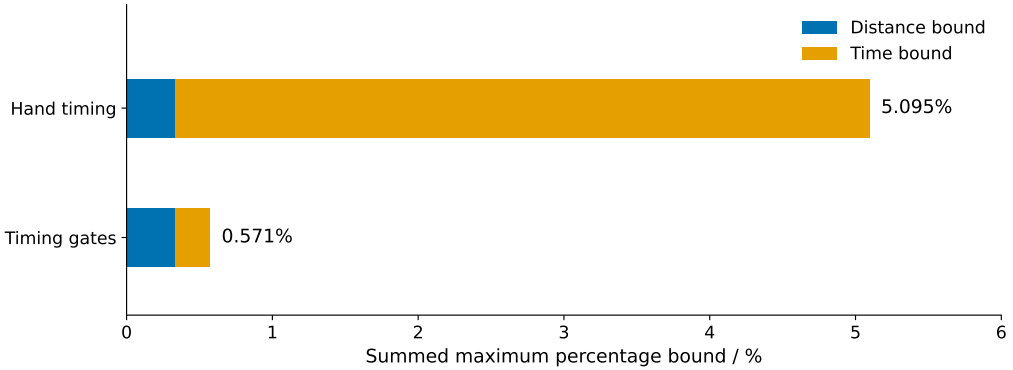
Field or laboratory

Field tests can be practical and relevant to sporting tasks; laboratory methods can control some conditions and measure specific quantities. Neither location guarantees validity, reliability, affordability or ecological relevance. Match the protocol, reference and purpose. **Normative data** 常模数据, tables of typical results for each age and sex, provide a comparison only when the reference population and testing protocol are appropriate. They are not universal diagnostic or talent-selection thresholds.

Uncertainty and data quality

Random and systematic errors

- **Random errors** 随机误差 make repeated readings scatter above and below the true value, for example the timer's reaction when starting a stopwatch. Independent repeats and averaging can reduce the random uncertainty of a mean, but genuine changing performance and correlated errors need separate consideration.
- **Systematic errors** 系统误差 shift every reading the same way, for example a jump mat that always reads 2 cm high, or an incorrect distance scale. Repetition alone does not remove such bias. **Calibration** 校准 compares readings with an appropriate reference; it can reveal a need for a justified correction, repair or a different method, without making all uncertainty disappear.
- People add their own variation: the same student will not jump the same height every time. This **biological variation** 生物学变异 is often larger than the measuring error.



Timing is one uncertainty component; changing the device does not remove every other limitation.

Calculating uncertainty

Use stated instrument specifications, calibration information and the actual protocol. Half the smallest analogue division or one digital increment can be a classroom resolution convention, but resolution alone is not total measurement uncertainty. Hand timing adds reaction-related uncertainty that depends on the procedure; **±0.20 s below is a supplied teaching assumption**, not a universal human constant.

For a stated maximum-bound approximation, add absolute bounds for a sum/difference and fractional or percentage bounds for a product/quotient. Independent standard uncertainties combine differently, commonly by root-sum-of-squares for a suitable model. Do not mix those interpretations without saying which is used.

> **Worked example.** Invented distance **30.0 ± 0.1 m**, hand-timed duration **4.20 ± 0.20 s**, treated as maximum bounds:

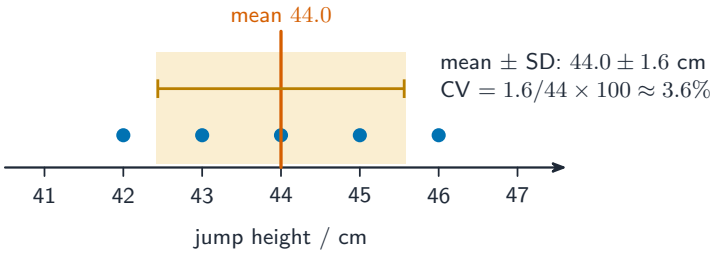
- Speed: 30.0/4.20 = **7.142857… m/s**.
- Fractional bound: 0.1/30.0 + 0.20/4.20 = 0.05095238…; percentage **5.095238… %**.
- Absolute speed bound: 7.142857… × 0.05095238… = **0.363945… m/s**. One-significant-figure uncertainty gives **7.1 ± 0.4 m/s**.
- If only the timing bound changes to ±0.01 s, the summed percentage is **0.5714286… %**, giving **±0.0408163… m/s**, or **7.14 ± 0.04 m/s**. The unrounded bound improves by a factor **8.92**, not exactly ten, because distance uncertainty remains.

Keep unrounded intermediate values. Round the final uncertainty to a sensible precision and the measured value to the same decimal place. A half-range is a descriptive spread estimate, not automatically a standard error or a justified uncertainty interval for the mean.

Analysing and presenting data

Describing data

- The **mean** 平均值 is the sum of the values divided by the number of values.
- The **standard deviation** 标准差 (SD) shows the spread of values around the mean. About 68 % of values in a normal distribution lie within one SD of the mean.
- The **coefficient of variation** 变异系数 is SD ÷ mean × 100. Use it for suitable ratio-scale data with a meaningful nonzero mean; it is not suitable for Celsius temperatures or means close to zero. A low within-person CV suggests low relative scatter under those conditions, not validity or freedom from bias. Between-person CV is not by itself test–retest reliability. See NIST on CV.
- **Percentage change** = (new − old) ÷ old × 100.



The SD shows how far single jumps scatter around the mean; the CV expresses that scatter as a percentage of the mean

Worked example. One student's five jumps are 42, 45, 44, 43 and 46 cm.

- Mean = 220 ÷ 5 = 44.0 cm.
- Differences from the mean: −2, 1, 0, −1, 2. Squares: 4, 1, 0, 1, 4. Sum = 10.
- Sample SD = $\sqrt{(10/(5-1))}$ = 1.5811388… cm; CV = 1.5811388…/44 × 100 = **3.593497… %**. Report about 1.6 cm and 3.6 %, using unrounded working.
- Half-range = (46−42)/2 = **2 cm**. If reported as 44 ± 2 cm, explicitly label the ±2 as half-range; it is not the SD or standard error.

In an investigation, calculators and spreadsheets do these calculations, but you must know what each value means.

Centre, spread and uncertainty of a mean

The sorted jumps are **42,43,44,45,46 cm**: median 44 cm and no single mode because no value repeats. Range is 4 cm. Using the stated convention of excluding the median when finding the two half-sample medians, Q 1 = 42.5 cm and Q 3 = 45.5 cm, so **interquartile range = 3 cm**. Software quartile conventions may differ; state the convention rather than silently mixing them. Median and IQR can be useful for skewed data; show the distribution and relevant individual values.



median = 3

mean = $\frac{2+3+3+5+7}{5} = 4$

mode = 3 (most common)

range = 7 − 2 = 5

Mean, median, mode and range of a small data set

Under suitable independent sampling, **standard error of the mean = sample SD/√n**. Here it is 1.5811388…/√5 = **0.7071068… cm**. SD describes observations' spread; SE estimates precision of a mean under assumptions. Five trials from one student do not create a sample of five independent students or establish population precision.

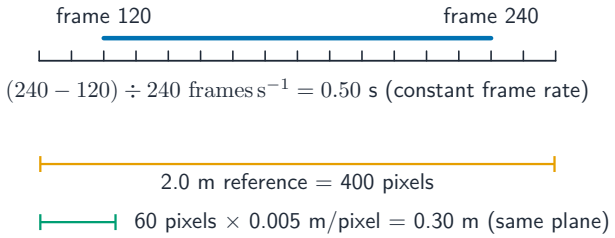
Percentage **change** compares new with initial; percentage **error** compares a measurement with a stated reference, often using absolute error/reference magnitude; a symmetric percentage **difference** may use the mean of two positive values when neither is a reference. State the denominator. For invented values 40 and 44 cm: change from 40 is 10 %, error of 44 relative to a 40 reference is 10 %, and symmetric difference is 4/42 × 100 = **9.5238… %**. Similar numbers do not make the questions identical.

Units, scale and technology

Use consistent units before substituting into a formula. **3,500 ms = 3.5 s** because milli means 10^{-3}; **2.5 × 10^3 J = 2.5 kJ** because kilo means 10^3. A rate of 120 beats/min is 2 beats/s, whose reciprocal is 0.5 s/beat for a steady rate. Scientific notation separates a coefficient and a power of ten; an order-of-magnitude estimate checks the scale without claiming all reported digits are precise. For v = d/t, doubling distance at fixed time doubles speed; doubling time at fixed distance halves speed. Those direct/inverse relationships require the stated other variable to remain fixed.



A chest-strap heart-rate monitor and watch: a valid, cheap way to record intensity during a field test



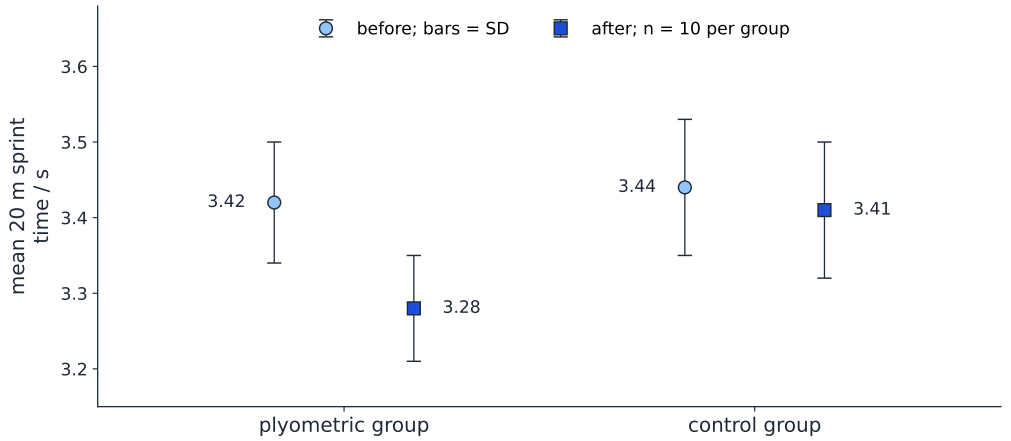
Timing and scaling from video

Technology needs a measurement model. In an invented constant-frame-rate video, frame indices 120→240 at 240 frames/s imply elapsed time $\mathbf{(240-120)/240 = 0.50\ s}$, not 121/240. If timing is variable or frames are dropped, inspect actual timestamps. A 2.0 m reference spanning 400 pixels in the same plane gives 0.005 m/pixel, so 60 pixels correspond to 0.30 m; parallax, lens distortion and calibration uncertainty can still matter. Do not assume a pixel count is automatically a valid physical measurement.

Use sensors with appropriate sampling rates and calibration, or extract documented database variables with justified inclusion/missing-data rules. Preserve raw values and units; in spreadsheets distinguish input cells from formulas and check a sample calculation independently. Simulation/model outputs depend on chosen parameters and assumptions and must be labelled as generated rather than observed athlete data. A perceived-exertion rating also needs its actual scale and anchors: a 0–10 score cannot silently inherit the interpretation of a 6–20 scale, and neither is a direct measurement of oxygen uptake.

Graphs

- A **bar chart** or a plot of means with **error bars** 误差线 compares groups or conditions. Error bars show the SD (or uncertainty); say which in the caption.
- A **scatter graph** 散点图 plots paired quantitative observations. Fit a justified linear or curved model rather than forcing every association into a straight line; inspect residuals and outliers.
- A **line graph** shows how a variable changes over time, such as heart rate during recovery.
- A histogram shows a quantitative distribution using appropriate bins; a pie chart represents mutually exclusive parts of a defined whole. Categorical counts, continuous measurements and percentages need suitable displays.
- Label axes with quantity and unit, state n and what error bars represent, and avoid misleading scales. Gradient has dependent-unit/independent-unit; an intercept may reflect an offset, and an area has the product of axis units. Interpolation stays within observed values; extrapolation needs additional assumptions. A curved relation can have changing gradients, maxima or minima.

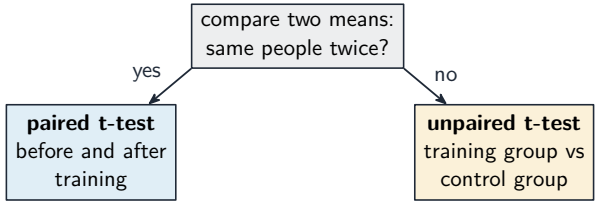


Mean sprint times before and after training (invented data, n = 10 per group)

These bars show **between-person SD**, not the uncertainty of a paired mean change. Their overlap does not determine a p-value. The plotted means/SDs alone do not supply the within-person covariance needed for a paired test. Mean changes are −0.14 s and −0.03 s, a descriptive difference in changes of −0.11 s; testing a training effect requires an appropriate comparison model and design.

Statistical tests

The **t-test** compares two means:



level chosen in advance: $p < 0.05 \Rightarrow$ reject the null;
$p \geq 0.05 \Rightarrow$ fail to reject (not proof of no difference)

Choosing the t-test

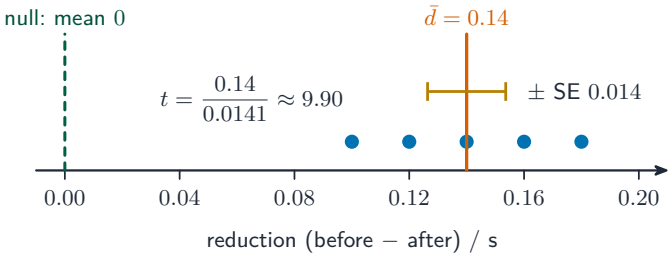
- a **paired t-test** for the same people tested twice (before and after training);
- an **unpaired t-test** for two separate groups (a training group and a control group).

A **p-value** is the probability, **under the specified null model and test assumptions**, of a test statistic at least as incompatible with the null as observed. It is not the probability the null is true, the probability the result "was caused by chance", or the chance an individual improves. Choose the significance level and one-/two-sided alternative in advance. At a preselected 0.05 level, $p < 0.05$ leads to rejecting that

null; p ≥ 0.05 is a failure to reject, not proof of equivalence.

Applying a paired t-test

Use one signed difference per independent participant, not all repeated trials as independent observations. For a small paired sample, examine whether a normal model for the **differences** is reasonable and whether influential outliers undermine it. An unpaired test instead requires independent groups; Welch's version need not assume equal group variances. A test label does not fix a biased sample or a confounded design.



One difference per participant: the mean difference sits about ten standard errors from zero

Invented paired reductions, defined as before minus after for five different participants, are **0.10,0.12,0.14,0.16,0.18 s**. Mean reduction = 0.14 s; squared deviations sum to 0.004 s^2. Sample SD of differences = $\sqrt{(0.004/4)}$ = 0.0316228… s; SE = SD/$\sqrt{5}$ = 0.0141421… s. Therefore:

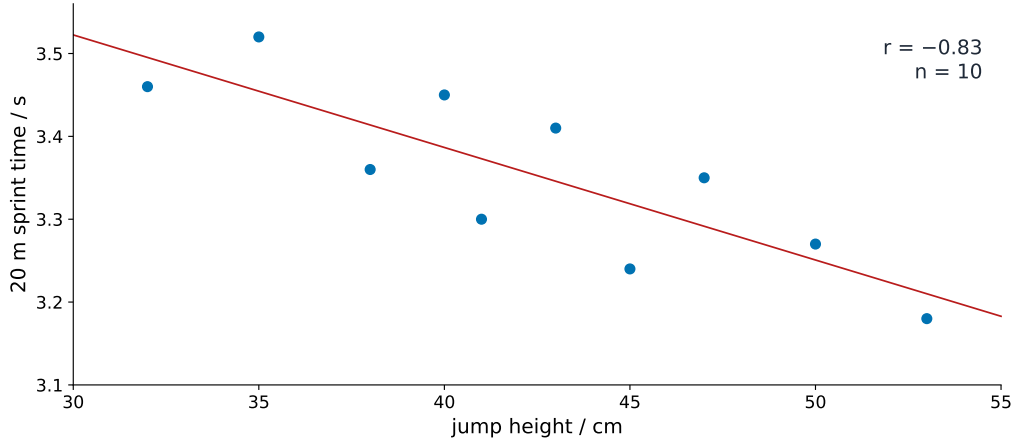
$$t = \frac{\bar{d} - 0}{s_d/\sqrt{n}} = \frac{0.14}{0.0141421\ldots} = 9.89949\ldots$$

With df = n−1 = **4** and a **supplied two-sided 0.05 critical magnitude of 2.776**, 9.899 > 2.776: reject the zero-mean-difference null, conditional on the assumptions. The observed mean reduction is 0.14 s; neither this rejection nor a large t proves causation, generalisability or sporting importance. NIST describes the paired-difference method.

A **statistically significant** 统计学显著 change can be too small to matter practically. Examine its magnitude, measurement limitations and relevance to the task. Several unplanned tests increase false-positive opportunities; predefine the main question and report the analysis transparently. Do not infer a difference between groups merely because one group's before–after test is significant and the other's is not.

Correlation

Pearson's correlation coefficient 皮尔逊相关系数, r, measures the strength of a straight-line relationship between two variables, from −1 (perfect negative) through 0 (no linear association) to +1 (perfect positive). For a stated Pearson test, compare |r| with the appropriate **critical value** 临界值 for n and the preselected alternative/significance level, subject to assumptions and independent pairs. Spearman concerns rank-based monotonic association; it is not a universal fix for every nonlinear pattern. A U-shaped association can have r near zero while still being strongly structured.



Higher jumpers tend to sprint faster (invented data)

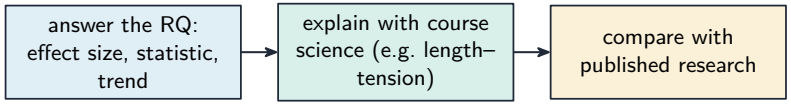
> **Worked example.** For the 10 athletes above, r = −0.83. The critical value for 10 pairs at p = 0.05 is 0.632. Since 0.83 > 0.632, there is a significant negative correlation: higher jumpers tend to have shorter sprint times. Using the actual unrounded plotted data gives r = **−0.828384…**, and r^2 = **0.686220…**. For ordinary least-squares regression with an intercept, that is about **68.6 % of the sample outcome variation accounted for by this fitted linear model**, not a percentage caused by jump height. For other models, R^2 need not equal the square of a separately computed Pearson r; inspect the fit, residuals and context.

Not true: "Jumping higher makes you sprint faster." A correlation does not prove cause. Both may depend on a third variable, such as the proportion of fast-twitch fibres or leg power, and direction, confounding and selection require careful causal design and analysis. An experiment can strengthen inference but is not automatically free of bias.

Evaluating and concluding

Drawing conclusions

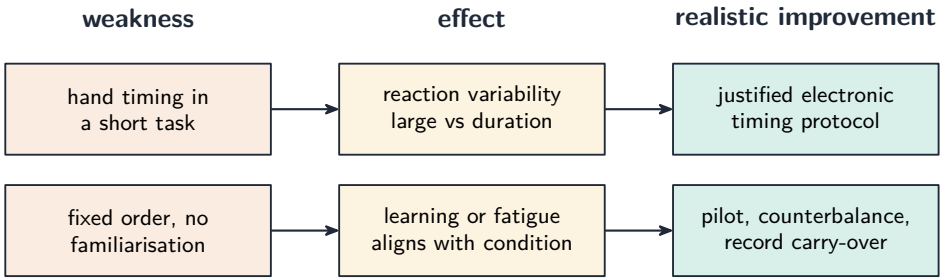
- Answer the research question directly, using the data: give the size of the effect, the statistical result and the trend.
- Explain the result with scientific knowledge from the course, for example the length–tension relationship or motor unit recruitment.
- Compare with published research. Compare relevance, methods and uncertainty as well as agreement. Do not select only supportive papers or force a mechanism merely because it fits the story.
- Keep the conclusion in proportion to the evidence: a sample of 12 classmates cannot prove a law for all athletes.



A conclusion in proportion

Evaluating the method

For each weakness, give its effect on the results and a realistic improvement.



Weakness, effect, improvement

Weakness	Effect	Realistic improvement
Hand timing in a short task	Reaction-related variability or bias can be large relative to duration	Use a justified electronic protocol and verify start/finish definitions
Small convenience sample	Imprecise estimates and limited representation	Justify recruitment and feasible sample size; do not claim a magic minimum
No familiarisation or fixed order	Learning or fatigue may align with a condition	Pilot familiarisation, counterbalance and record residual carry-over
Different uncontrolled sessions	Conditions may change with the comparison	Standardise feasible conditions and document remaining influences
Participants know the expected direction	Expectancy may influence responses	Consider ethical masking where feasible without misleading consent; acknowledge limits

Extensions suggest the next question, for example testing older athletes, or a different type of stretch.

The internal assessment and collaboration

The scientific investigation

In the **scientific investigation** 科学探究 you answer your own research question by collecting and analysing data. It takes about 10 hours, and the written report has a maximum of 3200 words. It is worth 24 % of the final grade at both SL and HL. Optional collaboration is limited to groups no larger than three. Each student needs a unique question and must not present the same raw data set as another: use different independent variables, a different dependent variable, or different selected data from a larger communal set as allowed by the guide. All report authoring, including methodology, is individual. These requirements are explained in the official SEHS guide.

The report is assessed on four areas:

1. **Research design**: a focused research question with background, and a method that explains how the data were collected, including controls, safety and ethics.
2. **Data analysis**: clear, accurate processing and presentation of the data, with uncertainties taken into account.
3. **Conclusion**: a justified answer to the research question, consistent with the analysis and compared with accepted science.

4. **Evaluation**: the strengths and weaknesses of the method, with realistic improvements and extensions.

Suitable topics are low-risk and measurable in school: warm-up type and sprint time, music tempo and heart rate during exercise, feedback type and a throwing task, caffeine-free sports drinks and taste preferences in a survey, or analysis of a published secondary data set. Choose a topic you can control and repeat, not one that needs maximal effort or medical equipment.

■ The collaborative sciences project

The **collaborative sciences project** 合作科学项目 is about 10 hours of group work with students from other science subjects. The group investigates a real-world problem, such as sport and health in the local community, from several scientific angles, and then reflects on how the sciences worked together. It is required but not separately graded.

■ Practical skills across the course

The **experimental programme totals 40 hours (SL) or 60 hours (HL)**: practical work itself is **20/40 hours**, plus **10 hours** for the collaborative sciences project and **10 hours** for the scientific investigation in each level. Do not add the two ten-hour components again to the 40/60 totals. The skills you use are the **tools**: experimental techniques (measuring safely), technology (data loggers, video analysis and spreadsheets) and mathematics (statistics, graphs and uncertainty). The **inquiry process** runs from exploring and designing, through collecting and processing, to concluding and evaluating.

Practice

1. Formulate a focused low-risk investigation question and identify explanatory/independent, dependent and three feasible controlled variables. Distinguish a prediction from a null model.
2. Explain random sampling, random allocation, familiarisation and counterbalancing. Why are ten trials by each of five people not 50 independent participants?
3. Explain consent/assent, withdrawal and school safety approval. Distinguish coded data with a name key from anonymous data and explain why a screening questionnaire is not clearance.
4. Distinguish validity and reliability using a sit-and-reach result. Why does a low-scatter target picture or a laboratory location not prove validity?
5. A jump device consistently reads 1.5 cm high. Explain detection/correction and remaining uncertainty. Distinguish resolution, random variation and total uncertainty.
6. For 30.0 ± 0.1 m and 4.20 ± 0.20 s, use the stated maximum-bound approximation to find speed and uncertainty. Repeat with a ± 0.01 s time bound; calculate the improvement factor from unrounded bounds.
7. A swimmer covers 50.0 ± 0.1 m in 31.50 ± 0.20 s, again as maximum bounds. Find speed and uncertainty, keeping unrounded working before final rounding.
8. Jumps are 42,45,44,43,46 cm. Find mean, median, mode, range, sample SD, CV, SE under independent-sampling assumptions and IQR using the stated median-exclusion convention. Which quantity is not automatically justified for five trials from one person?
9. A raw test score changes 8.0→9.2. Find relative change and explain why it need not be the same percentage change in physiological capacity. For two positive lengths 40/44 cm, compare change relative to 40 with symmetric percentage difference.
10. Calculate the paired t statistic for reductions 0.10,0.12,0.14,0.16,0.18 s. Use the supplied df 4 two-sided 0.05 critical magnitude 2.776. Explain the assumptions and what rejecting the null does not prove.
11. Interpret $p = 0.03$ at a preselected 0.05 level. Explain why the two groups' SD error bars and means do not supply a paired-test p-value or establish that their changes differ statistically.
12. For 12 independent pairs, $r = 0.54$ and a supplied appropriate critical magnitude 0.576. State the decision. Then explain what r near zero, sample $R^2 = 0.69$ and a correlation of sport with grades each cannot establish.
13. Choose displays for a categorical count, a continuous distribution, paired quantitative data and change over time. Explain gradient/area units, interpolation versus extrapolation, and how to label uncertainty bars. Convert 3500 ms to seconds; find the elapsed time between frame indices 120/240 at 240 frames/s and explain one video limitation.
14. Evaluate a convenience-sample phone-timing study with one trial on each of two afternoons. Outline the investigation criteria, individual authorship/data requirements, collaboration and the 40/60-hour experimental-programme totals.

Answers.

1. Example: "How does a teacher-approved visual cue condition relate to the time for a low-risk desktop response task in consenting 16–18-year-old students?" Define the cue conditions, time in seconds and population. Standardise equipment, instructions and feasible testing environment. A hypothesis predicts a pattern with a reason; the null specifies a tested no-difference/no-association parameter, not proof of reality.
2. Sampling selects who enters; allocation assigns conditions. Familiarisation can reduce learning, and counterbalancing distributes order effects; neither eliminates all bias. Trials within a person are dependent: five participants remain five independent sampling units, with repeat trials used according to the planned summary or model.

3. Explain tasks, risks, data use and withdrawal; follow school parent/guardian consent and student-assent requirements. Obtain approval and suitable supervision, and stop appropriately. A code/name key permits re-identification and needs confidentiality safeguards. A screening response supports review, not automatic medical clearance or diagnosis; truly unlinked data may no longer be retrievable for withdrawal.
4. Validity concerns evidence for the intended interpretation/use; reliability concerns consistency under suitably repeated conditions. Sit-and-reach is a specific reaching task affected by more than one joint and by proportions/technique; it is not whole-body flexibility. Low scatter can coexist with systematic bias, and a laboratory method may miss the sporting construct.
5. Compare the device with an appropriate reference method or calibration procedure over the relevant range. A constant +1.5 cm discrepancy suggests systematic bias; subtract it only if a justified calibration supports that correction, or repair/use another method. A known step height is not automatically a valid reference for a flight-time jump estimate. Resolution is the readout increment; random scatter and calibration/model limitations can remain.
6. Speed **7.142857... m/s**; summed maximum percentage **5.095238... %**; absolute **0.363945... m/s**, reported **7.1 ± 0.4 m/s**. With ±0.01 s: **0.5714286... %**, absolute **0.0408163... m/s**, reported **7.14 ± 0.04 m/s**. Unrounded improvement factor **0.363945.../0.0408163... = 8.91666...**. Distance uncertainty remains.
7. Speed **1.5873016... m/s**. Fractional bound **0.1/50 + 0.20/31.50 = 0.008349206...**; percentage **0.8349206... %**; absolute **0.0132527... m/s**. With two significant figures in uncertainty, report **1.587 ± 0.013 m/s**; a stated one-significant-figure convention gives **1.59 ± 0.01 m/s**. Do not round intermediate percentages first.
8. Mean/median **44 cm**; no single mode; range **4 cm**. Squared deviations sum 10 cm^2, so sample SD $\sqrt{(10/4)} = 1.5811388...$ **cm**; CV **3.593497... %**; independent-sampling SE **0.7071068... cm**. Q 1/Q 3 = **42.5/45.5 cm**, IQR **3 cm**. Half-range 2 cm, SD and SE are different quantities. Five same-person trials do not justify an SE for a population of five independent students.
9. **(9.2−8.0)/8.0 × 100 = 15 %** of the raw score; test levels may not scale linearly with physiological capacity. For 40→44 cm, change **10 %**; symmetric percentage difference **4/42 × 100 = 9.5238... %**. State the reference and construct rather than treating percentages as interchangeable.
10. Mean reduction **0.14 s**; squared deviations sum **0.004 s^2**; sample SD **0.0316228... s**; SE **0.0141421... s**; **t = 9.89949...**, df 4. Since **9.899 > 2.776**, reject the zero-mean-difference null under the stated test. Examine independent participants and a reasonable small-sample normal model for differences, including outliers. Rejection proves neither a causal training effect nor relevance to all athletes.
11. Under the specified null model and assumptions, a statistic at least as incompatible as observed has probability **0.03**; reject that null at preselected 0.05. This is not a 3 % probability the null is true or a diagnosis of "chance". SD bars show spread, not paired-change uncertainty. Before/after covariance and suitable data/model are needed; one significant within-group change and one non-significant change do not establish a significant between-group difference.
12. **|0.54| < 0.576**: fail to reject the specified zero-correlation null; do not prove no relationship or promise significance with more data. r near zero excludes neither a curved pattern nor confounding. For an appropriate fitted model, $R^2 = 0.69$ describes sample variation accounted for, not 69 % caused. Sport/grades may share causes, reflect selection or reverse direction; association alone does not establish a causal effect.
13. Bar: categorical counts; histogram: quantitative distribution; scatter: paired quantities; line: time course. Label axes/units and whether bars are SD, SE or bounds. Gradient units are y-units/x-units; area uses their product. Interpolation stays within observed range; extrapolation needs stronger assumptions. **3500 ms = 3.5 s**; video time **120/240 = 0.50 s**. Timestamps, calibration or parallax may limit inference. At fixed distance, doubling time halves speed.
14. Timing, recruitment, trial count and session changes create different limitations; improve each with a justified feasible method. Criteria: research design, data analysis, conclusion, evaluation. Optional groups of at most 3 still require unique questions, non-identical selected raw data and individual authoring. Experimental totals **40/60 h** comprise practical **20/40 h**, project **10 h** and investigation **10 h**, without double-counting.

Exam tips

- Define the sampling unit, construct and test assumptions. Distinguish association, statistical significance and a causal or practical conclusion.
- Show units, uncertainty convention and percentage denominator; keep SD, SE and half-range distinct. Credit sources and preserve individual questions, data selection and authoring.