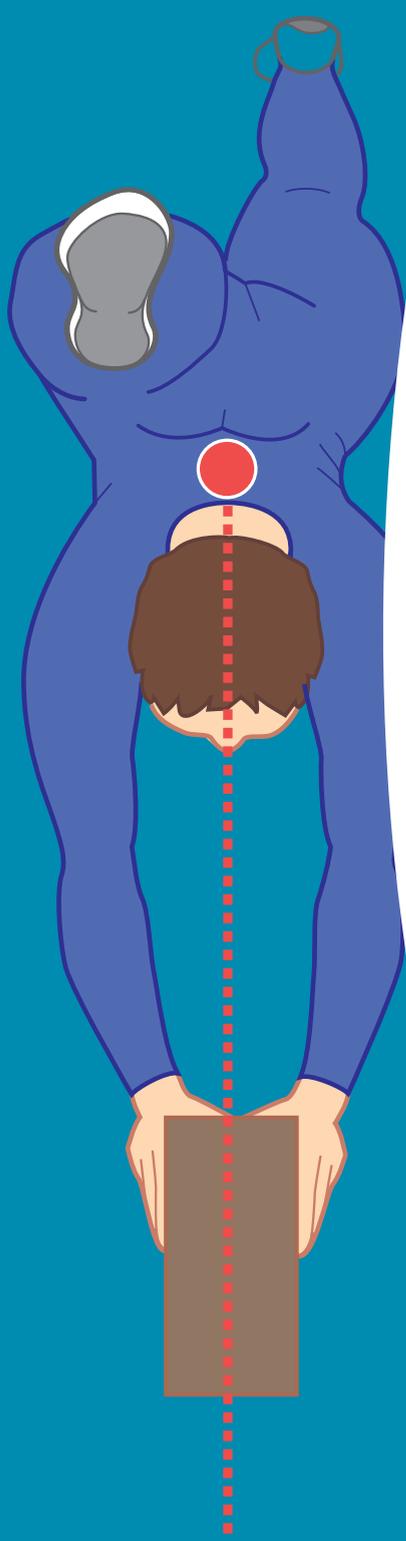




PART 3

BIOMECHANICS

CHAPTER 7 BIOMECHANICAL PRINCIPLES, LEVERS AND THE USE OF TECHNOLOGY



CHAPTER 7: Biomechanical principles, levers and the use of technology

Newton's laws of motion

Newton's first law

Newton's first law of motion describes what happens when **zero net force** acts, which means that all forces acting must cancel out. In figure 7.1 the forces (green arrows) **cancel out**. The vertical forces are the same size (arrows are the same length) but in opposite directions. The horizontal forces are also of the same size and in opposite directions, hence all forces cancel out.

When there is zero net force acting on an object:

- The object is **stationary**.
- **Or** the object moves at **constant velocity**.

Hence when any object moves at constant velocity, all forces must cancel out, the net force must be zero.

Inertia

The first law is also known as the law of **inertia**. The concept of inertia is that a massive object will remain at rest and will require a force to shift it, and once moving, will require a force to change its motion (accelerate or decelerate it). Sometimes, the word **inertia** is used to represent the **mass** of a body or object.

Newton's second law

Newton's second law of motion describes what happens when a **net force acts** on a body. **A net force** produces **acceleration** or **deceleration** of the body or changes the direction of the body (swerving). In the motion of a sprinter the acceleration is produced by the net force applied, which must be forwards if the sprinter is accelerating forwards. When the sprinter **decelerates**, there is a **net force backwards**. In figure 7.2, the vertical arrows (representing vertical forces) are the same length but in opposite directions, and hence cancel out. The horizontal forces are both acting backwards, therefore there is a net force acting backwards on her. This means that she is **decelerating** (horizontally!).

- Newton's second law also says that the bigger the **net** force, the greater the **acceleration** of the person.
- Hence a **stronger** sprinter should be able to **accelerate** out of the blocks quicker.
- However, the more mass an object has, the less the acceleration for a given force.
- Hence a heavier (more massive) sprinter will accelerate less than a lighter sprinter.

This is expressed mathematically as:

$$F = m \times a$$

(force = mass x acceleration)

As discussed above, slowing down (**deceleration**) is also caused by force. Hence a bike hitting a barrier encounters a large force, since a large deceleration slows the bike very quickly, possibly wrecking it and hurting the rider. However, if the cyclist had applied the brakes moderately, he or she would have encountered less deceleration, taking longer to stop, but would do so safely.

Newton's third law

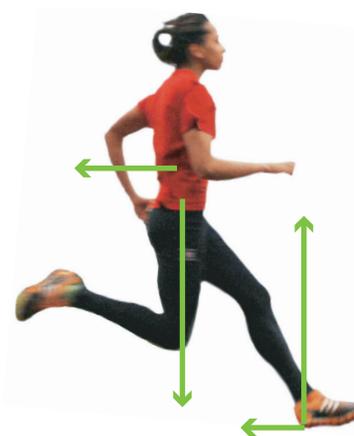
Newton's third law of motion describes what happens when **two bodies** (or objects) exert forces on one another. Action and reaction are equal and opposite and always occur in pairs.

Action acts on one of the bodies, and the **reaction** to this action acts on the other body. At a sprint start, the athlete **pushes back** on the blocks as hard as possible (this is the '**action**' - see figure 7.4e page 109), and the blocks **push forward** on the athlete (this push forward is the '**reaction force**'). The reaction provides forward acceleration on the athlete. In figure 7.4c (page 109), a swimmer pushes backwards on the water with hands and feet (this is the force in **black**, the **action**). At the same time, the water thrusts the swimmer forward (this is the force in **red**, the **reaction force**).

figure 7.1 – a sprinter at constant speed



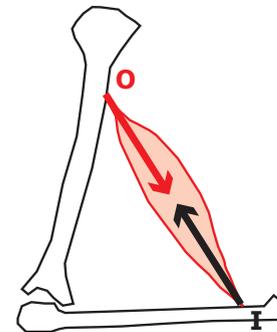
figure 7.2 – a sprinter decelerating



Newton's third law

For **internal forces** within the body, for example in figure 7.3, the origin (O) and insertion (I) of a muscle pull in opposite directions to change the shape of the body. In this example, the **action** is the pull of the muscle (red arrow) on the origin of the muscle, and the **reaction** is the pull of the muscle (black arrow) at its opposite end, on the insertion. The effect is to change the shape of the person, by pulling the origin towards the insertion, and bending the limb in question.

figure 7.3 – forces at origin and insertion

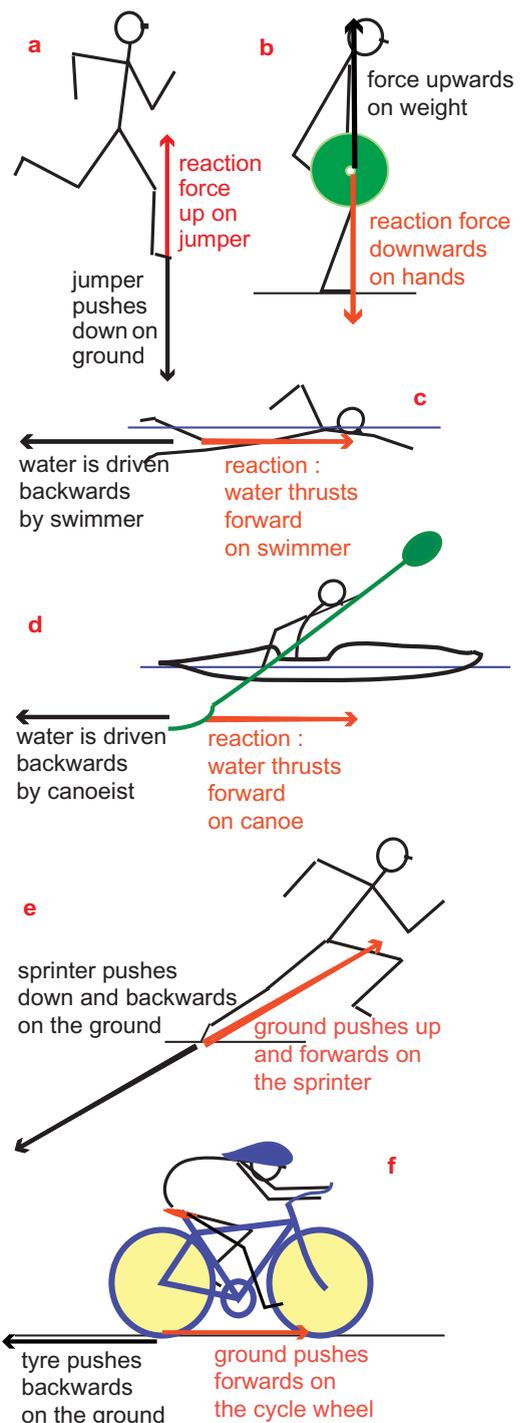


Reaction forces

Reaction forces are forces acting via Newton's third law as explained above. When one object pushes on another, the first object experiences a force equal but opposite in direction to the second (figure 7.4):

- **a**, the jumper pushes down on the ground (black arrow), the ground pushes up on the jumper (red arrow).
- **b**, the weight lifter pulls up on the weight (black arrow), weight pulls down on lifter (red arrow).
- **c**, the swimmer pushes backwards on the water (black arrow), the water pushes forward on the swimmer (red arrow).
- **d**, canoeist pushes backwards on the water (black arrow), reaction force thrusts the canoe forward (red arrow).
- **e**, sprinter pushes back and down on the ground (black arrow), the ground pushes upwards and forwards on the sprinter (red arrow).
- **f**, in cycling, the tyre on the rear wheel pushes backward on the ground (black arrow), the ground pushes forward on the rear wheel (red arrow).

figure 7.4 – examples of reaction forces



Force

Force is push or pull. The unit of force is the **newton** (10N is approximately the weight of 1 kg). Force changes the state of motion of an object, and causes acceleration or deceleration or change of direction.

One newton of force is the force required to produce an acceleration of 1 ms^{-2} in a mass of 1 kg. This is related to the inertial property of mass - the more force applied, the more acceleration produced (see Newton's second law, page 108).

Force has **direction** and size (**value**), and is therefore a vector. When describing a force it is important to explain where the force acts (the point of action), as well as the direction.

Vectors and scalars

The ideas behind **vectors** and **scalars** are used extensively in maths and physics. A **vector** is a quantity which has **size** (called magnitude) and **direction**. By quantity we mean something like weight, displacement, velocity, acceleration, force, and momentum, all of which are vectors, and therefore have to have a direction connected to them as well as value or size. For example, a force could be 100 newtons downward (the downward specifies the direction), an acceleration could be 10 metres per second squared forwards (the forwards specifies the direction).

Vectors and scalars

Usually in maths, the direction is specified by the angle to the x-axis in a graph of an arrow drawn on the graph, with the size (magnitude) represented by the length of the arrow (figure 7.5).

Net Force

The point of this is that when more than one vector has to be taken into account, then they must be added together taking note of the direction of each vector. In figure 7.6 for example, two forces of 500 newtons are acting, the green force acts upwards, and the red force acts downwards. Because they are acting in opposite directions, they add up to nil, in other words they exactly cancel out to give zero net force. Note that this gymnast is also in unstable equilibrium (see page 114).

- In figure 7.7, the vertical forces acting on the sprinter are the weight ($W =$ force due to gravity) acting downwards, and the ground reaction force (R) acting upwards. These two forces are identical in value but opposite in direction and therefore cancel out exactly to give zero net force vertically.
- The horizontal forces are the friction force (F) acting forwards, and the **air resistance** or drag (A) acting backwards. These two forces are equal in value but opposite in direction, and hence cancel out to give zero net force acting horizontally.
- Hence relatively large forces can act, but they can cancel out because of their direction. Note that zero net force does not mean that the sprinter is stationary, see Newton's first law of motion (page 108).
- Equally, when the forces are added up and there is an unbalanced **resultant** (the forces **do not cancel out**), then there is a **net force** acting. The body on which this force is acting will then accelerate in the **direction** of this net force as specified by Newton's second law (page 108).

A scalar

A **scalar** is a quantity which has size or value only. Quantities like mass, speed, energy, power, and length have a value only. For example, a person could have a mass of 60 kg, or an amount of 1000 joules of energy are used up when performing an exercise. No directional angle is required when talking about these quantities.

Energy is a scalar which has a value only, and the value of energy consumed daily by a Tour de France cyclist is 6,000 kilocalories - which has no direction.

Speed (measured in metres per second - ms^{-1} , distance and time are scalars which are linked by a simple equation.

$$\text{Speed} = \frac{\text{distance travelled in metres (m)}}{\text{time taken to travel in seconds (s)}} \text{ (ms}^{-1}\text{)}$$

Weight and mass

These two ideas are often confused. **Mass** is a scalar and represents the total quantity of matter in an object. **Weight** is the force due to gravity on a mass (with a direction towards the centre of the Earth). Weight will vary slightly over the surface of the Earth depending on the gravitational field strength. The gravitational field strength changes slightly depending on the thickness of the Earth's crust, the longitude, the proximity of large mountains, and the height above sea level. Weight is approximately 10 newtons for each kilogramme of mass, and will act on the centre of mass of a body (the point which represents the averaged position of all the mass of a body), with examples shown in figure 7.8. Hence if the mass of the sprinter in figure 7.7 is 50 kg, then her weight would be $50 \times 10 = 500$ newtons towards the centre of the Earth.

Weight is also the predominant force acting on an object projected into flight.

figure 7.5 – direction of a vector

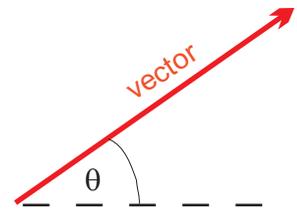


figure 7.6 – vectors cancel out

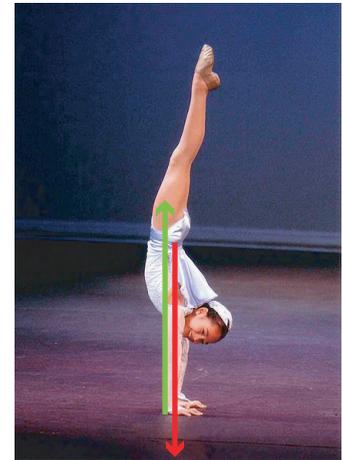


figure 7.7 – forces cancel out

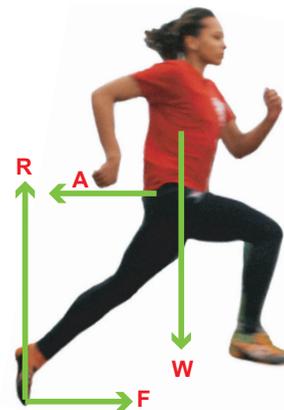
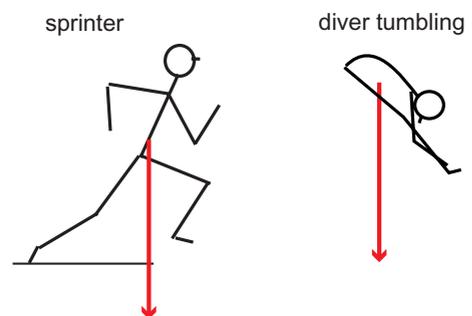


figure 7.8 – weight of various bodies



Friction

Friction is a force which acts sideways between two surfaces which tend to slide past one another. This force enables sportspeople to accelerate, slow down, swerve, walk, and run.

The magnitude of friction depends on the **grip of footwear** on floor surface, and the **nature of the surface** itself (rough, smooth, slippery, greasy and so on), for example:

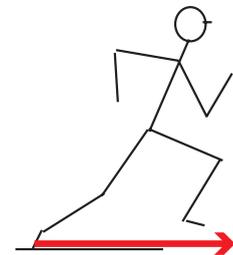
- **Studs and spikes** increase friction to enable better swerving and accelerating and decelerating in games or track situations. This applies to soft or wet surfaces.
- For **dry hard surfaces**, solid smooth rubber soles can give better friction as in discus or hammer shoes, rock climbing shoes, or tennis shoes for concrete surfaces.
- In **snow and ice**, long slender footwear (skates or skis) have low forward friction, but high sideways friction.

Note that friction acts forwards on the feet of the accelerating runner (see figure 7.9).

Friction depends on the force pressing the surfaces together, but not on the area of contact. For example:

- The inverted wings on racing cars increase the down force on wheels. This increases cornering friction between the wheels and the ground.
- When riding a mountain bike up a steep hill, you should sit back over the rear wheel to increase downward force on the rear wheel, so that there is more friction between the rear wheel and the ground.
- Friction also enables swerving by games players in rugby, soccer, hockey, and tennis. The friction force then acts sideways to the direction of motion, and changes the direction of motion.
- The direction taken after a bounce by a spinning ball depends on the direction of spin and the friction between the ball and the ground.

figure 7.9 – friction



friction acts forward on the foot of the accelerating sprinter

Rolling or sliding friction

- **Rolling friction** is the term which describes the force between surfaces which do not move relative to one another, like a wheel rolling over a surface, or a foot driving and pushing without slipping. The friction can be anything from zero up to a maximum just before slipping occurs. As soon as slipping occurs, the friction force falls, and would not be enough to keep a sportsperson upright (so he or she slips over!).
- **Sliding friction** occurs when the two surfaces are moving relative to one another, and is always less than the maximum rolling friction. This is why ABS (**advanced braking systems**) will reduce braking force on wheels if sensors detect the beginning of sliding.

Fluid friction

Fluid friction (or **drag**) is a term applying to objects moving through fluids (gases or liquids). The force acts in the opposite direction to the direction of motion. This term applies to the **air resistance** experienced by objects moving through air.

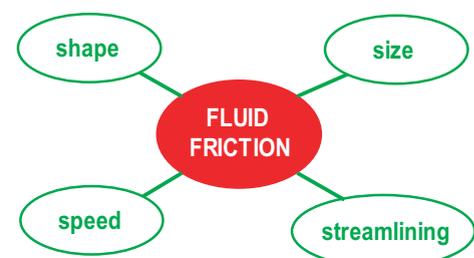
Fluid friction force depends on the shape and size of the moving object, the speed of the moving object, and the streamlining effect (summarised in figure 7.10).

Drag and air resistance

In order to minimise drag, the following developments affect sport:

- The body position and shape for a swimmer.
- The shape of helmets for cyclists.
- The use of lycra clothing.
- The shape of sports vehicles (cars or bikes).

figure 7.10 – factors affecting fluid friction or air resistance



Low values of fluid friction

This discussion concerns **low values of drag** compared with other forces. Examples are:

- Any sprinter or game player for whom air resistance is usually much less than friction effects and weight. Therefore streamlining is seen as less important.
- A shot or hammer in flight, in which air resistance would be much less than the weight, and therefore the angle of release should be around 45°.

High values of fluid friction

High values of drag will occur for any sportsperson or vehicle moving through water, and hence fluid friction is the critical factor governing swimming speed.

- Body shape or cross section, and clothing (surface material to assist laminar flow, see below), are adjusted to minimise fluid friction.

A cyclist (figure 7.11) travels much faster than a runner and therefore has high fluid friction:

- He or she crouches low to reduce forward cross section.
- The helmet is designed to minimise turbulent flow.
- Clothing and wheel profiles are designed to assist streamlining.

Cross sectional area is the area of the moving object as viewed from the front. The smaller the better to reduce drag, hence cyclists crouch down, and keep elbows in!

Laminar flow and drag

Fluid friction (or drag) depends on **laminar** flow, the smooth flowing of air or water past an object. Laminar means flowing in layers, and streamlining assists laminar flow. Figure 7.12 shows images of a streamlined helmet, and a non-streamlined helmet. The point of the streamlined shape is that the air moves past it in layers whereas in the case of the non-streamlined helmet, vortices are formed where the fluid does not flow smoothly. When this happens bits of fluid are flung randomly sideways which causes drag. The drag is caused by bits of fluid being dragged along with the moving object (the cycle helmet).

Free body diagrams

Pin men (free body) diagrams are used to represent the human body with forces acting on it when answering exam questions. Free body diagrams are a way of doing this without any anatomical details.

In figure 7.13, a runner is represented by a pin man, with forces depicted by red arrows. The figure shows four forces acting, two forces acting up on the foot and down on the body, and two forces acting backwards on the body and forwards on the foot. Longer arrows mean greater force.

The **point of action** of a force is also important, remembering that drag forces will act over the whole body but are usually represented by a single arrow acting somewhere in the middle of the body. A friction force will act on the foot of the runner, and the weight will act on his or her centre of mass. Reaction forces act at the point of contact between two objects (on the foot of the runner in figure 7.13).

figure 7.11 – a cyclist needs good streamlining

fluid friction (drag) depends on forward cross section and streamlining

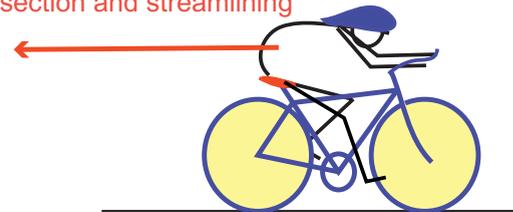


figure 7.12 – laminar flow and vortex flow

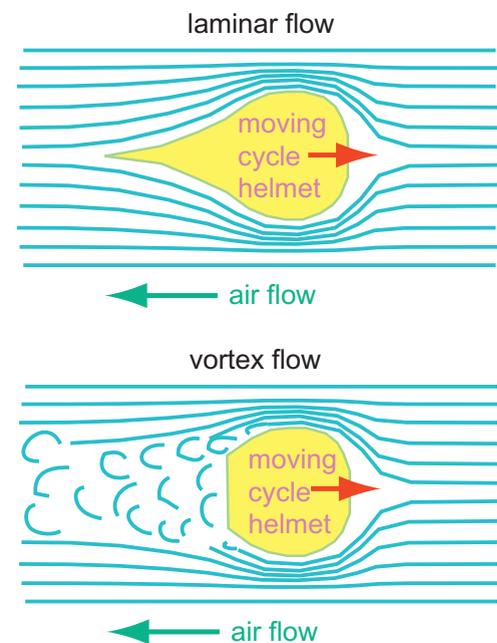
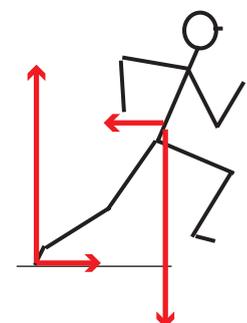


figure 7.13 – pin-man or free-body diagram



Momentum

Momentum is a concept derived from Newton's second law which says:

$$\text{force} = \text{rate of change of momentum}$$

$$\text{(linear) momentum} = \text{mass} \times \text{velocity}$$

Note that linear means in a straight line, and that momentum includes both mass and velocity.

- Hence an object which has a lot of momentum requires a lot of force to stop it, which is a good argument for fast heavy rugby players or American footballers.
- Momentum is a **vector** (and therefore has direction).

Distance and displacement

Distance is a scalar - usually measured in metres, **displacement** is a distance (also measured in metres) as the crow flies from start to finish of a movement. **Displacement** therefore has a value and a direction and is a **vector** (pages 109-110 for an explanation of vectors and scalars).

For example, the total distance run in a 10k race will be 10,000 metres - and this is the measure which the runner will be interested in. But the displacement will be zero, since the start and finish of a 10k race are usually in the same place. Start and finish of a marathon race are often not in the same place, so the displacement between start and finish will have a value in metres and a direction. But again, runners will be interested in the distance ran, not the displacement between start and finish.

figure 7.14 – a sprinter at constant speed



Speed and velocity

Speed = $\frac{\text{distance moved}}{\text{time taken}}$ or $v = \frac{s}{t}$ unit ms^{-1}

= **scalar** (no direction)

= distance moved in 1 second

Velocity = speed in a given **direction** = **vector**

The vector property of velocity is important because not only does it add up or cancel out a bit like the force example in figure 7.14, but it can change direction without changing value. Examples of this are a swerving rugby player (figure 7.15), or the head of a hammer which moves in a circular path, both of whose velocity changes in direction.

figure 7.15 – Jason Robinson sidesteps left then right



The swerving rugby play is running forwards but exerts a force **sideways** to the direction of motion. This force is part of the friction between his boots and the ground (players often slip when performing this manoeuvre). His direction of motion will therefore change - hence the swerve.

This means that the player or the hammer head is accelerating towards the centre of the arc (circle) in which it is moving, which means that from Newton's second law (see page 108) a force is required (also towards the centre of the arc in which the object is moving).

Acceleration

Acceleration = $\frac{\text{change of velocity}}{\text{time taken to change}}$ $a = \frac{v - u}{t}$ unit ms^{-2}

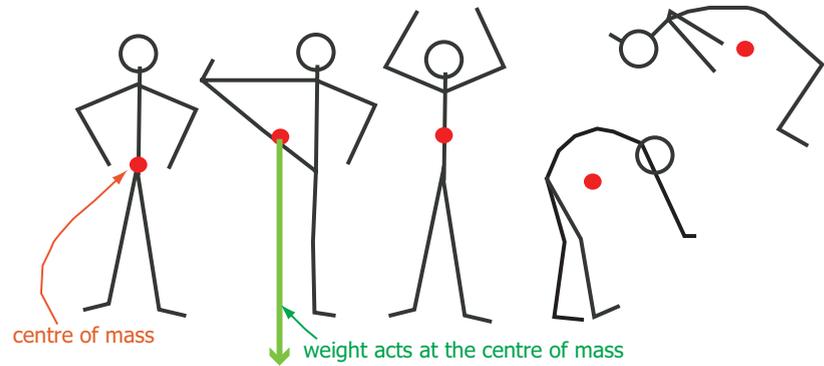
- **Acceleration** will be in the same direction as net force, and therefore acceleration is a vector (has direction).
- In the case of the swerving rugby player, the direction of acceleration is along the radius of the path of the player. This is a **radial acceleration**.
- **Deceleration** is **negative acceleration** (slowing down).

Stability and the centre of mass

Centre of mass

Centre of mass (CofM) is the single point (on a body) which represents **all the spread out mass** of the body. So, since gravity acts on mass to produce weight, the weight acts at the centre of mass of a body. In figure 7.16, the weight is marked as a green arrow, and it acts downward on the CofM. The CofM can be defined as **‘the point of balance of the body’**. As limbs are moved, or the torso changes shape (as when bent over for example), so the position of the centre of mass of the body will move as in figure 7.16. Note that the CofM does not always lie within the body shape, when the torso is bent, it can lie well outside the body mass.

figure 7.16 – centre of mass position changes with body shape



Note that the right hand image in figure 7.16 is that of the layout position for the Fosbury flop high jump technique. The CofM lies underneath the body, and can be below the bar even though the athlete clears the bar.

Balance

The CofM must be **over the base of support** if a person is to be balanced. In figure 7.17, with the leg stuck out sideways, the centre of mass moves to a position to the left of a vertical line through the foot. So, the weight (force) acts downwards through the centre of mass (see the green vertical line in figure 7.17, also known as the centre of gravity projection), and will topple the person to the left. Therefore to maintain balance, the person must lean to the right (as we look at her), and thereby bring the CofM back vertically over the supporting foot.

figure 7.17 – a gymnast topples to the left



Toppling

Toppling is caused by the weight acting vertically at the CofM and therefore to **one side** of the near edge of the base of support. This fact can be used by divers or gymnasts to initiate a controlled spinning (twisting) fall. And hence lead into somersaults, cartwheels or twists.

figure 7.18 – unstable equilibrium



Stability

If an object has its CofM over the base of support, it is said to be in equilibrium. If a slight movement of the object will make it topple, then the object is said to be in unstable equilibrium. An example of this would be a beam gymnast who must carefully control the position of her CofM if she is to remain on the beam (figure 7.18).

The gymnast who lies on the floor would be said to be in neutral or stable equilibrium (figure 7.19). When pushed, he would remain in the same position (or nearly the same) without toppling or falling.

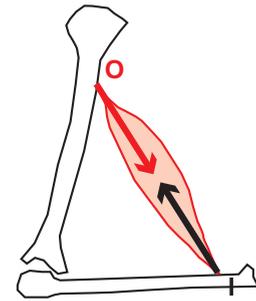
figure 7.19 – neutral or stable equilibrium



Components of a lever

The term **internal forces** describes the forces acting (figure 7.20) when a muscle pulls on its **origin** **O** and **insertion** **I**. The force on the origin (in red) is equal in size but opposite in direction to the force on the insertion (in black). This changes the **shape** of the person.

figure 7.20 – forces at origin and insertion

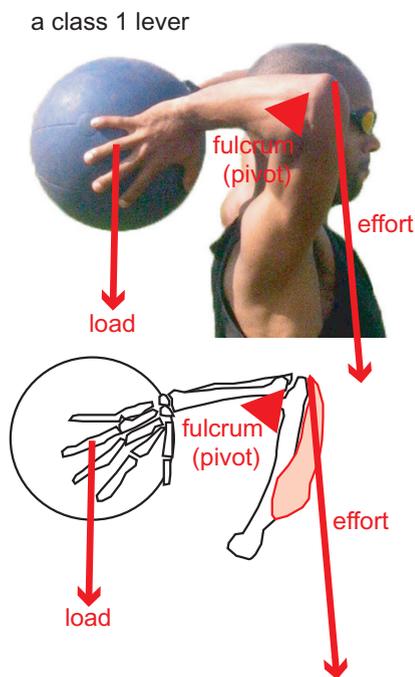


Levers

A lever is a **means of applying force at a distance** from the source of the force and has a **fulcrum (pivot)**, **effort** and **load**. In the human body, usually a **joint** and the **attached limbs** or bones act as a lever. **Force** is applied as **effort** by a **muscle** or group of muscles. The **load** is the **force applied** to the **surroundings** by the lever.

Classification of levers

figure 7.21 - elbow/triceps lever



Class 1 lever

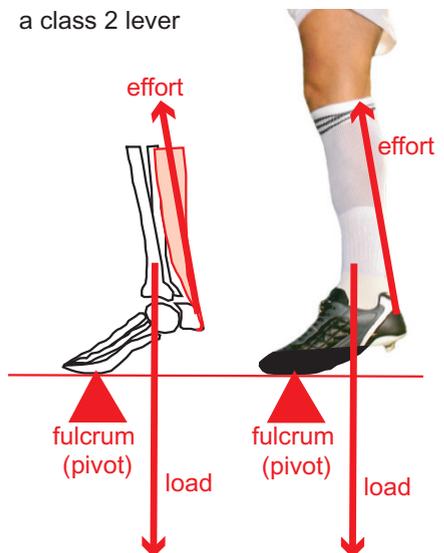
This is a see-saw lever with the fulcrum in between the effort and the load. It is found rarely in the body, for example the triceps/elbow/forearm lever (figure 7.21), or the atlas/neck muscles used in the nodding movement.

Sometimes, there will be mechanical advantage and disadvantage depending on the relative distances of the load and effort from the fulcrum. Basically, the further away the load, the less the advantage of the lever.

Class 2 lever

This is a wheelbarrow lever where the load is bigger than the effort, and the fulcrum is at one end of the lever with the load in between the effort and the fulcrum. This is found rarely in the body, the main example being the Achilles tendon/calf muscles (gastrocnemius and soleus) and ankle joint lever (figure 7.22). This is used in most running or walking movements with the fulcrum underneath the ball of the foot as it drives the body forward. This class of lever always has a **mechanical advantage** - the load is always bigger than the effort.

figure 7.22 - ankle/calf lever



Class 3 lever

This class of lever again has the fulcrum at one end of the lever arm, with the effort in between the load and the fulcrum. It has a **mechanical disadvantage**, the effort is always bigger than the load and is the most common system found in body. For example the elbow/biceps/forearm lever (figure 7.23), or the knee/quadriceps/tibia/fibula systems (figure 7.24 page 116).

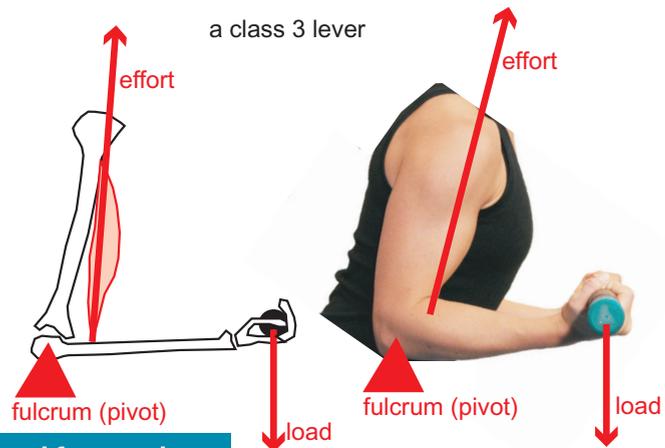


figure 7.23 – the elbow and forearm lever

Effects of the length of lever

The **length of the lever** or **resistance arm** of the lever (**d** in figure 7.25) affects the **load** able to be exerted by the lever, and the **speed** at which the hand can move. The longer the lever **d**, the smaller the value of the load for a given biceps strength and value of the **effort arm** (distance between effort and pivot). The longer the lever arm **d**, the faster the load can be applied (as the limb moves through its range - a longer limb - the hand would move further in the same time).

This means that the hand of a thrower with long arms will be moving faster than the hand of a thrower with short arms if each is turning (rotating) at the same speed.

The **shorter** the **effort arm** the less load can be exerted. The shorter the load (resistance) arm of a person the bigger the load can be. This is why successful weightlifters tend to have short arms.

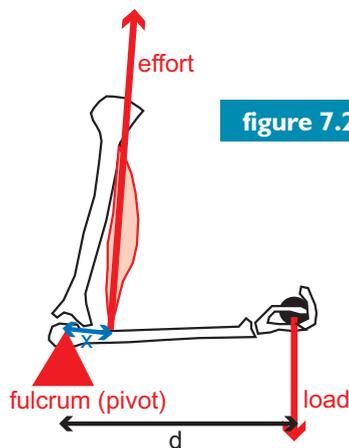


figure 7.25 – the length of a lever arm

figure 7.24 – knee/tibia/quadriceps lever

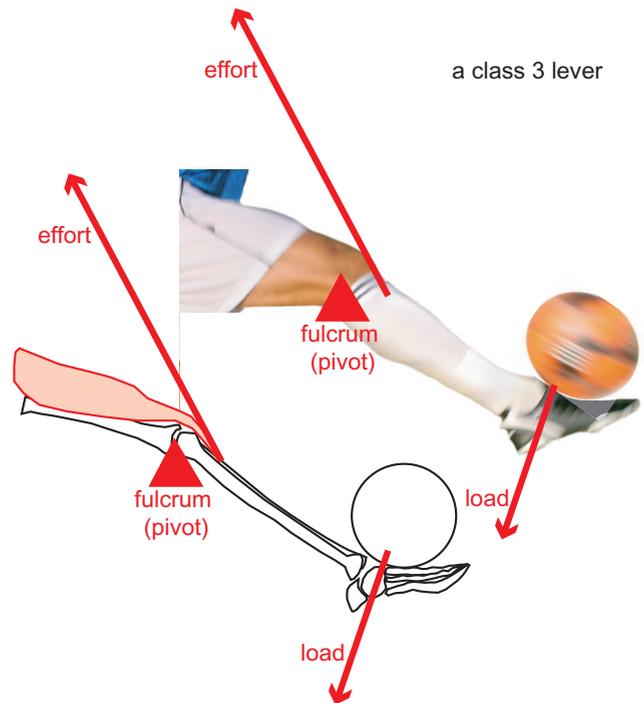


figure 7.26 – video software



Analysis through the use of technology

Modern technology in sport has developed significantly over the past decade. Athletes, coaches, physiotherapists, podiatrists and sports scientists need to understand how to use technology in order to optimise sports performance, especially at the elite level.

Limb kinematics

Kinematics is the science of motion. In human movement, it is the study of the positions, angles, velocities, and accelerations of body segments and joints during motion. Body segments are rigid bodies such as the thigh, foot and forearm. Joints between adjacent segments include ankle, knee, hip, elbow and shoulder. Position describes the location of a body segment or joint in space.

In limb kinematics **reflective markers** are placed in the appropriate anatomical positions on the performer. High-speed 3D video cameras capture the performance and biomechanical software, such as Quintic and Dartfish, enable a coach to highlight and analyse technical aspects of the performance by using a variety of drawing tools or playback facilities over the actual video footage, as illustrated in figure 7.26. Automatic reports enable the user to analyse a movement which quantifies the key variables. The video clips can be repeated over and over again to reinforce the positive aspects of the performance and/or the ones that need improvement. Over time, the coach and performer can assess if technical improvements have been made.

Force plates

Force plates are laboratory-based measuring instruments that measure the ground reaction forces generated by a body standing on or moving across them, to quantify balance, gait and other parameters of biomechanics.

- A **force plate** is inserted into the ground at the take off area for a long jump or high jump, or in the space in a track immediately after a sprint start. This enables the patterns of force (figure 7.27) made by a foot striking the plate to be determined.
- This information (combined with video of the same footfall) can tell a coach the precise way in which the foot is active during its strike with the ground, and enables him or her to assess whether **changes in foot posture** are required.

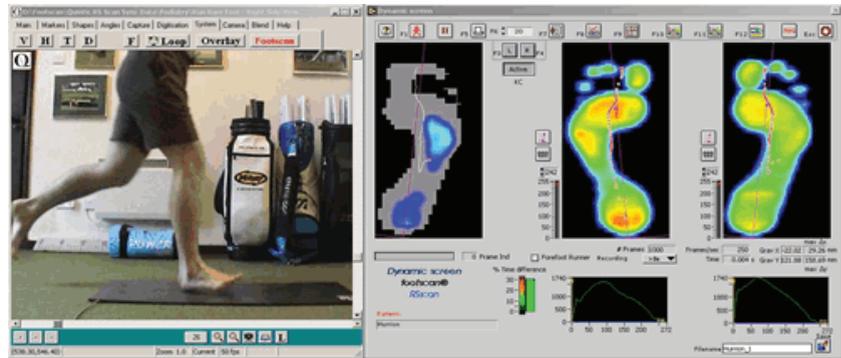


figure 7.27 – force plate output

Wind tunnels

Wind tunnels are increasingly being used to assess the aerodynamics (improved flow of fluid - air or water - reducing drag or fluid friction) of bikes (figure 7.28), cycle helmets, and cyclist overall profile. This is done by blasting air past the stationary object in a tunnel, and using smoke to illustrate the layers of flow of the air. The task is to avoid vortex generation in the air flow, since smooth (laminar) flow generates less drag.

Factors investigated include:

- Wheel spokes and profiles.
- Width of handlebars.
- Riding posture, and hand position on the bars.
- Type of cloth and design of clothing.
- Forward cross-sectional area of frame and brackets.

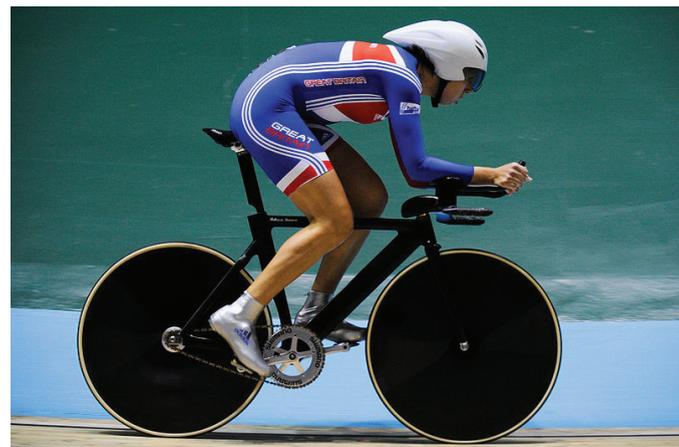
Advantages of technology

- Technologies such as limb kinematics, force plates and wind tunnels provide precise, accurate data analysis that measure and improve biomechanical performance, especially at the elite world class level of sport.

Disadvantages of technology

- Many technologies, such as limb kinematics, force plates and wind tunnels are specialised laboratory-based pieces of equipment and have limitations in their sporting applications.
- Such types of equipment is expensive to buy.
- Their complex analysis often requires assistance from research professionals.
- These technologies are mainly located in National Centres for Sport and universities, such as Loughborough University, and so athletes may have to travel to such venues if they wish to use such technologies.

figure 7.28 – bike design in the wind tunnel



Practice questions

- 1) For which of the following is the athlete's centre of mass most likely to lie outside of his or her body?
 - a. diver performing a tucked dive.
 - b. trampolinist in a fully piked position.
 - c. gymnast performing a cartwheel.
 - d. gymnast performing a layout somersault.

- 2) In a first class lever, if the resistance arm is 300 mm and the force arm is 30 mm, what force is necessary to balance a weight of 10 N?
 - a. 10 N.
 - b. 1 N.
 - c. 100 N.
 - d. none of the above.

- 3) Which of these is not one of Newton's three laws of motion?
 - a. the acceleration of an object is directly proportional to the force causing it and is inversely proportional to the mass of the object.
 - b. body moves in a circle about a point called the axis of rotation.
 - c. body will continue in a state of rest or of uniform velocity unless acted upon by an external force.
 - d. for every action there is an equal and opposite reaction.

- 4) What is the difference between distance and displacement?
 - a. displacement is the distance between the start and end point only, distance is the total distance travelled along the path of motion.
 - b. displacement is the total distance travelled along the path of motion, distance is the distance between the start and end point only.
 - c. displacement is the distance between the start and end point only, distance is the distance between the start and end point.
 - d. displacement is the total distance travelled along the path of motion, distance is the total distance travelled along the path of motion.

- 5) A rugby prop sprints away from a scrum with an acceleration of 0.2ms^{-2} for 10s. How far did he travel?
 - a. 15 metres.
 - b. 10 metres.
 - c. 18 metres.
 - d. 20 metres.

- 6) a) Explain with diagrams what is meant by the centre of mass of a body. 2 marks
 b) Explain with the aid of pin-man diagrams how the centre of mass of a long jumper changes from the take-off position to the flight phase shown in figure 7.29. 5 marks

- 7) Figure 7.30 shows a swimmer holding a balance just before the start of a race. Explain how the position of the centre of mass can affect the swimmer's balance. Describe how the swimmer in figure 7.30 can use his knowledge of balance to achieve his most effective block start. 5 marks

- 8) Sketch the lever system which would represent the action of the biceps muscle in flexing the arm. Show on your diagram the resistance arm of the lever. 3 marks

figure 7.29 – a long jumper in flight



figure 7.30 – swimmer starting a race



Practice questions

9) In figure 7.31 of a jumper taking off, name, sketch and label the lever system operating at knee **B** during this action. 3 marks

10) In softball, what order (class) of lever is shown in the hitting action in figure 7.32? State **one** disadvantage and **one** advantage of reducing the bat length for a beginner. 3 marks

11) a) Name, sketch and label the lever system which is operating at the ankle of leg **C** when doing the sprint set action illustrated in figure 7.33. 3 marks
 b) This class of lever always has a mechanical advantage. Explain why is this so? 2 marks

figure 7.31 – long jumper taking off

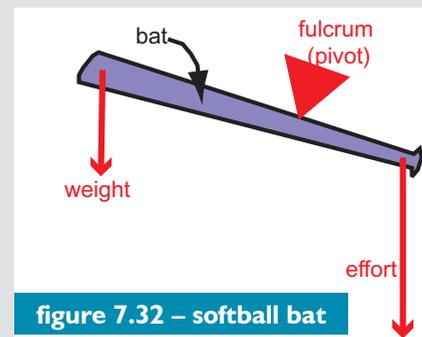
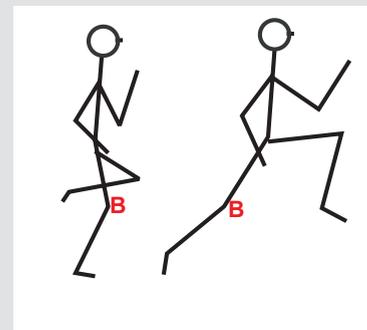
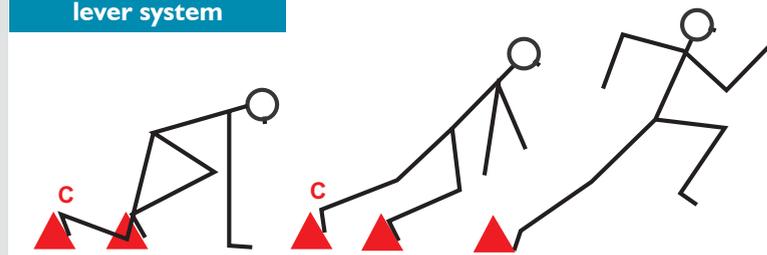


figure 7.32 – softball bat

figure 7.33 – ankle lever system



12) Table 7.1 shows the speed of a 19 year-old male sprinter during a 200m race.

a) Plot a graph of speed against time during this race. When does he reach maximum speed and what happens to his speed between 8 and 22 seconds? 7 marks
 b) Acceleration is the change of speed per second. Use the graph to establish his speed at 0.5 seconds and 1.5 seconds and calculate the average acceleration between 0.5 and 1.5 seconds. 3 marks
 c) Successful games players are often able to change their velocity rapidly in the game situation. Explain the biomechanics behind this ability using examples from a game of your choice. 6 marks

speed (ms ⁻¹)	time (seconds)
0.0	0
6.0	1
7.5	2
8.2	3
8.4	4
8.5	5
8.5	7
8.4	8
8.3	10
8.2	13
8.1	18
8.0	22

table 7.1

13) a) A sprinter uses her calf muscles to push on the blocks at the start of a run. Explain, using Newton's laws, how this enables her to accelerate forwards out of the blocks. 3 marks
 b) If the resultant forward force was 300 newtons and the runner's mass was 60 kg, what would be her acceleration? 2 marks
 c) What would be the speed of the runner after 1.5 seconds, assuming that the acceleration is the same over that period of time? 2 marks
 d) A squash player drives forward into a forehand stroke. Show how Newton's third law of motion explains his ability to do this. 3 marks

Practice questions

- 14) a) Use the diagram in figure 7.34 of a basketballer just about to take off into a jump shot, and your knowledge of Newton's Laws of motion to explain why the basketball jumper takes off.
- b) If the vertical upward ground reaction force on the jumper is 2000N, and the weight of the jumper is 800N, estimate the net upward force acting on him.
- c) The mass of the jumper is 80 kg, calculate his upward acceleration during this part of the jump.

3 marks

1 mark

2 marks

- 15) a) The graph in figure 7.35 shows the start of a 100m sprint swim race. Using Newton's laws of motion, explain how the swimmer achieves the initial forward motion.

3 marks

- b) Describe what has happened to the swimmer at point A and explain the motion that occurs. 3 marks

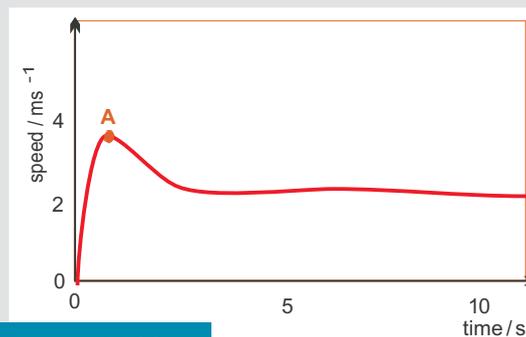
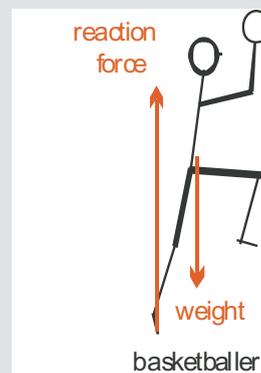


figure 7.35 – start of 100m swim race

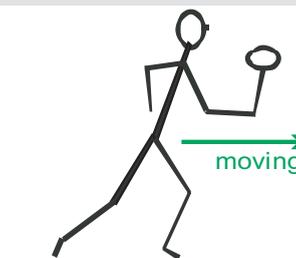
figure 7.34 – basketballer about to take off



- 16) Tennis players have to change direction quickly during a match to recover to the centre of the court. Figure 7.36 shows a tennis player just after hitting a forehand and then starting to recover to the centre of the court in the direction shown.

figure 7.36 – a tennis player moves between strokes

Draw a pin diagram of the tennis player as he pushes off the court surface to recover to the centre of the court, showing all forces acting on the tennis player at this point. All forces must be clearly identified.



Explain the factors that affect the horizontal force at this point. Apply Newton's second law of motion to explain the effect of this force on the player. 10 marks

- 17) How do the following technologies aid analysis and feedback for improving sporting performance?

- a) Video and computer software analysis.
b) Force plate technology.
c) Wind tunnels.

9 marks

Answers link: http://www.jroscoe.co.uk/downloads/as_a1_revise_pe_ocr/OCRAS_A1_ch7_answers.pdf