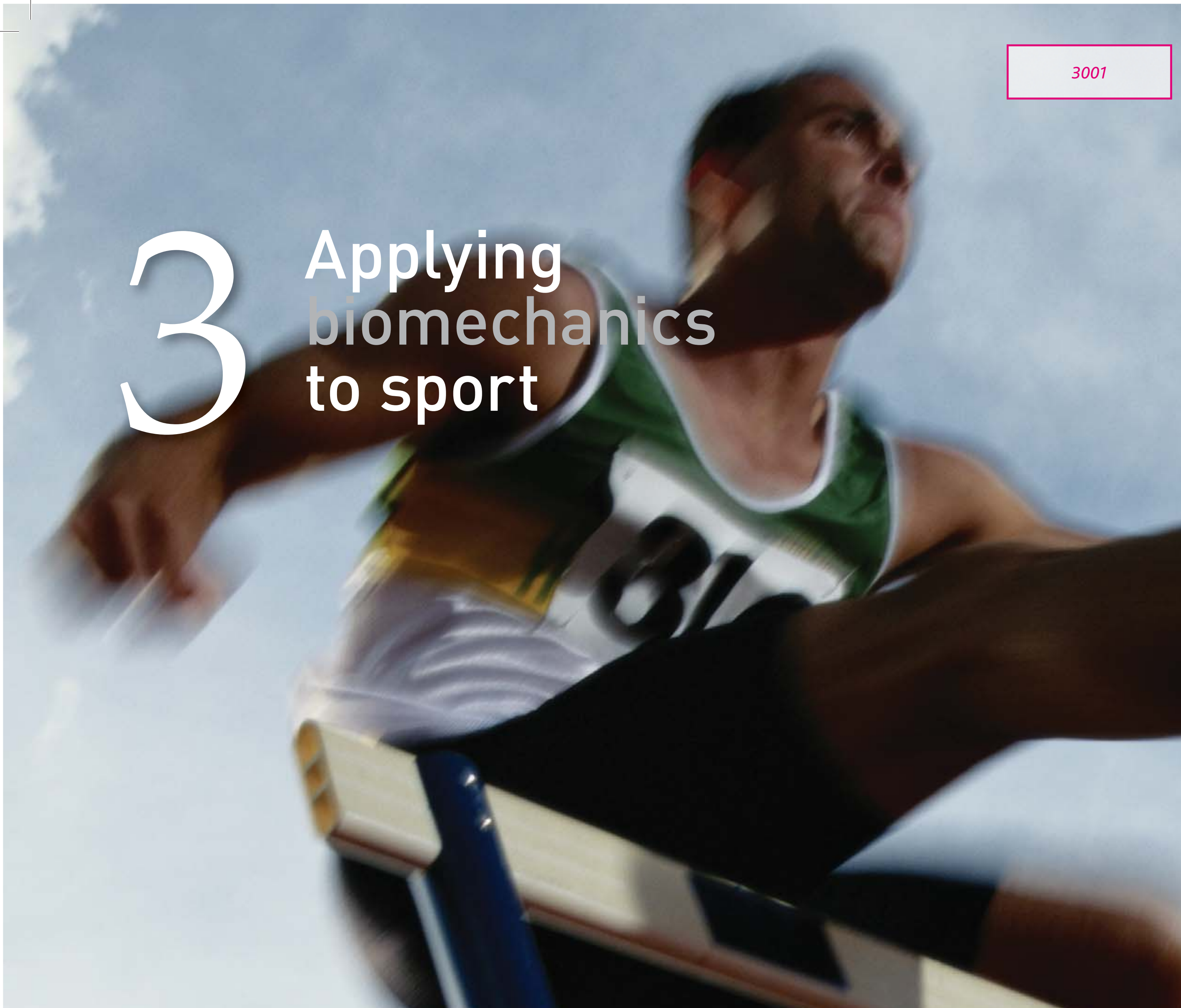

3 Applying biomechanics to sport

BEFORE YOU START

Have you ever wondered why some players are able to regularly make a skill look effortless, producing perfect results every time? What about equipment? Why has the swimsuit evolved to look like something from space? Why do athletes spend so much money on the latest gear?

An understanding of biomechanics will enable you to answer these questions (and others) and improve your performance.

CHAPTER OVERVIEW

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What is biomechanics?

Biomechanics is the study of the body as a machine. This study of the body looks at the internal and external forces that act on the body, and the movements that these forces produce.

By grasping biomechanical concepts, we can program this machine, our body, to move with precision. Furthermore, this vital study enables us to correct technical errors, reduce injury and understand the importance of equipment design.

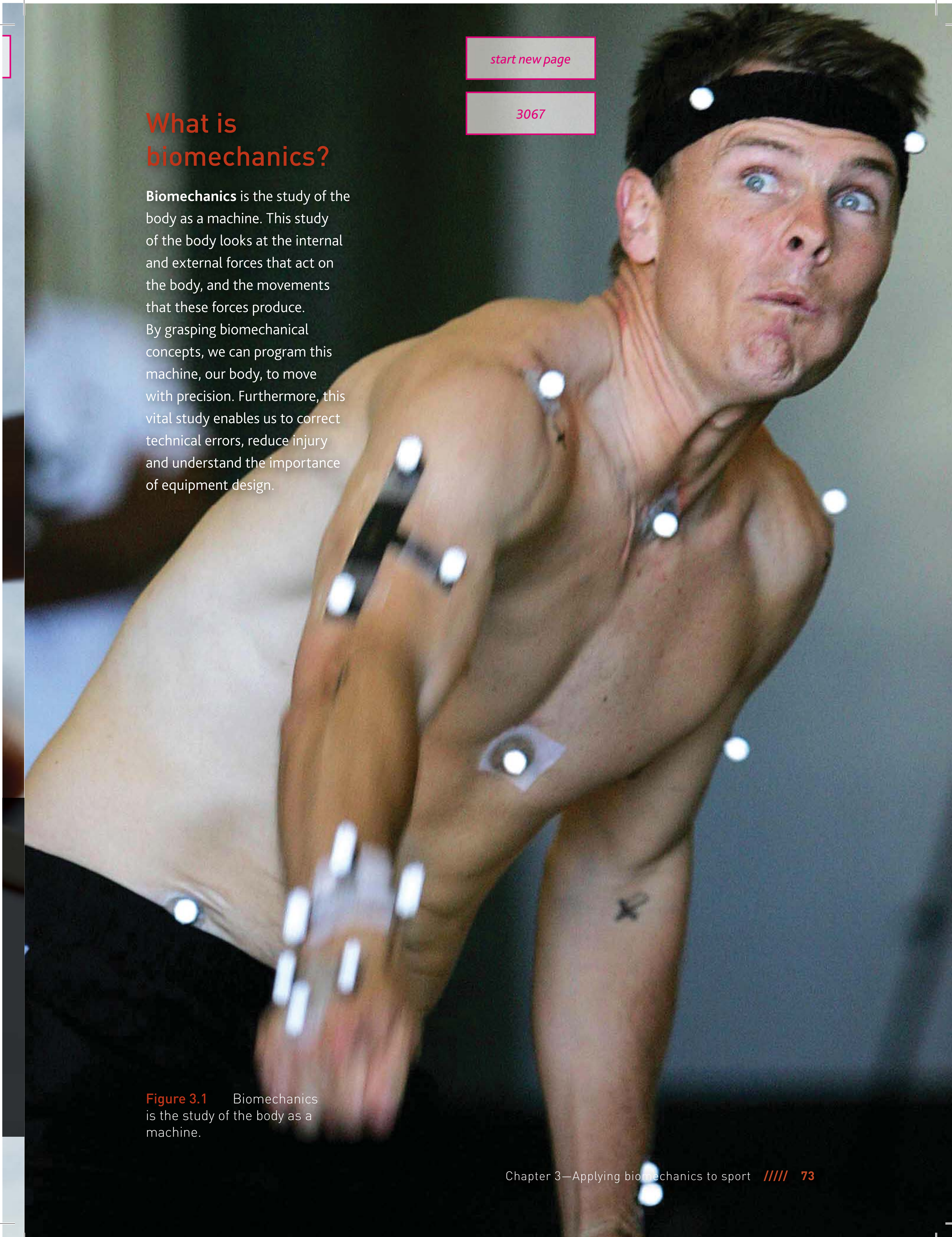

Figure 3.1 Biomechanics is the study of the body as a machine.

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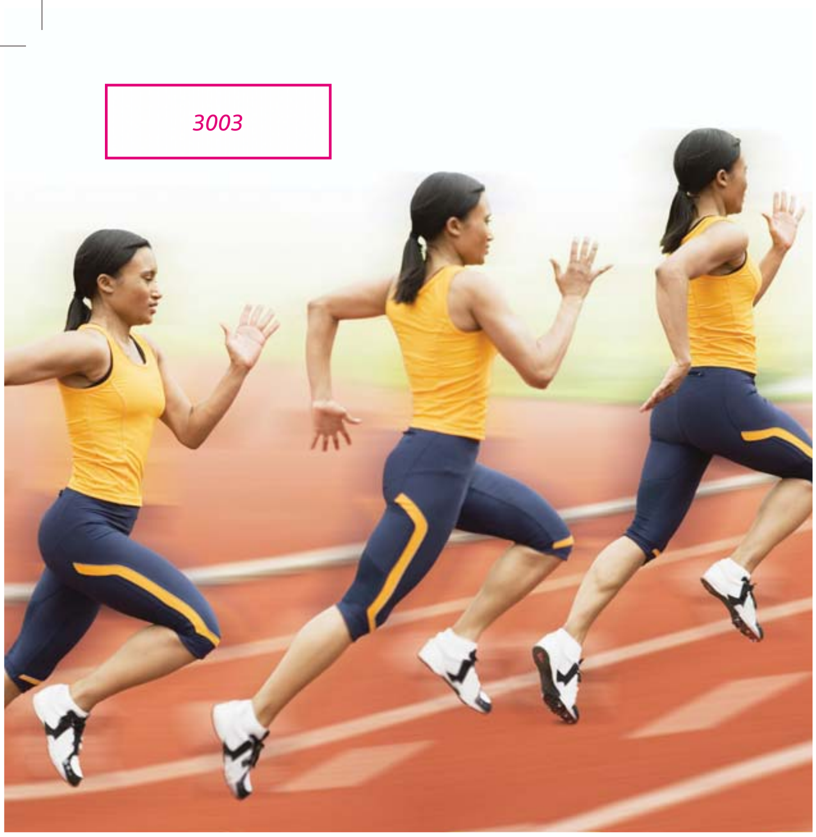

Figure 3.2 Linear, or rectilinear, motion is movement along a straight line.

Motion

Motion is an inherent part of all sports. The athlete and the ball or other implement are required to constantly change their position. The nature of these changes in position depends on many factors.

Linear and curvilinear motion

Linear motion occurs when an object—or, in the case of sport, a human body, a human limb or an object propelled by a human—moves in a straight line. One example of linear motion is someone running in a straight line. Linear motion is also called rectilinear motion.

When the movement follows a curved path, it is called **curvilinear motion**. One example of curvilinear motion is the path a tennis ball takes in a lob shot.

Velocity and speed

In everyday discussion, most people use the words ‘speed’ and ‘velocity’ interchangeably, but they do not mean exactly the same thing when discussing the laws of physics.

- **Velocity** measures the rate of change of distance with time in a given direction (**displacement**).
- **Speed** measures the rate of change of distance with time.

3004

Figure 3.3 Curvilinear motion is movement along a curved line.

Speed describes only how quickly the body is moving; velocity describes both how quickly and in which direction.

Speed and velocity are equal only if movement occurs in a straight line. The speed and the velocity of a cricket batter running one run will be the same; however, if the batter runs two runs, the speed and velocity will differ quite markedly as the batter has returned to his starting point and the displacement would be zero.

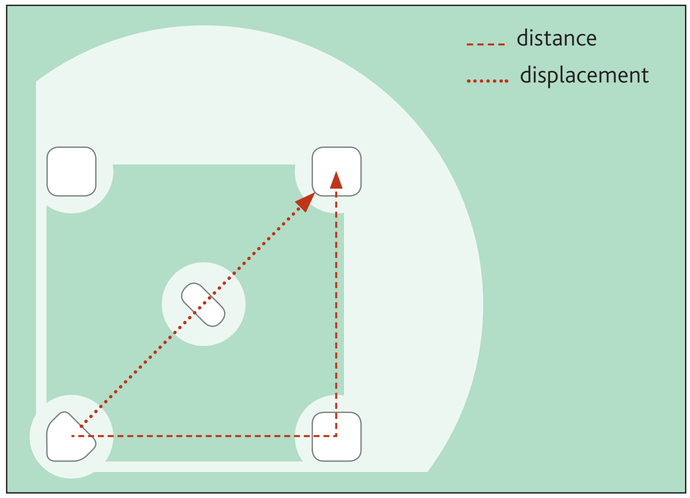

Figure 3.4 At second base, a baseballer's distance and displacement will be different.

Acceleration, deceleration and momentum

In most sports, athletes need to be able to increase and decrease velocity rapidly. For example, a rugby league player carrying the ball needs to build up as much velocity as possible to make it difficult to be tackled. A softballer stealing a base needs to be able to build up velocity before the fielders can react; the softballer needs to sprint to the base, but then slow down to avoid over-running the base.

These are examples of linear acceleration and linear deceleration, which are required in most team sports and short-distance sprints.

We all understand that a heavy truck travelling quickly will be harder to stop than a small car travelling at the same speed; this is because of the **momentum**. We usually think of momentum as the impetus or force behind a moving body or object. Momentum is the product of the **mass** and the velocity of an object. Momentum is looked at in more detail later in this chapter.

Table 3.1—Measuring motion

Measurement	Definition
Distance	The length of the path along which a body travels. (Measured in metres or kilometres.)
Displacement	The length between the starting and end points 'as the crow flies'. (Measured in metres or kilometres, often with compass direction.)
Speed	The distance travelled divided by the time taken. $speed = \frac{distance}{time\ taken}$
Velocity	The displacement divided by the time taken. $velocity = \frac{displacement}{time\ taken}$
Acceleration	The rate at which an object's speed changes over time. (Measured in metres per second squared.) $acceleration = \frac{change\ in\ velocity}{time\ elapsed}$ $acceleration = \frac{final\ velocity - initial\ velocity}{time\ elapsed}$
Momentum	The mass of the body multiplied by its velocity. (Measured in kilogram metres per second.) $momentum = mass \times velocity$

ACQUIRE

1 In your own words, explain the difference between speed and velocity.
2 Give two examples each for linear (rectilinear) and curvilinear motion.

PRACTICAL

Acceleration and velocity

Measure the velocity and acceleration of a person sprinting 100 metres.

Equipment

- eleven markers, such as orange traffic cones
- ten stopwatches
- starting whistle

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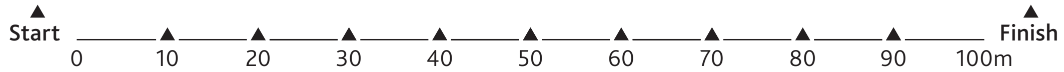
Procedure



1 Measure a 100-metre straight line, marking the start line, finish line and 10-metre intervals.
2 Place a person with a stopwatch at each 10-metre interval and at the finish line.
3 On 'go', everyone starts their stopwatches. They stop the stopwatches at the moment the sprinter runs past their cone.
4 Copy the table and complete it to record the results.

Tasks

1 Graph the results for velocity and acceleration.
2 Identify the point at which the sprinter had the:
   a greatest velocity
   b least velocity
   c greatest acceleration
   d greatest deceleration.
   Give reasons for each of the above.
3 Discuss the variations in the sprinter's velocity and acceleration over the 100 metres.
4 Explain the effects these variations could have on the sprinter's overall performance in a 100-metre sprint race.

Distance (m)	10	20	30	40	50	60	70	80	90	100 finish line
Time										
Velocity										
Acceleration										

Source: P Nicolson and R Whitely, *Australian Physical Education Master Series*, Eduguide, Victoria

Newton's laws of motion

More than 300 years ago, scientist Sir Isaac Newton developed three laws of motion.

1 **Newton's first law of motion—inertia**

Newton's first law introduced the concept of inertia: the resistance of a body to a change in its state of motion. It states that a still object will continue to be still, and a moving object will continue to move in the same direction at its current velocity, unless an external force acts on the object.

This seems to be a basic, commonsense theory, but it becomes more important when we examine the forces that act to change the state of motion of a body.

2 **Newton's second law of motion—acceleration**

Newton's second law of motion is the law of acceleration. It explains the relationships linking force, mass and acceleration, and is linked to momentum.

This law states that the sum of the force that moves an object is equal to the object's mass multiplied by the acceleration. This law can be expressed as the following equation:

$$\textit{Force} = \textit{mass} \times \textit{acceleration}$$
$$(F = ma)$$

As the mass of an object increases, more force is required to produce the same acceleration. For example, to throw a 4-kilogram shot-put as far as a 3-kilogram shot-put, the force applied must be greater.

To look at it in another way, more force is required to increase the acceleration of an object if the object's mass remains the same. For example, a golf ball's mass does not change, but a putted golf ball will not accelerate as quickly or travel as far as one hit with a driving iron because of the effort (or force) the golfer applies.

3 **Newton's third law of motion—action and reaction**

You may have heard the saying 'for every action, there is an equal and opposite reaction'. This is one way of explaining Newton's third law, which shows that forces act in pairs.

Newton's third law of motion states that for every force that is exerted by one body on another, there is an equal and opposite force exerted by the second body on the first.

Although forces always act in pairs, the result on each body or object is not always the same. For example, when you land after performing a long jump, you apply a force to the ground and it applies one back to you. The effect on you is much greater than your effect on the ground, however, because the earth is much bigger and heavier.

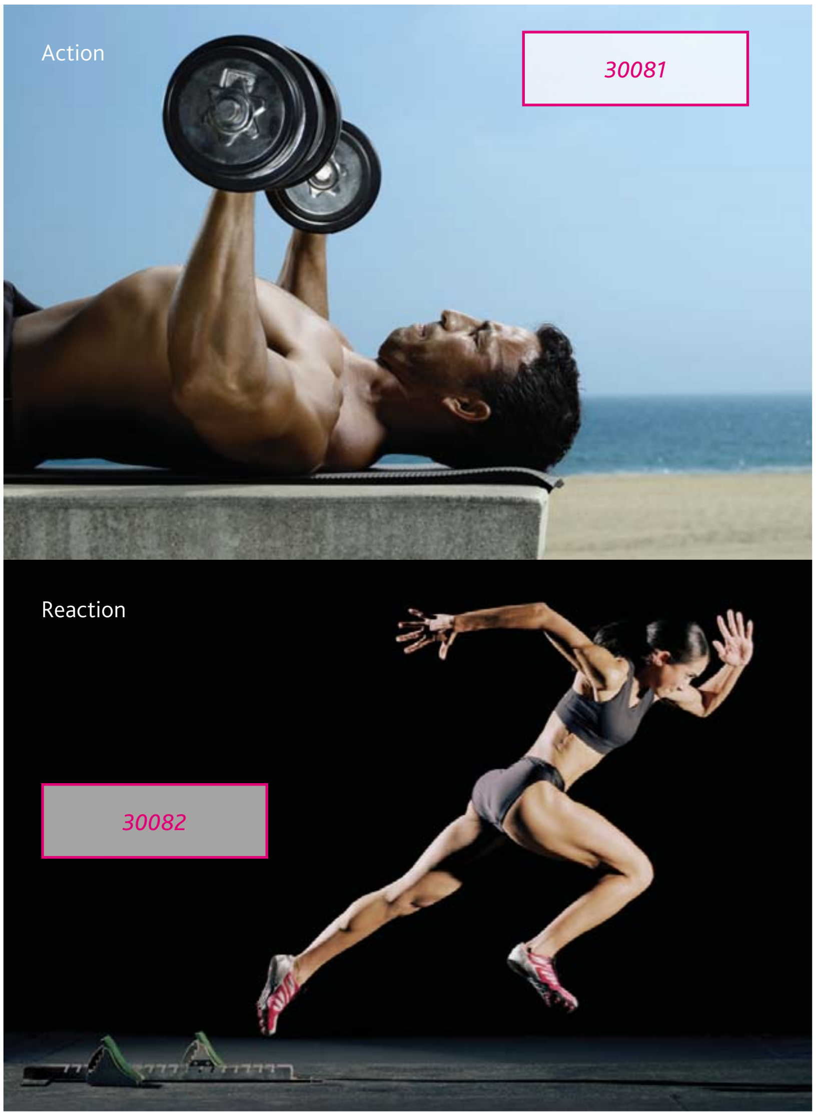


Figure 3.5 Newton's third law of motion shows that for every action, there is an equal and opposite reaction.

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Balance and stability

Every athlete must be able to maintain balance and stability.

Athletes' loss of stability can have an adverse effect on their ability to perform the skills of the given sport with control. A loss of control can affect factors such as force production and accuracy.

The two types of balance are:

- **static balance**, which is balance when the body is at rest (not moving)
- **dynamic balance**, which is balance when the body is moving.

Do you find balance easier when you are moving or stationary? How does this affect your performance in your current physical activity?

Base of support

The **base of support** is the area by which the body is supported. For example, when you stand with your legs apart, the area under and between your feet is your base of support. If you hang from a parallel bar, your base of support is the area between the outer limits of your hands.

The larger the area of the base of support is, the greater the stability. For example, when doing the stork stand balance test, people are asked to balance on just the ball of one foot. With such a small base of support, it is difficult to maintain balance.

Have you ever done the stork stand balance test? Did you find it challenging?

It is important to note, however, that a body may be stable in one direction but not in another. For this reason, it is essential to consider the orientation of the base of support relative to the force being applied. For example, a wrestler wanting to prevent being pushed back will brace himself by placing his feet in a wide stance—one foot behind the other. Just having a wide stance with his feet side by side would not prevent the wrestler from losing balance backwards.

Figure 3.6 The base of support is the area by which the body is supported.

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Figure 3.7 With a small base of support, such as when doing the stork stand balance test, it is difficult to maintain balance.

Centre of gravity

All people and objects have a **centre of gravity**, which can shift depending on the position or movement of the person or object. A centre of gravity is an imaginary point (within or outside the body or object) around which the body or object is balanced.

You can often easily find the centre of gravity on an inanimate object. For example, take a ruler and place it across one finger until it stays horizontal and does not fall to the ground. The point at which it is balancing on your finger is its centre of gravity.

It is not always so easy, however, to find the exact centre of gravity on a human, particularly in sport. In some sports, the centre of gravity shifts very rapidly: for example, during high jump, diving or gymnastics. Remember also that the centre of gravity need not lie within the physical limits of an object or person.

Individual body parts, such as limbs, also have their own centres of gravity.

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Figure 3.8 The centre of gravity is an imaginary point around which a body or object is balanced.

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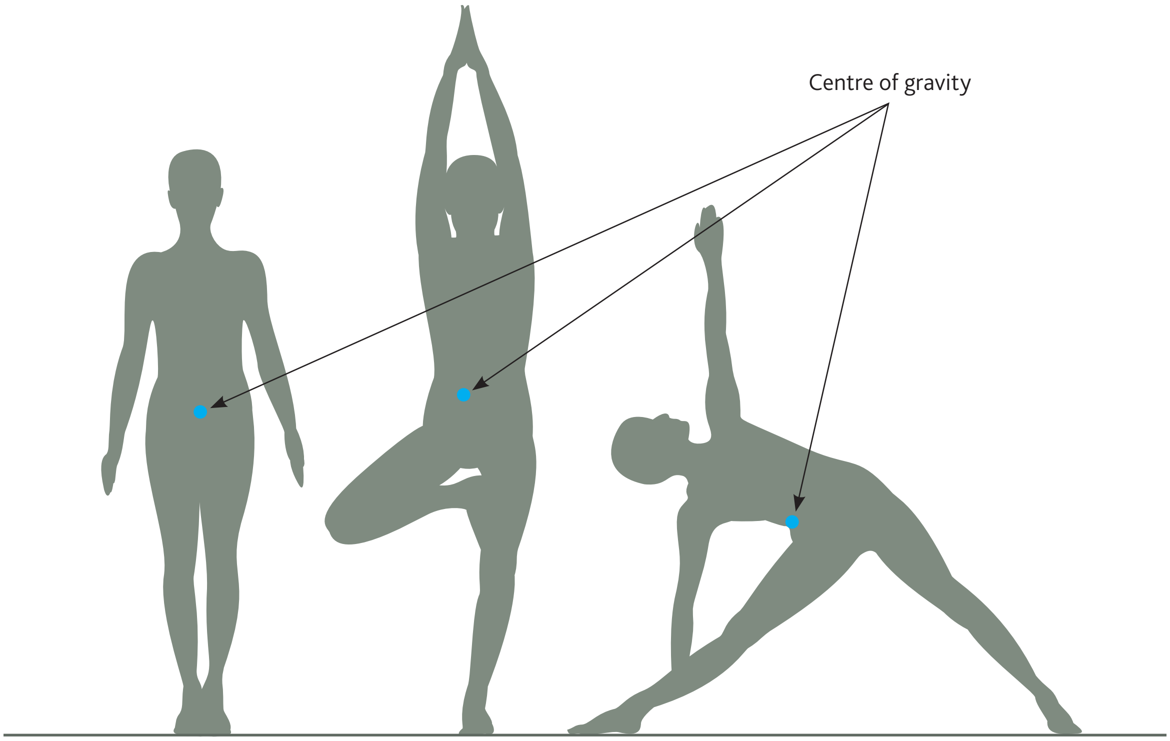

Figure 3.9 A body's centre of gravity can shift, depending on the body's movement and position.

Think of a time when you were performing a dynamic movement. When your centre of gravity fell outside of your body, what was your natural movement to try to correct it?

The height of the centre of gravity relative to the base of support can affect stability. An athlete with a low centre of gravity will tend to be more stable than one with a high centre of gravity. For example, during contact a rugby player tries to lower his or her centre of gravity to maintain force, and raise the centre of gravity of the opposing player to put him or her off balance.

Do you think your height has an effect on your stability?

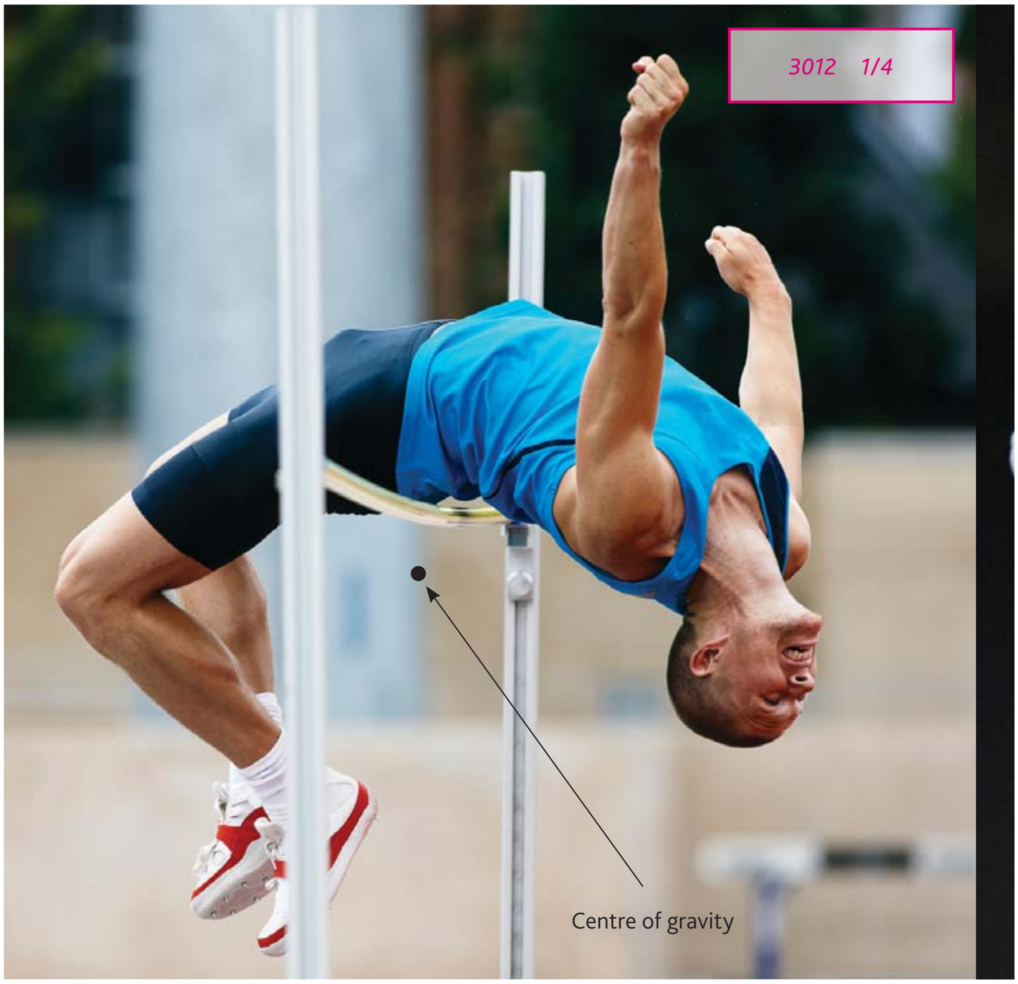

Figure 3.10 For a period time in flight, a high jumper's centre of gravity can be outside the body.

Figure 3.11 A rugby player will lower his centre of gravity to increase his stability.

Line of gravity

The **line of gravity** can be represented by drawing a straight line from the centre of gravity to the ground.

An object is most stable when the line of gravity falls through the centre of the base of support. This is because it increases the distance that the centre of gravity can be moved before balance is compromised.

Moving the line of gravity towards the edge of the base of support reduces a body's stability. The further off-centre from the base of support the centre of gravity is, the less stable the body.

Figure 3.12 The line of gravity can be represented by drawing a straight line from the centre of gravity to the ground.

Mass

Another factor to consider is the mass of an object. The greater the mass an object has, the greater its stability. It takes more force to move a heavy object. Boxing competitions, in which stability is an important component, enforce weight divisions to make competition fairer.

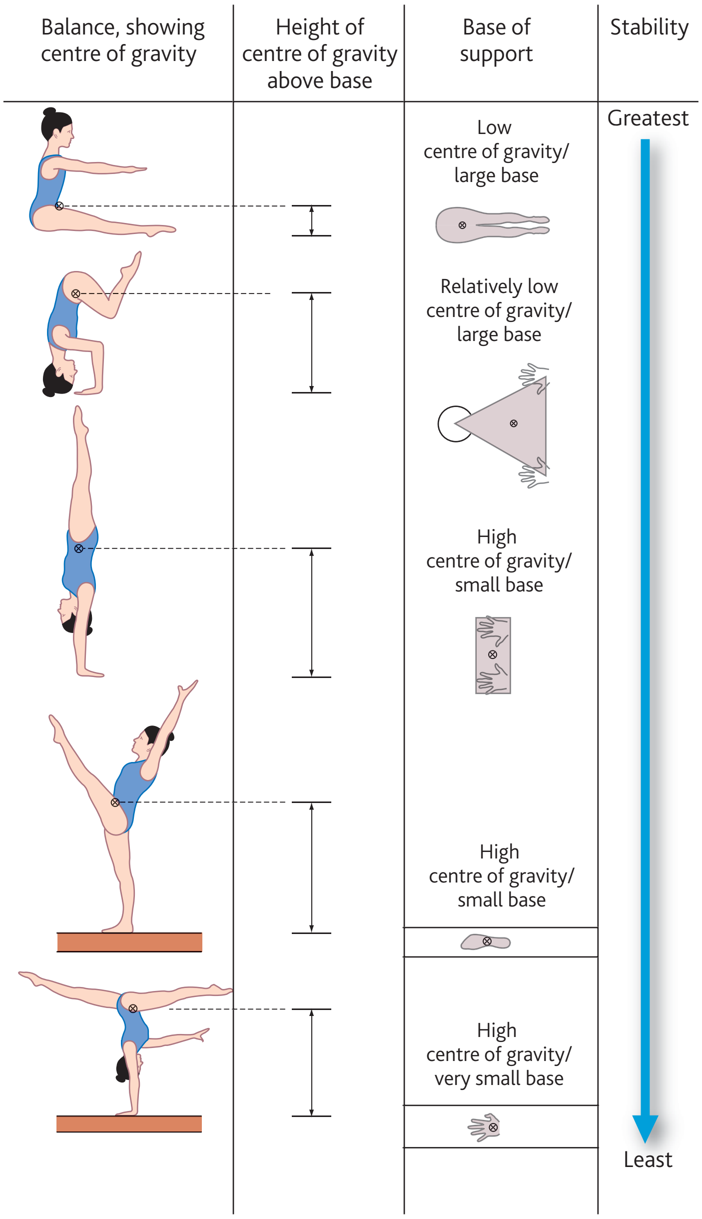

Figure 3.13 Stability is determined by the centre of gravity and the base of support.

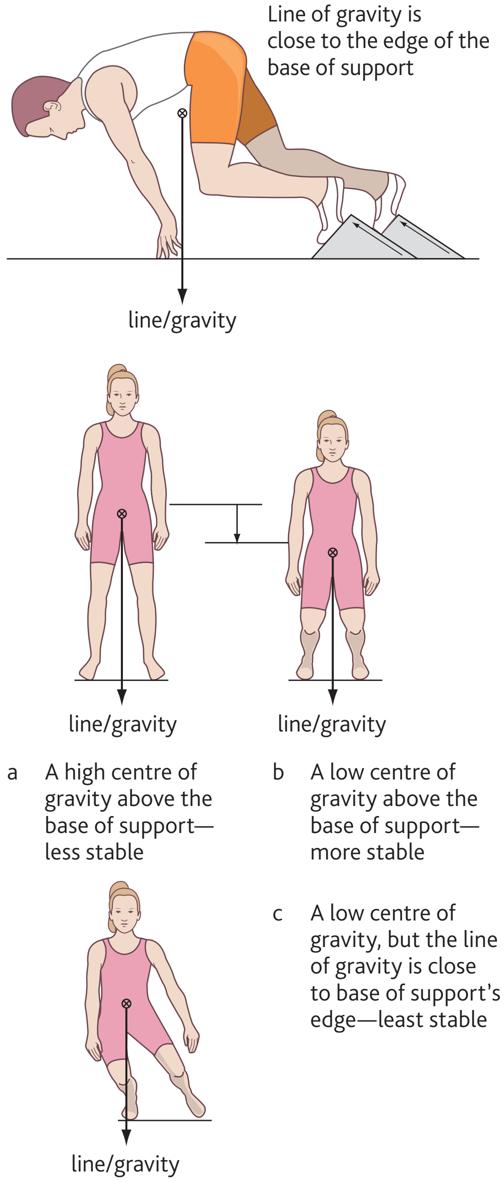

Figure 3.14 Stability is affected by the position of the line of gravity and the height of the centre of gravity in relation to the base of support.

Source: G Schembri, *Introductory gymnastics*, Australian Gymnastic Federation, Melbourne 1983

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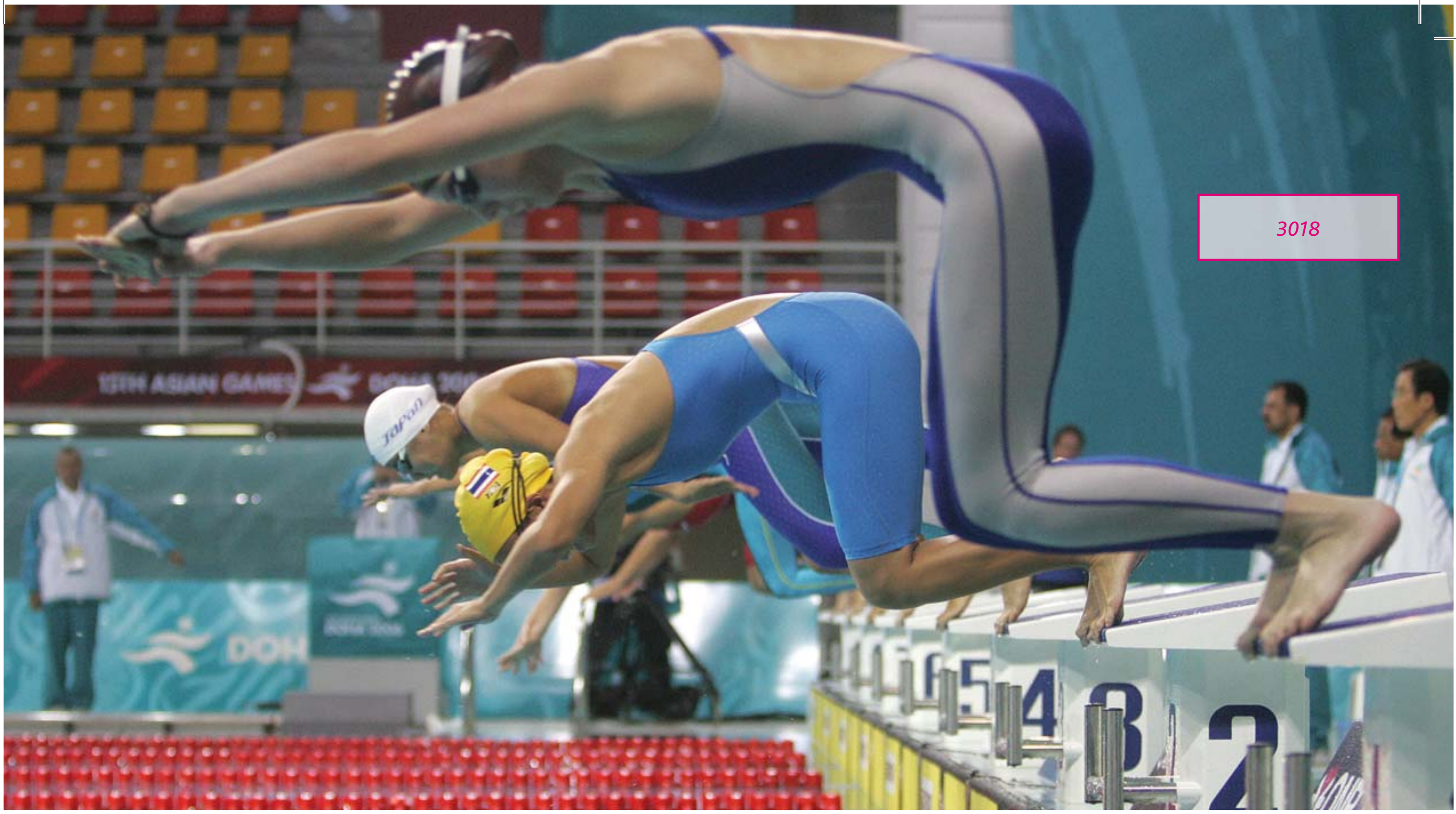

Figure 3.15 Swimming blocks are designed to improve a swimmer's start.

ACQUIRE

1. Explain the difference between static and dynamic balance.
2. Describe how athletes' base of support and line of gravity affect their balance and stability.

APPLY AND EVALUATE

1. Look at Figure 3.15. Using your understanding of balance and stability, justify the sloped design of the swimmer's starting blocks.
2. What roles do static and dynamic balance play in the sport you are currently studying? Is good balance essential for optimum performance? Describe some game-play scenarios where it is essential.

Figure 3.16 Balance and stability are vital in martial arts.

PRACTICAL

Balance and stability

Investigate the factors that affect balance and stability by participating in the following activities.

Equipment

- starting blocks
- stopwatches
- tape measure

Procedure

1 Have one partner time the other for a 10-metre sprint, starting from the following positions.
   a standing in the 'get set' position, with feet close together and legs straight (upright stance)
   b standing in the 'get set' position, with feet further apart and knees bent (more of a crouched stance)
   c squatting in the 'get set' position

   Record the times in a table like the one below.

Starting position	Time

Tasks

1 Explain, referring to balance and stability, which starting position was fastest and why.

2 Describe the effect of the:
   - height of the centre of gravity on balance and stability
   - area of the base of support on balance and stability
   - alignment of the line of gravity on balance and stability.

3 Discuss how the performance of a sprinter or wrestler is affected by the base of support and changes to the line of gravity.

   Least stable — Most stable

   3019

   Copy the continuum and on it mark the relative stability of each of the six positions.

4 In pairs, have one partner try to push the other off balance when in the following positions. Ensure that the push is always from the side.
   - standing on tiptoes with arms above the head
   - standing normally
   - standing with knees bent
   - standing with feet wide apart, side by side
   - standing with feet wide apart, one in front of the other
   - kneeling, with hands also on the floor (on all fours)

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Force

Force is anything that causes or has the potential to cause the movement, diversion or slowing of the object on which it acts. In simple terms, a force can be a push, a pull, a blow, a collision, gravity or **friction** (when two surfaces rub together).

Whether an object or body is at rest or in motion, forces are acting on it. Whether you are sitting at a desk, running around a track or jumping out of an aeroplane, forces are acting on your body.

Forces can be described as internal (acting from inside) or external (acting from outside) to the system. For example, if we consider the whole human body, the muscles that contract to exert a force on bones, cartilage or ligaments around a joint are considered inside the system and are, therefore, internal forces. Any forces exerted outside the body (such as gravity, friction, contact with the ground or another body, air resistance and **fluid resistance**) are considered external forces.

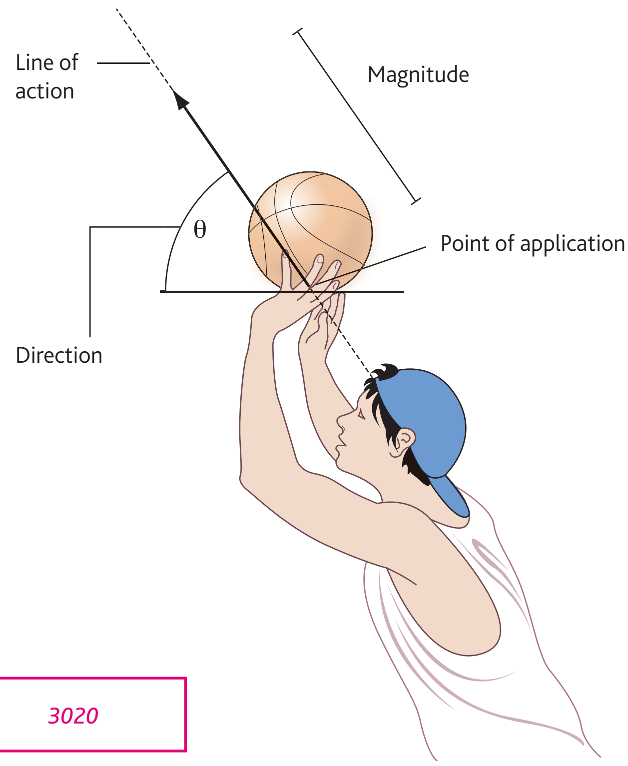

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Figure 3.17 Forces have four properties.

All forces have four common properties:

- magnitude (the amount, or how much is applied)
- direction (the angle at which the force is applied)
- a point of application (the specific point at which the force is applied)
- a line of action (represented by a straight line through the point of application in the direction that the force is acting).

Measuring force

Force is measured in a unit called a **newton**, after Sir Isaac Newton who recognised three laws of motion (which are explained on page 77).

To speed up, change the direction of or slow down an object, force needs to be applied. The amount of force (F) required depends on how heavy the object is (its mass—m) and the desired rate of acceleration (a). This relationship can be expressed as:

Force = *mass* × *acceleration*

$(F = ma)$

A newton (N), which is the unit commonly used to measure force, is equal to the amount of force from 1 kilogram of mass and 1 metre per second squared of acceleration.

$1N = (1\,kg) \times (1\,m/s^2)$

Contact forces

Depending on whether they involve contact between objects or bodies, forces are separated into two groups: contact forces and non-contact forces.

- Contact forces are forces that involve the actions (push or pull) of one object in direct contact with another. Examples include a foot hitting the ground, a bat striking a ball or players colliding into each other.
- Non-contact forces involve no contact between objects. The most common non-contact force is gravity. Weight is also a non-contact force.

Understanding weight and mass

The weight and mass of an object or body are not the same thing.

Mass is a measure of how much matter there is in an object or body. Weight depends on the force of the gravity acting on the body or object. If you landed on the Moon, which has a much lower gravity than Earth's, your body would have the same mass as it has now, but a much lighter weight.

In science, mass is measured in kilograms, and weight is measured in newtons.

Humans can apply contact forces to other humans, to the ground and to implements (such as a bat or a racquet). For movement to occur, the force applied needs to be greater than the external forces acting on the human body. For example, if a footballer does not step hard into the ground, he or she will not change direction to swerve around an opponent. In the same way, a long jumper will jump further by accelerating to the board and applying a greater force to it than by running up slowly and hitting the board with less force.

Most forces are the result of contact between objects and bodies. Contact forces can be any one of six types:

1. In most sports, athletes are in contact with the ground, and the force or resistance that the ground applies to the athlete is called the **ground reaction force**.
2. The force that two bones apply to each other across a joint is called the **joint reaction force**.

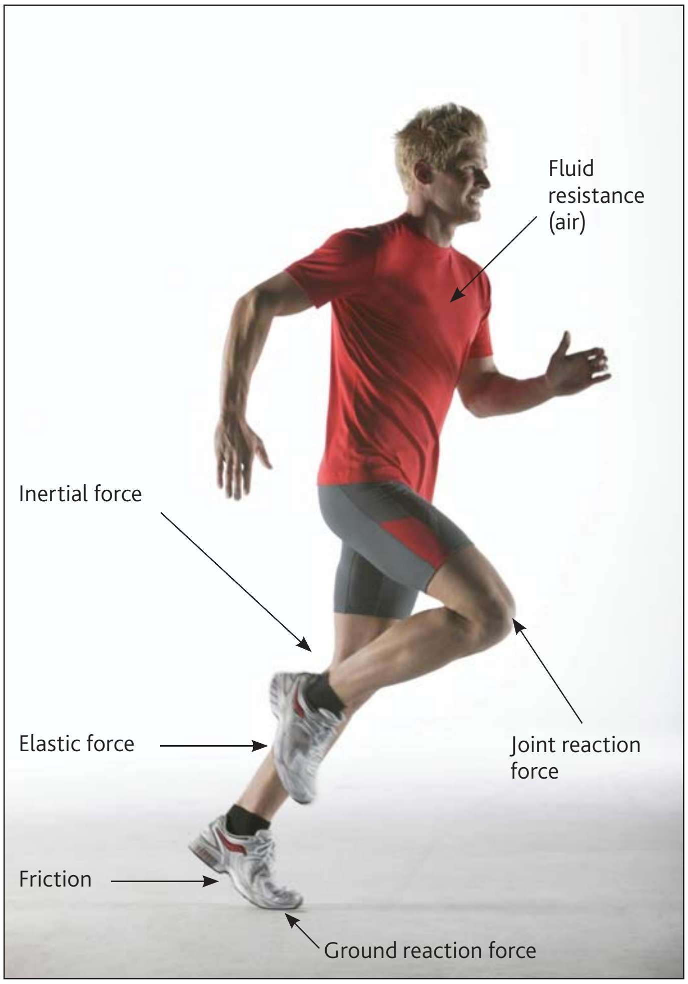

Figure 3.18 All six types of contact forces act on a runner.

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3 **Friction** is the force created when one surface is moved across another.

4 In many sports, motion is affected by the fluid (such as air and water) in which it is performed. This is called **fluid resistance**.

5 **Inertial force** can also affect movement. For example, the ankle swings through when running because of the force of inertia placed on it by the leg.

6 **Elastic force** is that where a material changes its length when a force is applied to it. Examples of elastic forces are those provided by diving boards, muscles, sprung floors, trampolines and some running shoes.

Force production

Force production is the combined result of several factors, including the summation of force, momentum and **impulse**.

Most sports require an athlete to be able to generate and control forces. For sports where success is determined by achieving a maximum distance, it is necessary for the athletes to produce as much force as possible, such as in a volleyball spike or baseball pitch. While it is not always necessary for the force produced to be the maximum possible, certain principles can be used to produce the appropriate amount of force for the skill being performed.

In your sport, can you differentiate between the skills that require maximum force and those that require control and accuracy?

Summation of force

We already know from Newton's second law of motion that the greater the force applied to an object is, the greater the acceleration. But how do we create the force to produce this rapid acceleration? To obtain maximum force, it is necessary to combine or add up the forces applied by different body parts. This concept is known as the **summation of force**.

The summation of force is influenced by the:

- number of body parts used in the movement
- order and timing of their involvement
- force and velocity generated
- way in which the body and body parts are stabilised and balanced.

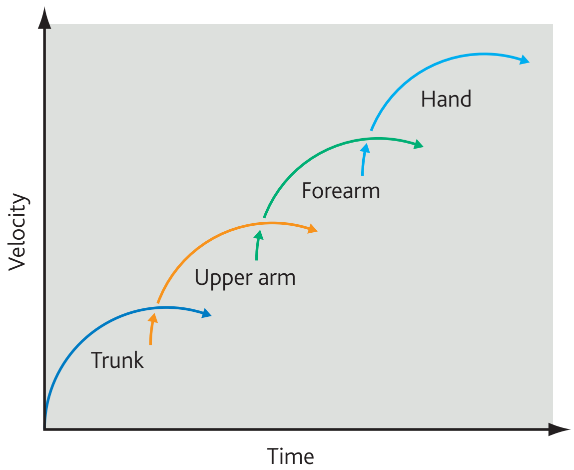

Figure 3.19 The sequential summation of force from body parts is essential to maximise force production.

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To explain how the principle of summation of force works, let's look at the example of a long jumper. The summation of force principle explains that the force produced during the movement of one body segment (for example, the lower leg) will be added to the force produced by the next body segment (the thigh), and the next (trunk, chest and arms), and so on. Long jumpers are able to propel themselves further through the air by using the combined force of many parts of their bodies: legs, trunk, shoulders and arms.

When a player uses just a few body parts, the force produced will be less than when a player uses many body parts. This is why the best techniques for throwing, kicking and striking use more than just the obvious body part that finishes the action.

Also important for force production is the sequence in which parts of the body are used. For best results, movement begins with the larger, slower body parts and finishes with the smaller, faster body parts.

Case study—summating forces in volleyball

To generate the greatest amount of power when spiking, a volleyball player needs to summate the forces.

A volleyball spike can be broken down into the approach, the take-off, the flight and, finally, the hit.

- The approach has two purposes: direction and acceleration. The direction of the approach must respond to the placement of the set. Accelerating during the approach allows momentum to be transferred into the flight phase. The approach steps must be powerful and low to allow for the greatest amount of spring.
- At take-off, the feet are firmly planted to allow momentum to be transferred up through the body, the muscles of the legs and buttocks contract, and the arms swing through and up, as the player launches into the air.
- The outcome of the spike depends on two crucial factors during the flight: the back swing of the hitting arm and the direction in which the hips are facing. Look closely at the placement of the spiker's hips in Figure 3.20. Her hip position is ideal because at the start of the hitting action she will be able to use the large muscles of her trunk to rotate her hips to a forward-facing position.
- The final stage of the volleyball spike is hitting the ball. After the hips rotate, the arm whips through and the hand makes contact with the ball. The acceleration of the travelling ball will be relative to the force generated from the very first step of the approach.

Figure 3.20 Volleyball spikes can be broken down into four stages: the approach, the take-off, the flight and the hit.

Figure 3.21 The summation of forces generated by all parts of the body allows long jumpers to propel themselves further through the air.

ACQUIRE

1 Define force.
2 In your own words, explain the difference between weight and mass.
3 List the six main types of contact forces.
4 a Why is stabilisation an important factor in force summation?
  b Explain why the order and timing of body parts is crucial in maximising force summation.

APPLY AND EVALUATE

1 Explain how the concept of force might apply to the sport you are currently studying. How could you use it more effectively?
2 Choose one physical skill from your current sport. Which body parts do you use to produce maximum force? In which order?
3 Discuss why even elite discus and javelin throwers spend so much time concentrating on developing technique. How is their technique linked with force summation?

PRACTICAL

Summation of forces

To demonstrate the principle of summation of force, try the following exercises.

Procedure

1 *Throwing a tennis ball*

Measure the distance that the ball is thrown under the following conditions:

a sitting against a wall, legs straight out in front, using only your throwing arm (ensure your back stays against the wall throughout the throw)

b sitting on the ground away from the wall, legs straight out in front, using only your torso and arms

c standing with feet shoulder-width apart, facing forward

d standing side-on with feet shoulder-width apart

e with no restrictions (may run or take a 'crow hop').

Record your findings in a table.

2 *Doing a standing long jump*

Measure the distance that is jumped under the following conditions.

a jumping off one leg (arms fixed by your sides)

b jumping off two legs (arms fixed by your sides)

c jumping off two legs, using arms freely

d with no restrictions (using both legs, both arms and a run-up)

Record your findings in a table.

spacing to pad

Tasks

1 Describe the process that you used to achieve the best distance in the tennis ball exercise.

2 Describe the process that you used to achieve the best distance in the long jump exercise.

3 Discuss the factors that influenced the summation of forces in each of the two activities.

Momentum

The summation of forces allows more momentum to be produced. When a body (or object) is in motion, whether it is a sprinter running along a track or a bowling ball rolling down an alley, it has a certain mass and a certain velocity. The product of these is known as the momentum: the quantity of motion the body possesses.

Differences in momentum are brought about by variations in mass and velocity. For example, if two people who are tenpin bowling have exactly the same technique and release the ball with the same velocity, the one bowling the heavier ball is likely to get a better result. This is because the heavier ball, having a greater momentum, will cause the pins to fly around more, knocking down other pins. Similarly, a heavier racquet in tennis will have greater momentum than a lighter one moving at the same velocity and produce more force when it hits the ball.

When you sprint, how many steps does it take you to come to a complete stop? How does this compare with your classmates or competitors? Why?

Velocity also affects momentum. Softball batters wanting to hit a home run will swing the bat faster, with a higher velocity, when hitting the ball to apply more momentum to the ball. By increasing the velocity of the bat, they can hit the ball further. If batters want to bunt, they would swing the bat with reduced velocity so that the ball will not go as far.

In most sports, mass is constant, so velocity becomes the main factor influencing momentum. So, to increase momentum, simply increase velocity.

Figure 3.22 Changing velocity affects a player's momentum.

Transfer of momentum

Newton's first law of motion explains that once a body is in motion, it will tend to stay in motion unless acted on by another force. The principle of the **transfer of momentum** states that momentum cannot be lost—it is just transferred from one object to another.

In many sports, it is necessary for momentum to be transferred to another object or body part. The greater the momentum an object has, the greater its effect on other objects it collides with.

For example, in striking sports such as tennis, softball and golf, a player will gather as much momentum as necessary during the swing by summating forces and then transfer this momentum to the ball being struck. In other activities such as long jump and high jump, momentum gained in the run-up is transferred to the jump, which allows a greater distance to be achieved.

Have you ever played pool? Why is it that when the white ball strikes another ball straight on, the white ball stops moving while the ball that was struck moves forward?

For momentum to be efficiently transferred from one object or body part to another, stabilisation must first occur. If the object or body part is not stable, then some of the momentum will be transferred to movements other than those intended.

For example, in tennis it is common for athletes to brace (tense up) their muscles just before the impact of a forehand. Stopping the rotation of the body by bracing causes a whip-like effect on the arm—all the momentum gained in the trunk rotation is sent into the arm for a powerful swing. Not all of the momentum will be transferred to the ball as the player's racquet will continue to follow through after the ball is struck. However, a full follow-through ensures that at the point of contact the velocity of the swing is high and not decelerating to a stop.

In volleyball, players completing a spike will take one large, accelerated approach step before propelling themselves vertically into the air. If players are not completely stable before the jump, they will not be able to effectively transfer the horizontal momentum of the run-up to the vertical movement.

How high can you jump during a volleyball spike? What could you do to increase your height?

Impulse

The amount of force needed to change the momentum of an object varies depending on the amount of time that the force is applied. A small force applied over a long period of time can be as effective as a large force applied over a short period of time. A large force applied for a long time is most likely to increase the momentum of an object.

The combined effect of force and time is known as impulse.

impulse = *force* × *time*

By considering both force and time, an athlete can maximise the transfer of momentum. For example, a hockey player performing a push pass generates more momentum on the ball the longer the ball stays in contact with the stick. Ideally, a sprinter starting a race will push off the blocks and then take a series of short, fast steps to maximise the time the feet have in contact with the ground, thus maximising the momentum developed. A discus thrower uses intricate footwork in the wind-up to maximise the distance and time spent generating force.

In some sports, such as softball and golf, the time of contact with the ball is very brief. In these sports it is not possible to increase the contact time; the only way impulse can be increased is by increasing the force applied.

ACQUIRE

1 Define momentum.

2 a Explain the concept of impulse in your own words.

  b Explain how an increase in impulse can benefit performance.

PRACTICAL

Momentum

1 a Perform a standing long jump and a long jump with a measured run-up. For each, measure the distance travelled.

  b Explain the reasons for the different distances.

2 a Using a tee-ball bat, ball and stand, hit a ball off the stand with and without force.

  b Compare the differences in the force applied and the distance the ball travels.

3 a Run a 5-metre sprint at less than your best pace, pulling up as quickly at the finish line as possible. Repeat, but this time run at your top speed.

  b Compare your ability to stop in both cases. Suggest reasons for the differences based on your understanding of momentum.

4 Video and analyse the footage of a contact football game.

  a Describe what happens to the velocity of a player when tackled.

  b Compare the mass of the players running the ball and executing tackles, and suggest why some players are more successful than others in the game.

5 Using a trampoline, spring high into the air. Describe what happens when:

  a you keep your body straight and upright and your arms above your head

  b you keep your body straight, but your arms are swung forward and down

  c your arms stay above your head, but your legs are swung forward and up.

Source (task 5): P Nicholson and R Whiteley, *Australian Physical Education Masters Series*, Eduguide, Victoria.

Figure 3.23 To slow a fast-moving ball, cricketers must absorb the force of the ball by moving their arm back as they make the catch.

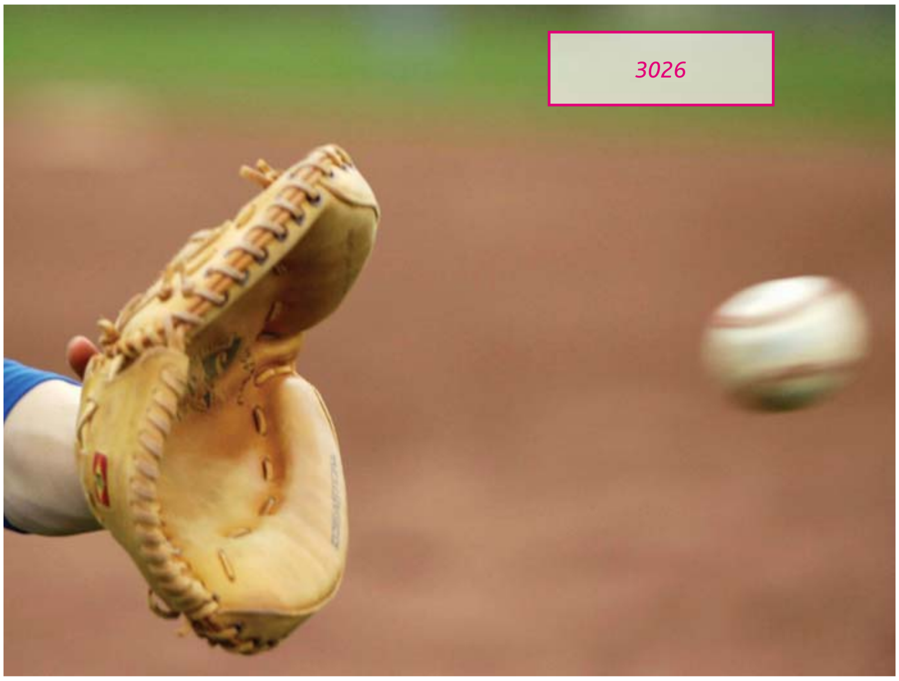

Figure 3.24 When catching a ball, the muscles (along with the soft glove) absorb the force of the impact.

Absorbing force

In addition to applying force, the human body also absorbs force. When we land from a height, the momentum of the body causes the knees, ankles and hip joints to flex. The muscles of these leg joints give during landing to cushion the impact. The same is true when catching a ball that is heavy or thrown very hard—the muscles contract and give.

In most sports, the momentum gained during a catch, landing or impact can often be redirected into the next movement. For example, a softball player can take a catch then make a quick throw to effect a double play.

Do you ever have balls rebound out of your hand when you think you have caught them? What causes this?

Propulsive and resistive forces

A force that acts to cause movement is called a **propulsive force**. A force that acts to resist the movement created by a propulsive force is called a **resistive force**.

For example, the controlled lowering of a barbell requires the barbell's momentum to be reduced to zero or near zero. This is done by the weightlifter exerting a resistive force that acts against the barbell's propulsive force (in this case, gravity).

Figure 3.25 Safety equipment is used in many sports to absorb the force of impact and avoid injuries.

Safety on impact

Moving objects and bodies often need to be stopped and controlled, without injury to athletes. Force is often absorbed by the body during an impact, which is when one object or body strikes or collides with another.

Athletes can take a number of simple precautions to ensure safety on impact.

- Use as large a surface area as possible when landing or catching. For example, land on two feet, or put the body behind the ball when catching.
- Use as much mass as possible when landing or catching. For example, land on bigger, heavier body parts, or put the body behind the ball.
- Keep your centre of gravity low and over your base of support for maximum stability. For example, bend your knees and place your feet in a wide, balanced stance.
- Absorb the force of the impact with equipment and not body parts. For example, use gloves, mitts or headgear.
- Protect limbs and avoid using small body parts such as fingers during impact.
- 'Give' with the impact.

APPLY AND EVALUATE

1 Why does a softball player need to invest in a well-padded glove? Justify your response.

2 Suggest how a movie stunt person is able to fall from height and land on solid ground without injury.

Accuracy

Often force production is not necessarily just about producing the most force possible. For some skills, such as bowling in lawn bowls, and shooting a goal in basketball, accuracy is critical for success. A player must, therefore, be able to control both the amount and direction of force produced.

Direction can be controlled in a number of ways. For example, increasing accuracy in a volleyball dig may involve smoothing out the platform created by the forearms. This can be done by straightening the arms at the elbows and bending the wrists backwards. The flat platform reduces the likelihood of the ball rebounding off the arms at an incorrect angle. When attempting to shoot a goal in netball, a straight-back linear arm movement followed by a straight follow-through can increase the accuracy of the shot. In striking sports such as baseball and tennis, flattening the arc can improve accuracy.

Think about your accuracy in your current sport. What can you do to gain greater control?

AWB = add path / pic different … pls mark-advise

Case study—accuracy and flattening the arc in striking sports

In softball and other striking sports, accuracy in batting can be increased through a concept known as flattening the arc.

If a batter were to simply stand and swing a bat, the bat would move in a perfect arc. A bat swinging through the air in such an arc only has a very small opportunity to come into contact with the ball at the exact moment the bat is positioned to produce the desired direction.

By rotating the hips as the bat begins to swing and by flexing the wrists through the swing, the bat's path is 'flattened' for a time, which gives the batter a greater chance at hitting the ball in the desired direction.

Figure 3.26 Flattening the arc improves accuracy.

Rotary forces

Concentric and eccentric forces

Concentric force can be described as force that is applied along an imaginary line that passes through an object's centre of gravity. A concentric force will result in the object travelling along a direct path in the direction of applied force. This is known as **translation**: where all parts of an object in motion are moving with the same velocity and in the same direction.

When force is not applied along the line of centre of gravity, the object will turn. Force that is not applied along the line of centre of gravity is known as **eccentric force**. Eccentric forces produce rotation.

Rotational force—torque

A force that produces a rotating or twisting motion is known as **torque**. Torque is also sometimes known as **rotational force**. The amount of torque (T) produced depends on:

- the amount of force used (F)
- the distance from the centre of the object that the force is applied (d).

$$T = Fd$$

More torque, and a greater rotation or twisting movement, will be generated when more force is applied further from the centre of an object.

3028 TS

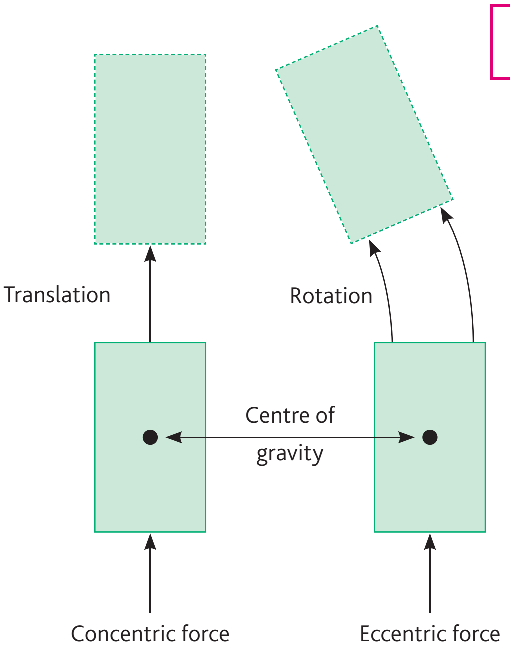

Figure 3.27 Concentric and eccentric forces cause objects to move along a straight path or turn.

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Force couples

A **force couple** is when two equal forces are applied in opposite directions, causing an object to spin. This can be seen when two canoeists try to turn a canoe 180 degrees. To turn the canoe efficiently, each canoeist needs to apply the same amount of force simultaneously—one canoeist applying force by paddling forwards while the other canoeist paddles backwards on the other side.

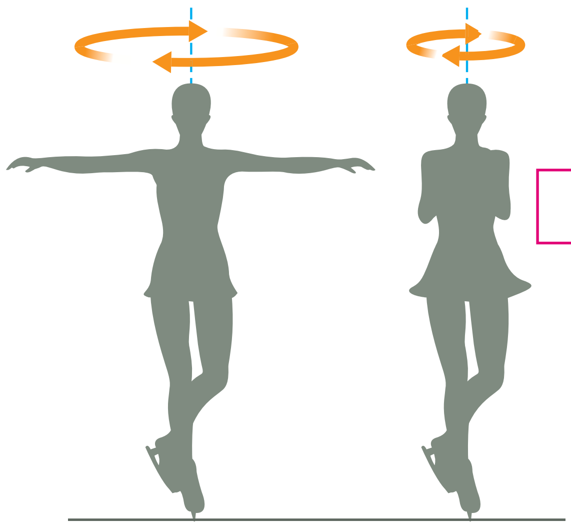

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Figure 3.28 An ice skater uses the distribution of weight to control the rate of rotation.

Rotational momentum

We already know that momentum is the quantity of motion an object has, which depends on its velocity and mass. Momentum explains why heavy objects that are travelling quickly will be harder to stop than light objects moving slowly.

Rotational momentum is the momentum generated through rotational forces.

Because of Newton's first law of motion—inertia—we understand that a spinning object will continue to rotate in the same direction and speed until another force acts on it.

Thanks to Newton's second law of motion, regarding an object's resistance to acceleration, we also know that it will require less force to cause a light object to spin than it will to cause a heavy object to spin at the same velocity.

An object's mass alters its rotational momentum. Heavy objects will have more momentum than light objects travelling at the same velocity. In baseball, athletes can apply this knowledge to their sport by choosing a heavier bat to generate more momentum and a more powerful strike on the ball. A baseball player often takes the weight of a bat and its distribution into consideration when buying a new bat.

An object's weight distribution—where the mass or weight is on the object—can affect its resistance to rotation. An object that has most of its weight close to the axis of rotation (the point around which it is spinning) will move more quickly than one that has weight further from its axis of rotation. A simple way to demonstrate this principle can be done by a person sitting in a swivel chair. After the person has begun spinning around in the chair, the rate of spin can be controlled by tucking in the legs (to rotate faster) or extending the legs (to rotate more slowly).

In sport, this concept is most clearly demonstrated in ice skating. When spinning on the ice, skaters can control the rate of spin by moving their limbs closer to the axis of rotation (to rotate faster) or extending their arms and legs (to rotate more slowly).

Conservation of rotational momentum

The rotational momentum of an object is based on its mass and acceleration. Newton's first law of motion—inertia—explained how this momentum will be conserved unless another force is applied. Unless another force acts on it, an object will maintain its momentum while rotating; this is known as the **conservation of rotational momentum**.

This principle is particularly relevant to physical activities such as diving and gymnastics. Athletes performing twisting or spinning movements while airborne are not affected by other external forces that will change their rotational momentum; therefore, their bodies' rotational momentum will remain the same—it will be conserved.

Transfer of rotational momentum

Closely linked to the idea of conservation of rotational momentum is the **transfer of rotational momentum**. On page 91 we looked at the principle of the transfer of momentum, which states that momentum cannot be lost, but it can be transferred from one object to another.

Rotational momentum can be also transferred from one axis of rotation to another. This can be seen when athletes move from a spinning position to a twisting position in diving, trampolining and ski jumping.

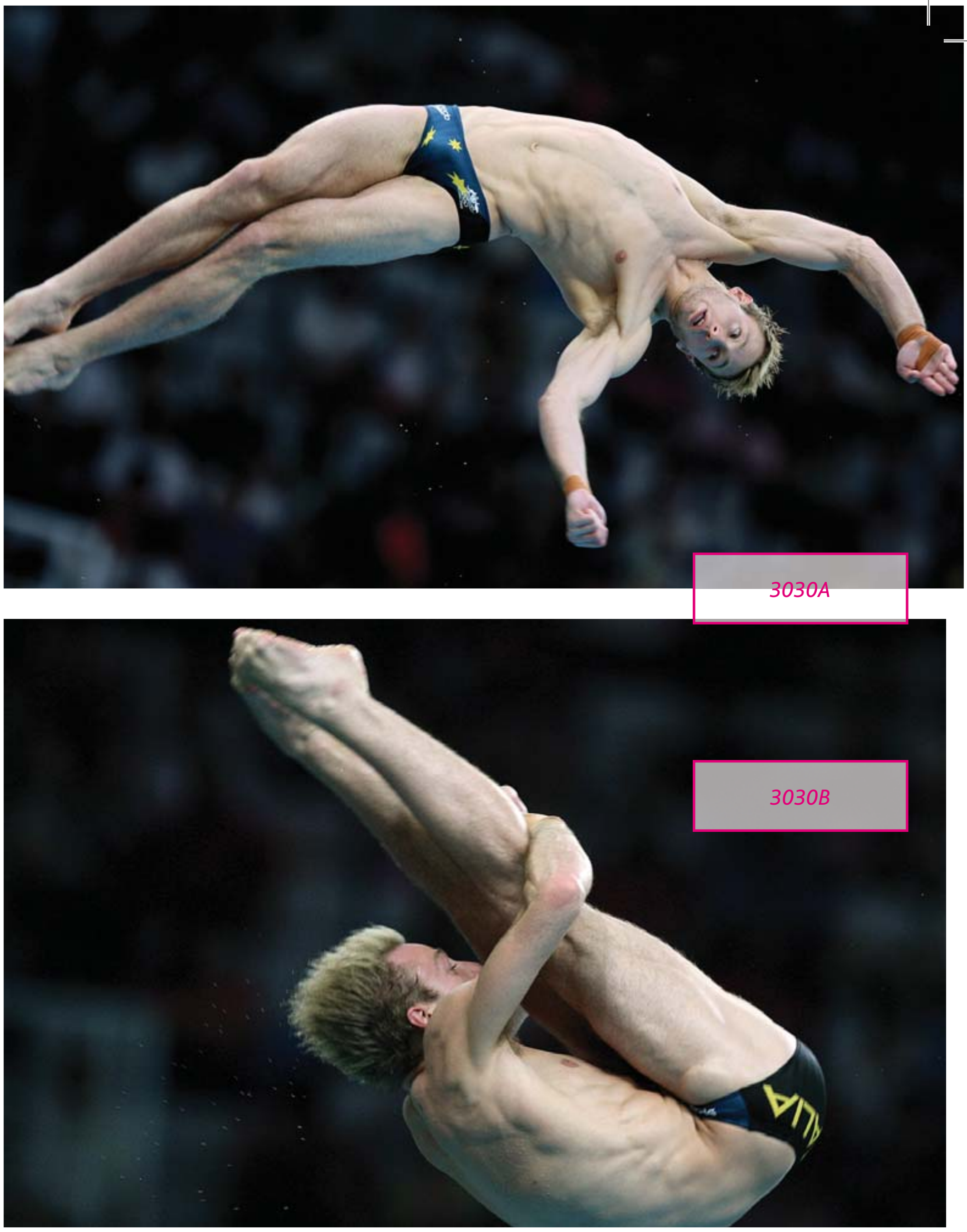

Figure 3.29 Rotational momentum can be transferred from one axis of rotation to another.

APPLY AND EVALUATE

Explain how the conservation of rotational momentum can be applied to the following:

1 ice skating
2 hammer throwing
3 hitting a forehand in tennis
4 performing a vault (tucked versus layout position).

Centripetal and centrifugal forces

According to Newton's third law of motion, for every action there is an equal and opposite reaction. When an object is rotating around a fixed axis in a circular path, two opposing forces are at work: centripetal force and centrifugal force.

- **Centripetal force** is the force that causes rotating objects to move *towards* the centre, or axis, of rotation.
- **Centrifugal force** is the force that causes rotating objects to move *away from* the centre, or axis, of rotation.

Both forces working together ensure that an object will remain on a circular path while rotating around a fixed point. For example, when a ball is attached to a line and spun around in a circular path, the line exerts a centripetal force on the ball, keeping the ball moving in its orbit. To keep the line taut to allow this circular path, the ball exerts a centrifugal force on the line.

Striking sports—those that use a bat, racquet or club, such as tennis, squash, golf and softball—can also be used as an example of centripetal and centrifugal forces. Swinging a bat more quickly will increase the centrifugal force, causing the bat to want fly out of your hand. Centripetal force is needed by the athlete to maintain their grip. If the rotational momentum is too great, the centrifugal force could cause the athlete to lose their grip and send the bat flying off into the distance!

ACQUIRE

What is the difference between centripetal and centrifugal force?

APPLY AND EVALUATE

Describe how centripetal and/or centrifugal forces could be applied to:

1 performing a giant swing on a high bar in gymnastics
2 using a golf club that is too long
3 swinging a softball bat that is too heavy

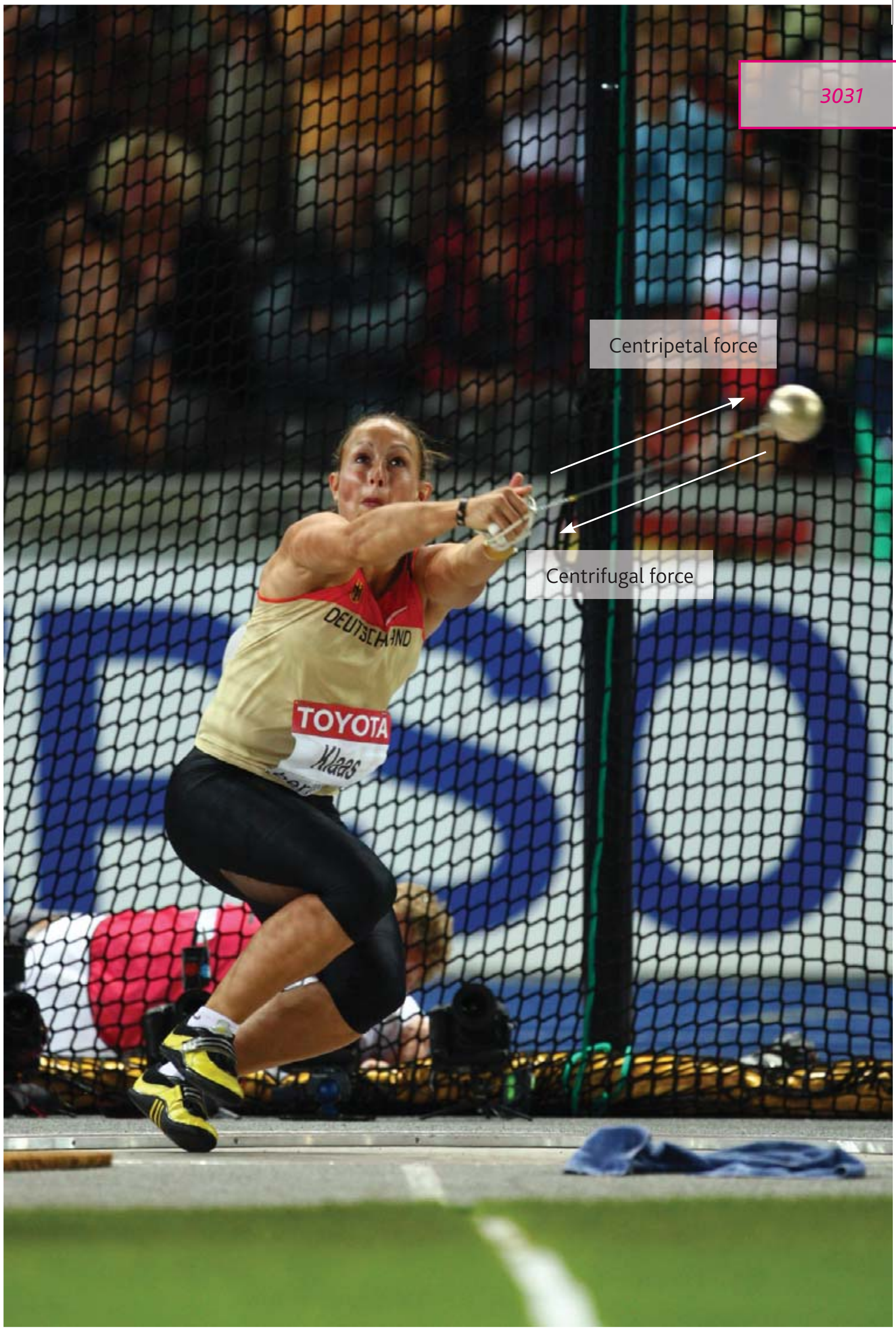

Figure 3.30 Centripetal force causes objects to move *towards* the axis of rotation; centrifugal force causes objects to move *away from* the axis of rotation.

Levers

We use levers every day. Objects such as scissors, nutcrackers, wheelbarrows and nail clippers all work because of levers.

Levers are also frequently used in sport. The human body contains many levers made up of bones and muscle. Our arms, legs and fingers are all levers. These levers allow the body to move and generate force. Many types of sporting equipment are also levers, such as bats and racquets, which allow us to hit objects faster and further.

In sport it is necessary to understand the mechanics of levers; understanding how they work allows athletes to optimise efficiency in movement.

3032 AT

How levers work

Every lever has a point at which force (or power) is applied, a point of resistance and a **fulcrum** (or axis), but the three different types of levers, all of which play a role in sport and physical activity, work slightly differently.

- **First-class levers** have the fulcrum between the force and the resistance. An example of a first-class level in action is a rower's oar: the force is applied by the rower, the fulcrum is the oarlock, and the water offers the resistance.
- **Second-class levers** have the resistance between the force and the fulcrum. An example of a second-class lever is when a person stands on tip-toe: the length of the foot is the arm of the lever, the ball of the foot acts as the fulcrum, and the Achilles tendon and calf muscle provide the force, lifting the weight of the body by the back of the heel.
- **Third-class levers** have the force between the resistance and the fulcrum. Our forearms act as third-class levers, with the elbow as the fulcrum or point of rotation of the lever.

Can you think of levers that are used in your sport?

The first two types of levers enable heavier weights to be moved with less force using mechanical advantage.

Most of the levers used in sport, however, are third-class levers. These levers are better at generating speed than force because of the position of the fulcrum. Lengthening a third-class lever increases the speed that can be achieved. The additional length increases the range of motion of the lever's end and, therefore, its speed. This in turn results in more force at the end of the lever. For example, using a bat or racquet adds length to the forearm, which acts as a lever, and allows a ball to be hit with more force.

The **principle of leverage** states that the velocity at the end of a long lever is faster than the velocity at the end of a short lever, and that the end of a lever will move more quickly than any other point on the lever.

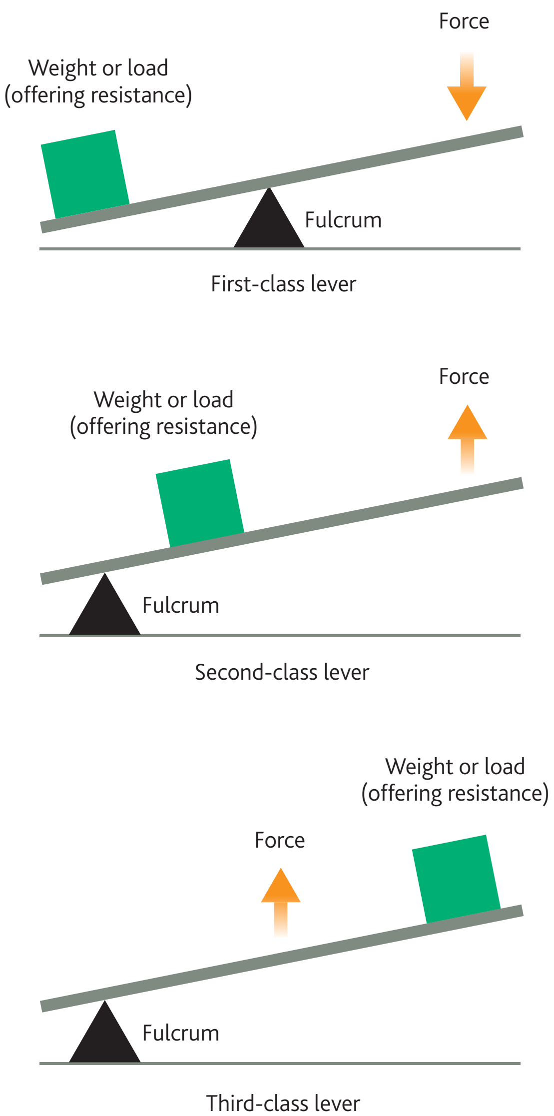

Figure 3.31 Every lever has a point at which force is applied, a point of resistance and a fulcrum.

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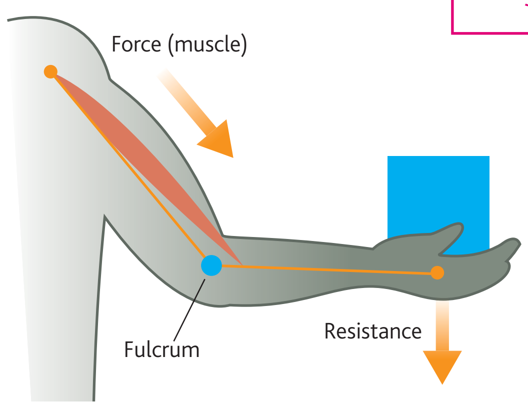

Figure 3.32 Bones and muscles form many different levers within the body.

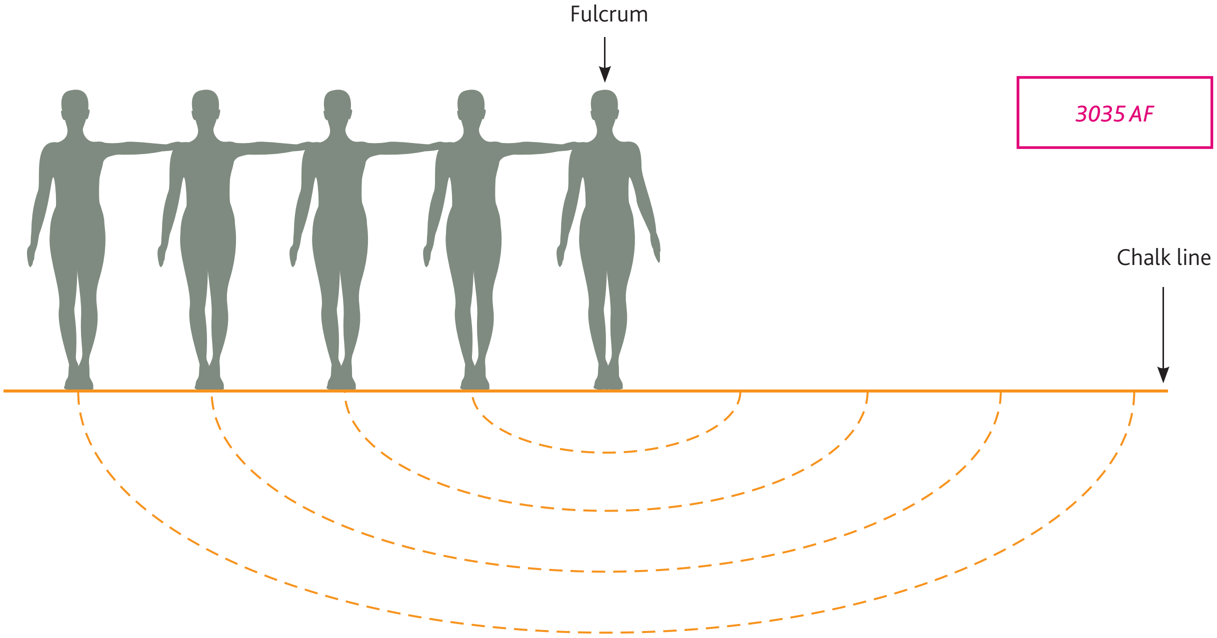

Figure 3.33 In this activity, students demonstrate the motion of a lever by moving around a fulcrum.

PRACTICAL

Levers

On a hard-paved area, five students stand next to each other in a straight line with their left hand on the next person's shoulder. (See Figure 3.33.) The person standing furthest left will be the 'fulcrum' of the lever.

Draw a straight chalk line behind the heels of the group. Then, extend the straight line an equal length on the opposite side of the person acting as the fulcrum.

While the fulcrum remains in the same place, the other four members of the group, still linked by their left arms, walk around the fulcrum until they reach the extended chalk line and are facing the opposite direction. The person acting as the fulcrum will rotate on the spot. As the group walks, four other students mark each member of the group's path in chalk.

1 Time how long it takes for them to move 180 degrees.
2 Using a piece of rope, measure the total distance each student travelled.
3 Determine the speed of each student, using the following formula:

$$speed = \frac{distance}{time\ taken}$$

a Which student travelled faster?
b If there were a sixth student, would they have travelled faster again?

The principle of leverage means that when using levers in sports to produce force, it is often best to maximise the length of the lever being used and to strike the object at the end of the lever. For example, in cricket, bowlers will generate more speed on the ball if they use a straight arm; a straight arm lengthens the lever. In a tennis serve, too, a fully stretched arm will ensure the racquet head is moving at its top speed at the moment of impact.

As with most force production, however, it is necessary to balance force with accuracy. There is a limit to the optimal lever length as increasing the lever's length too much can create handling errors. A softball player would not use a 4-metre-long bat, and tennis racquets are usually less than a metre long. Some

Figure 3.34 Using a bat or racquet increases the length of the lever that is your forearm.

players will shorten their grip on the bat or club to improve accuracy. For junior players, racquets and bats are often shortened to match the strength and height of the player. Beginners may find they do not have the strength to produce the correct technique if the racquet or bat is too large and heavy for them.

What can you do to use levers more efficiently in your sport?

Force is applied to cause the lever to rotate around the fulcrum. Even so, getting a lever moving can be difficult as levers have inertia: they have a reluctance to begin rotation. To make it easier to move and swing through with speed, players will often shorten the length of the levers in their body, such as by bending their arm or leg. For example, in soccer the kicking leg starts in the bent position before opening out to a straight position just before contact. This same skill is used in other sports, such as in tennis and volleyball serves and javelin throws. In all these examples it is important that the lever is straightened at the point of contact to ensure the maximum speed—and, therefore, force—is transferred to the ball or object.

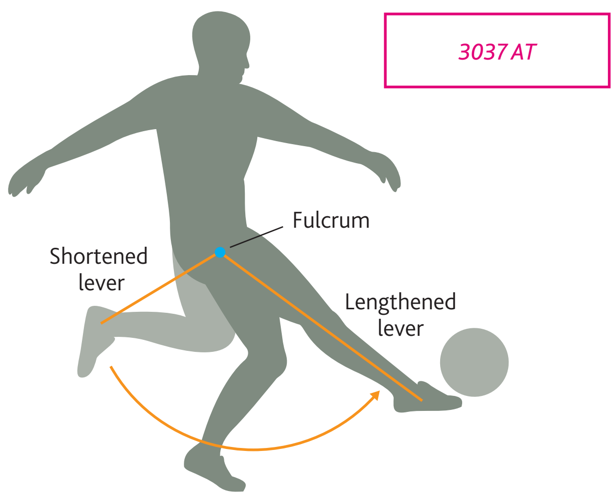

Figure 3.35 Shortening the lever length can help overcome the moment of inertia.

If a lack of speed or force is evident in your performance, it could be that you are not taking full advantage of levers.

ACQUIRE

Draw three diagrams showing first-class, second-class and third-class levers. Provide a sporting example of each.

APPLY AND EVALUATE

1 a Which part of a softball bat would produce the most speed when hitting a softball?
  b Would a long bat or a short bat be a better choice?
  c Are there any limits with the length? Explain.
2 It is important for a javelin thrower to bring their elbow through first. Justify this statement.

Sweet spots

In sports that use racquets, bats and clubs, you will often hear discussion of the **sweet spot**. A sweet spot is the ideal point on the equipment with which to hit the ball to maximise accuracy and force.

The sweet spot is the point that, when struck, causes no backwards nor forwards rotation of the bat. Sweet spots are also the point at which vibration and jarring are minimised. They are often near the centre of equipment.

Have you ever felt the effects of hitting a ball outside the sweet spot? What did it feel like?

Hitting the ball with the sweet spot has to be balanced with the effects of leverage. For ideal leverage, the ball should be hit with the end of the bat (lever). However, if a ball is hit with the end, the tip of the bat will rotate backwards, driving the handle forwards out of the batter's hand. If the ball is struck close to the handle, the tip will rotate forwards, causing the bat handle to push into the batter's hands.

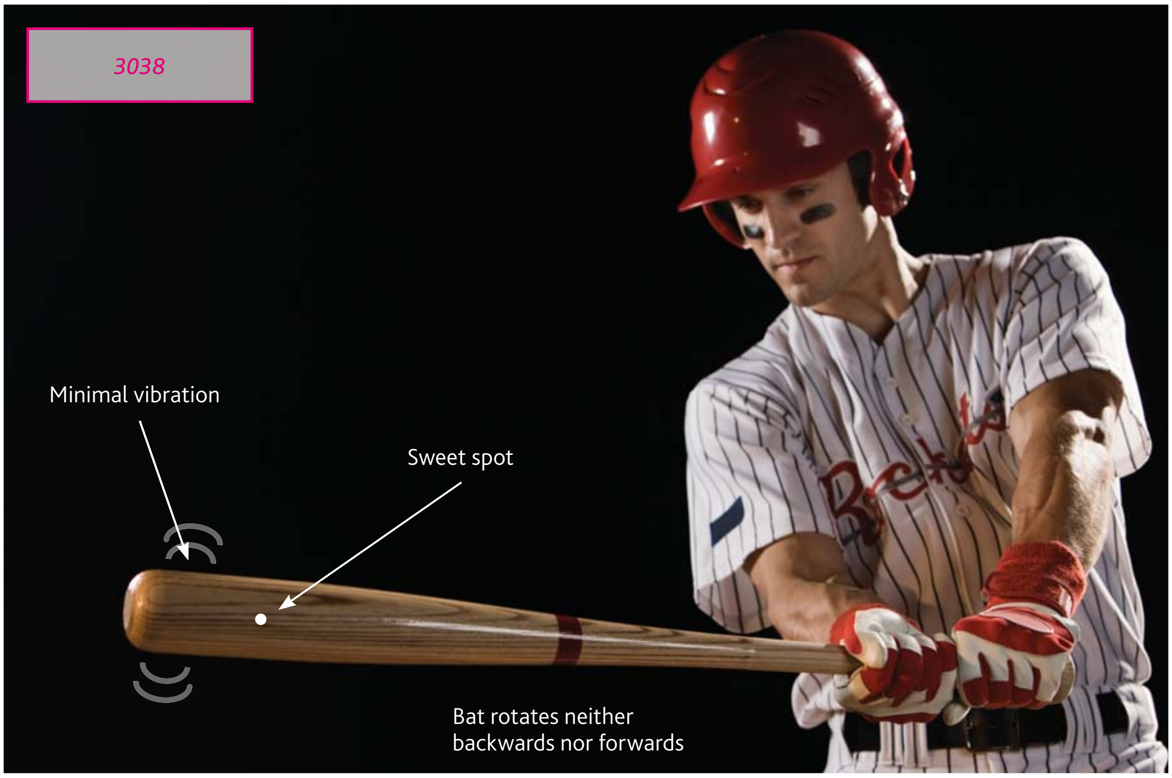

Figure 3.36 The 'sweet spot' is the point on equipment such as bats and racquets where vibration is minimal.

Projectile motion

A projectile is any object that is launched, hurled or thrown, such as a bullet shot from a gun or a tennis ball hit by a racquet. The path of a projectile is called its **trajectory**.

When we think of projectiles in sport, we usually think of objects that have been thrown or hit, such as balls and javelins. However, the human body can also be a projectile—think of gymnasts launching themselves from a beat board or swimmers mid-dive.

Factors affecting the flight of a projectile

The trajectories of all projectiles are affected by the external forces of gravity and air resistance. For example, air resistance can affect the flight of a javelin and take metres off the total distance. A shot-put will be strongly pulled down by the forces of gravity.

In addition, three other factors affect the flight of a projectile and, ultimately, the distance it will travel:

- angle of release
- height of release
- speed of release.

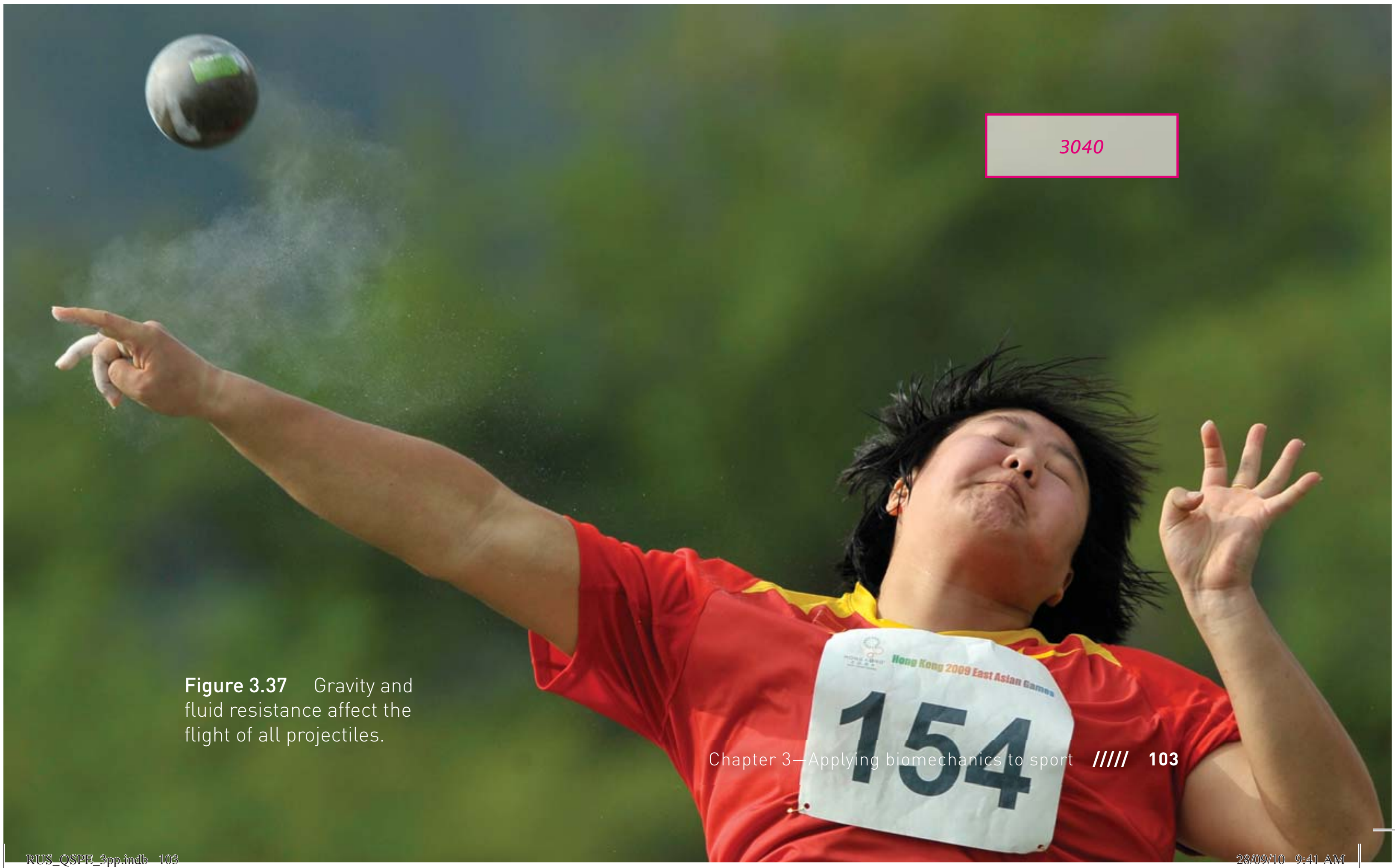

Figure 3.37 Gravity and fluid resistance affect the flight of all projectiles.

Figure 3.38 A projectile's flight is affected by its angle of release, height of release and speed of release.

Angle of release

All projectiles have two types of velocity: horizontal velocity and vertical velocity. Once the projectile has been released, its horizontal velocity does not change; it will continue to move in a horizontal line until it is overcome by the vertical forces of gravity. The combination of horizontal and vertical velocity results in a flight path in the shape of a parabolic curve.

Assuming that a tennis ball is thrown at the same speed, the following things would happen, depending on the ball's angle of release.

- If the ball was thrown straight up into the air, it would stay in flight for a long time but travel only a short distance.
- If the ball was thrown low (relatively parallel to the ground), it would travel further from the point of release, but its flight time would be short.

The optimal trajectory is a result of an even combination of forward (horizontal) and upward (vertical) flight. In theory this equates to an optimal angle of release of 45 degrees.

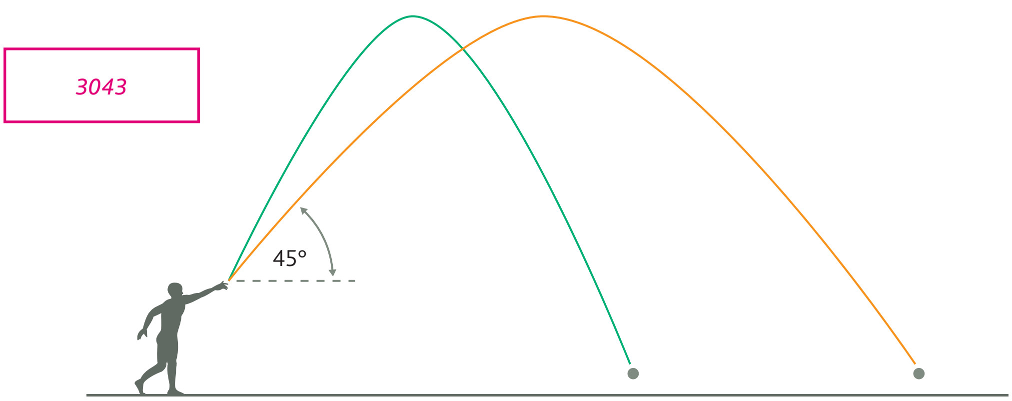

Figure 3.39 The optimal angle of release of a projectile is just less than 45 degrees.

In practice, however, the optimal angle of release can vary—usually between 35 and 45 degrees. For shot-putters, for example, the optimum angle of release lies somewhere between 41 and 43 degrees. However, a biomechanical study at the University of Kansas found that shot-putters release their shots at angles between 32 and 38 degrees, with few cases reported above 40 degrees.

The difference between theory and practice can be explained by other variables, including the effects of fluid resistance, and the technique and physical attributes of individual athletes. If an athlete can get a higher velocity at a lower angle, then there is a trade-off between the optimum release angle and maximum release velocity.

Height of release

The height of release refers to the height at which an object is released relative to its landing point. If the angle of release and the velocity remain constant, a projectile thrown from a greater height of release will travel further than one thrown from a lower height of release.

For example, if a tall athlete and a short athlete release a discus at the same speed and angle, the taller athlete will be releasing the discus at a higher release point. In theory, this would mean that the projectile thrown by a taller athlete would have more time in the air and that a taller athlete would be able to throw further than a shorter athlete.

Do you think you have a height advantage when throwing?

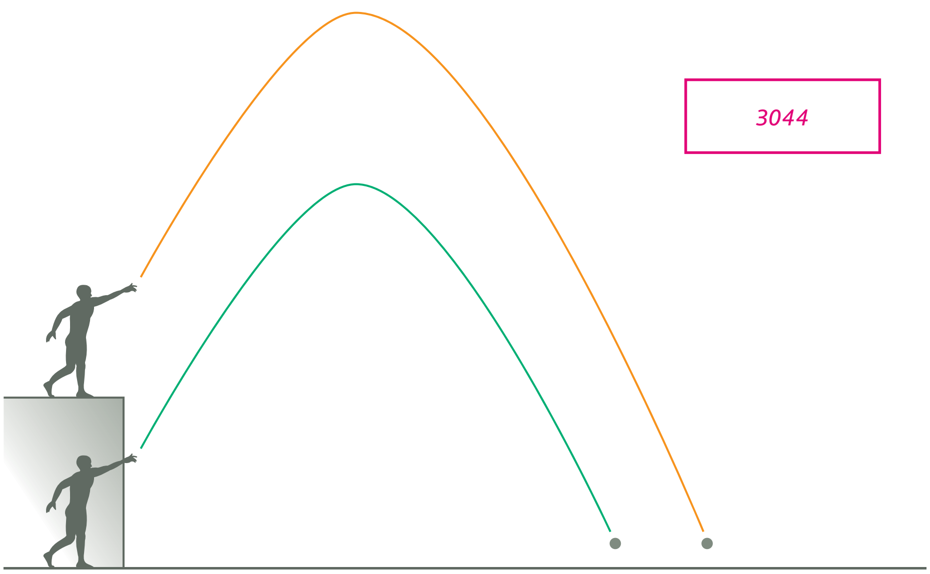

Figure 3.40 Projectiles thrown from a height will travel further.

The height at which a projectile is released also has implications for the optimum angle of release.

- When the height of release is equal to the height of landing, the optimum angle of release is 45 degrees. This occurs in soccer, when the ball is kicked from the ground and lands on the ground.
- When the height of release is greater than the height of landing, as in a hammer throw, the optimum angle of release is less than 45 degrees.
- When the height of release is less than the height of landing, as in a bunker shot in golf, the optimum angle of release is more than 45 degrees.

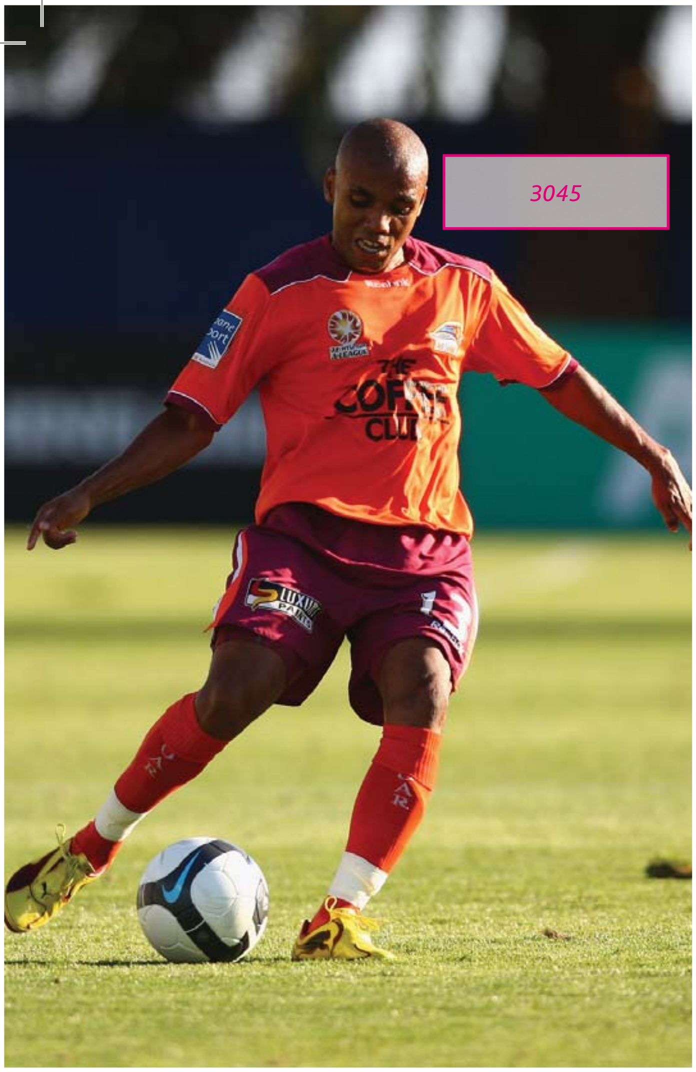

Figure 3.42 In a hammer throw, the height of release is greater than the height of landing.

Figure 3.41 When a soccer ball is kicked, the height of release is equal to the height of landing.

Figure 3.43 The height of release is sometimes lower than the height of landing.

APPLY AND EVALUATE

1 With a partner, discuss and list several sporting situations when the height of release is:
   a equal to the height of landing
   b greater than the height of landing
   c lower than the height of landing.
   What implications does each scenario have on the optimal angle of release?
2 Two shot-putters weigh the same; however, one is 20 centimetres taller than the other. Who has an advantage and why?

Speed of release

Once a projectile has been released, its horizontal velocity remains constant for the duration of its flight. In sports that require projectiles to be thrown a great distance, athletes try to generate as much velocity as possible by releasing the projectile with the greatest possible amount of force.

Not all sports, however, need distance; in some, accuracy is more important. In those sports, the speed of release decreases and more emphasis is placed on perfecting the angle and height. For example, basketball players attempting a free throw would slow down their throwing action, placing all their focus on techniques to improve accuracy. If the same players had to beat the shot clock from well before the 3-point line, their throwing action would speed up as their need for maximum force outweighs their need for precision.

The Magnus effect on spinning projectiles

Often, when a projectile is thrown, techniques are used to cause the projectile to spin. For example, bowlers in cricket often deliberately apply spin to the ball. By causing the ball to spin, bowlers can make the ball follow a curved flight path, which makes it difficult for the opposing batter to read the ball's direction and hit it accurately.

The Magnus effect occurs when a spinning object is moving through air or water. To understand this, let's look at a spinning cricket ball. In cricket, as the spinning ball moves through the air, its spinning motion causes the air pressure on one side of the ball to be less than on the other side. Velocity increases (and air pressure decreases) on the side of the ball that is travelling in the same direction as the air around it. Velocity decreases (and air pressure increases) on the other side of the ball where the spin is moving against the direction of the air flow around it. The effects of the different velocity and air pressure on each side of the spinning ball cause it to curve towards the side with the higher velocity and lower air pressure.

Bowlers control the direction of the ball's curved trajectory by varying the ball's velocity, its axis of rotation and the direction in which it spins.

The Magnus effect has some similarities to **Bernoulli's principle**, which is explained on page 111.

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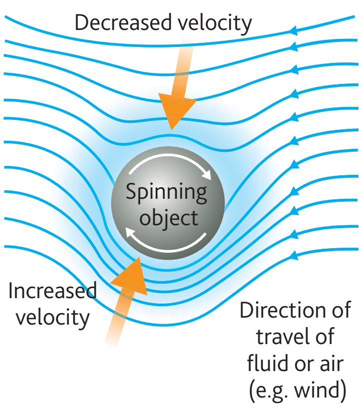

Figure 3.44 The Magnus effect explains how a spinning projectile, such as a ball, curves in flight.

Figure 3.45 Imparting spin to a ball alters the ball's trajectory.

ACQUIRE

1 List the factors that affect the flight of a projectile.

2 a In theory, what is the optimal angle of release to maximise distance?

  b Give one reason why this angle might change in practice.

PRACTICAL

Applying force

Watch video footage or demonstrations of the topspin serve in tennis and a variety of spin bowling techniques. Then, practise the techniques in small groups and rate their effectiveness. Discuss your findings as a group.

Case study—golf balls in flight

Have you ever wondered why golf balls are covered in small dimples? The dimples on the balls actually improve the balls' ability to travel further. Dimpled balls will fly further than smooth balls. As a result, golf ball manufacturers spend a great deal of effort determining the optimum depth and pattern of golf ball dimples.

The dimples work in several ways. First, they act to reduce the air resistance. As the ball flies through the air, a boundary layer of air forms around the ball. The dimples on the ball act like small scoops to push air around and enhance the effects of Bernoulli's principle and the Magnus effect. This helps to increase lift and reduce drag.

Because the dimples help to force the air around the ball as it spins, less air pressure builds up behind the ball, reducing the backwards drag on the ball.

Dimples on a golf ball cannot be any size. If the dimples are too deep, they increase the ball's resistance through the air and shorten its trajectory. If they are too shallow, they do not provide the benefits of reducing air pressure and increasing lift.

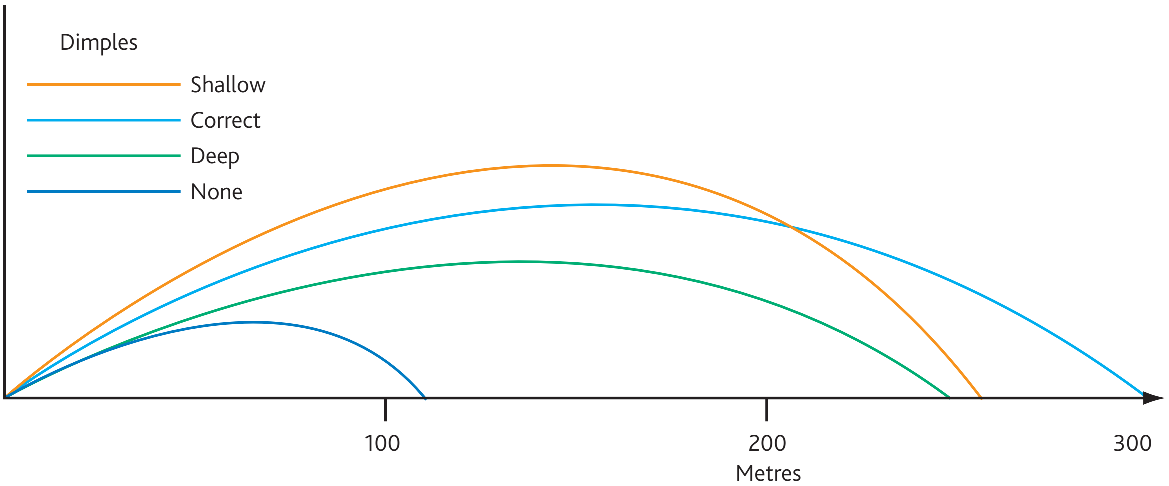

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Figure 3.46 The dimples on golf balls increase the distance the balls can travel.

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Fluid mechanics

Fluid mechanics refers to forces that operate in water and air. This section will only look at the forces operating in water. These forces affect how well we can move through the water, either in a vessel or as a swimmer.

The forces of fluid mechanics include buoyancy, **propulsion** and resistance. Efficient swimmers are able to alter their technique in a way that minimises opposing forces to gain maximum propulsion.

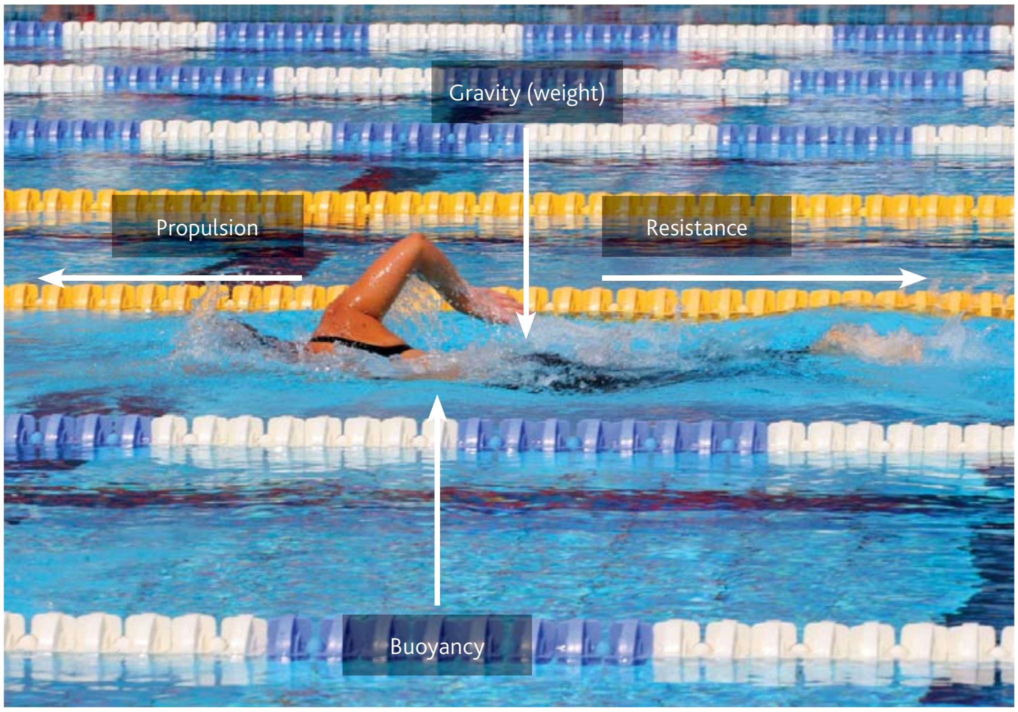

Figure 3.47 The forces of fluid mechanics influence a swimmer's motion.

Buoyancy

An object's buoyancy determines whether or not it will float. Buoyancy, in turn, depends on the object's **density**.

Density is different from mass or weight in that it refers to an object's ratio of mass relative to its volume. A shot-put and a rubber ball can be the same size (take up the same volume) but because the shot-put is heavier for the same volume, it has a higher density than the ball. Density explains why, if we threw the shot-put and the rubber ball into a pool, the shot-put would sink to the bottom, but the rubber ball would float.

Specific gravity, also known as **relative density**, is the ratio used to compare the density of an object with the density of water. Water has a specific gravity value of one; anything with a specific gravity less than one will float when placed in water; anything placed in water that has a specific gravity more than one will sink when placed in water.

People are not purpose-built for water. Although our bodies are made up of high proportions of low-density air, fat and water, the density of our bodies is uneven. Also, dense muscle and bone have specific gravity values of 1.5–2.0 and have a negative effect on buoyancy. Therefore, when we try to float, we are buoyed up by our chest and core, but sink at the legs due to their high percentage of muscle and bone. A person with a higher proportion of body fat will float more easily than a heavily muscled person.

Archimedes' principle

Buoyancy was first understood by Archimedes in the third century. **Archimedes' principle** states that a body that is partially or totally immersed in a fluid will be buoyed up by a force that is equal to the weight of the fluid that is displaced by the body.

Put simply, the buoyancy force of an object is the same as the weight of the water it displaces. Again, using the example of the shot-put, a men's shot-put weighs about 7.3 kilograms, but would only displace about 500–600 grams of water from the pool; therefore, it would sink.

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Centre of buoyancy

The **centre of buoyancy** is related to volume and displacement. The centre of buoyancy of an object is at the geometric centre of the submerged volume of the object.

In swimmers, the centre of buoyancy can change depending on the position and movement of a swimmer's body, particularly the legs, and how much of the body is submerged. Synchronised swimmers, for example, take advantage of the opposing forces of centre of buoyancy and centre of gravity to generate subtle and elegant rotation in the water, simply by moving their limbs.

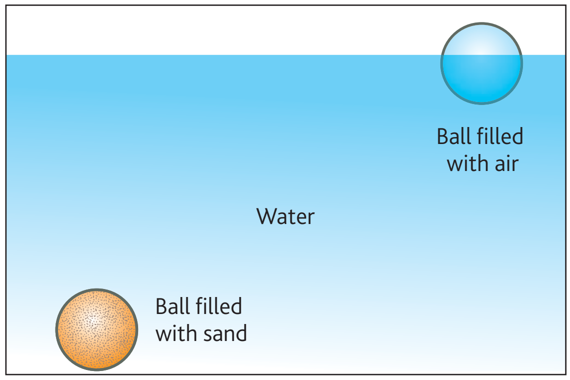

Figure 3.48 Objects the same size can have very different densities.

The position in which a body floats in water depends on where the centre of gravity (downward force) and centre of buoyancy (upward force) are situated at any given time. As these two forces work in opposite directions, the body will rotate and only come to rest when the centre of gravity and centre of buoyancy are vertically aligned.

The centre of gravity and the centre of buoyancy are not always in the same place. When a swimmer lies horizontally in water, the centre of buoyancy is located closer to the head than the centre of gravity. This is because the chest is filled with air, making it the least dense area of the body, and because the legs are the densest area of the body, with high proportions of heavy muscle and bone.

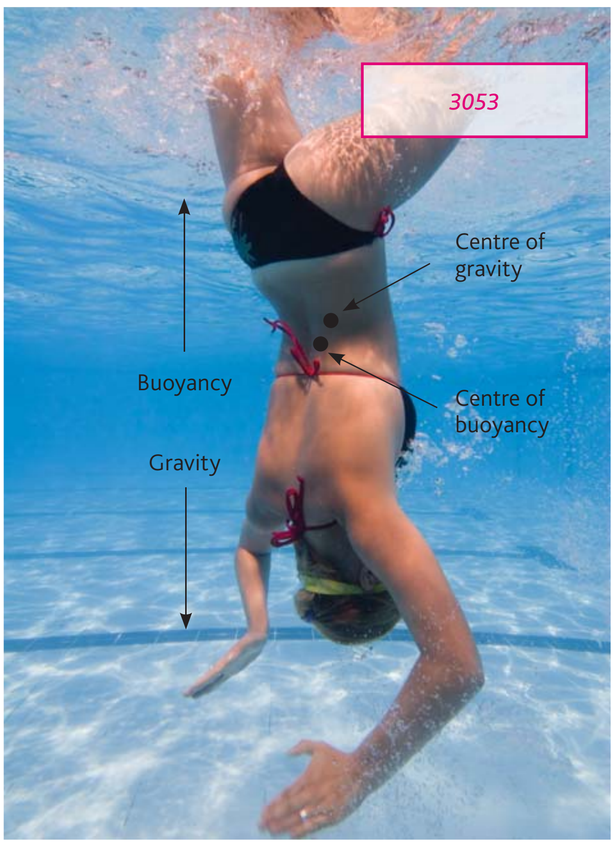

Figure 3.49 Buoyancy and gravity are two opposing forces.

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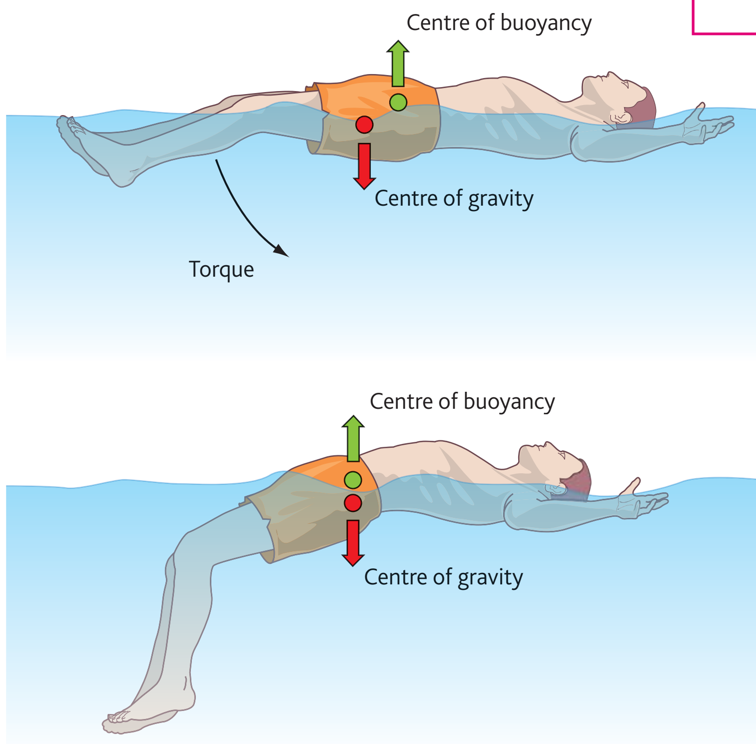

Figure 3.50 The centre of buoyancy can change depending on the body's position in the water.

PRACTICAL

Buoyancy

During your next swimming lesson, try to maintain the following positions. Note what happens:

- Lie on your back with your feet stretched out and your hands by your side.
- Lie on your back with your arms and legs spread far apart, making a 'star' shape in the water.

1 Did your body respond the same way to both positions?
2 Were you able to maintain your initial position for longer in either one? If so, use the concepts of centre of gravity and centre of buoyancy to explain why.

Propulsion

Propulsion refers to the force that drives an object or body forward.

In most sports, forward motion is achieved by athletes pushing against a solid surface. For example, sprinters push their feet against the solid ground to propel themselves forwards. Water, however, provides no such solid surface. Swimmers, therefore, need to somehow 'pull' or 'push' themselves against the resistance of the water.

Two types of forces are at work when swimmers propel themselves through water: lift and **drag**. For all swimming strokes, both forces come into play at different points in the pulling, pushing and sideways sweeping actions of swimming.

Bernoulli's principle

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Bernoulli's principle explains that as the velocity of a fluid or gas increases, its pressure decreases, and vice versa. Bernoulli's principle is usually used to explain how the wings of aeroplanes work, but it can also be applied to sports such as swimming.

In an aeroplane wing the air has to travel further across the curved top of the wing than it does underneath the wing. The slower flow of the air beneath the wing creates an area of higher pressure. The difference in pressure above and below the wing is what creates the wing's lift. A curved swimmer's hand moving through water can have a similar effect.

Bernoulli's principle explains how water pressure will decrease as the speed of the flowing water increases. Furthermore, water naturally moves from high- to low-pressure zones.

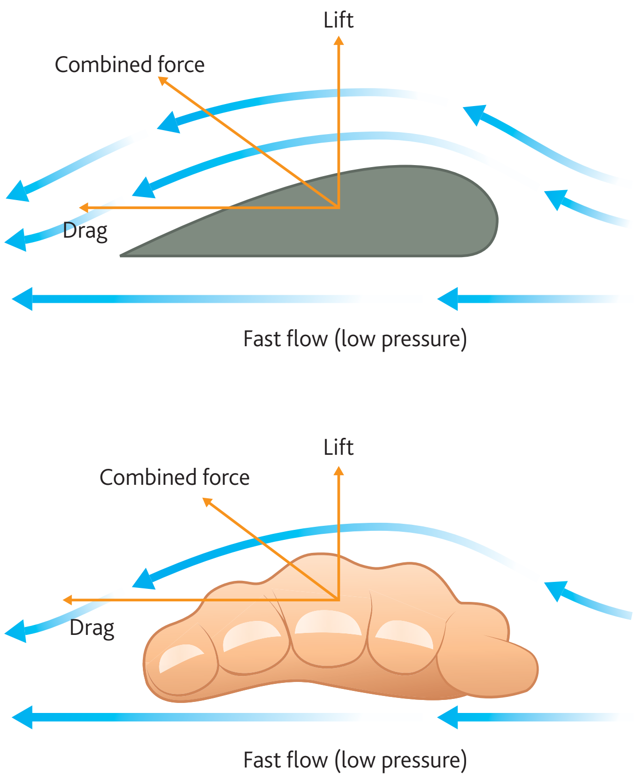

Figure 3.51 Bernoulli's principle is used to explain lift.

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Lift

Lift is the force that allows swimmers to move themselves forward in the water. Bernoulli's principle helps to explain lift—the difference in water pressure on opposing sides of a part of the body (such as the swimmer's hand) acts to propel it forward.

For example, when a swimmer's hands move in a sideways sweeping motion through the water, the flow over the curved knuckle side of the hand is much faster than on the palm side of the hand, as the knuckle side has a much larger surface area. The difference in the speed of the travelling water on the two sides of the hand creates high- and low-pressure systems. A swimmer can manipulate the angle at which they face the curved side of their hand to change the direction of the lift force.

Another example of lift is when performing an eggbeater kick in water polo. Lift force is created as the legs circle under the water, creating pressure differences between the top and bottom of the leg and foot. The lift force acts to push the athlete upwards. Similarly, synchronised swimmers are able to support themselves in the water with the continuous sculling action of their hands. The flow of water over the hands creates a lift force that pushes the swimmer to the surface.

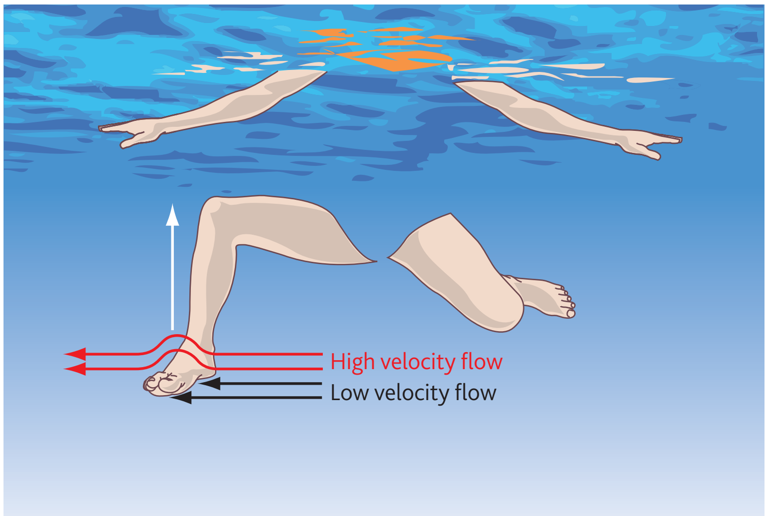

Figure 3.52 The eggbeater kick is often used in water polo to create lift.

Drag

We usually understand **drag** as the resistance to movement that acts on a body or object as it moves through a fluid—water or air. It is the force that opposes movement. Drag is sometimes simply called fluid resistance. Fluids have an inertia—a resistance to motion—that swimmers have to work against to propel themselves through the water. This resistance to being pushed aside to allow the swimmer's body to move through the water is one element of drag. Swimmers try to minimise this effect of drag by using skills such as streamlining and pitching the entry of their hands to ensure the water surface is cut cleanly.

However, the effects of drag and resistance can also have a positive effect on propulsion and help a swimmer move through the water. It is the combined forces of drag and lift that determine propulsion.

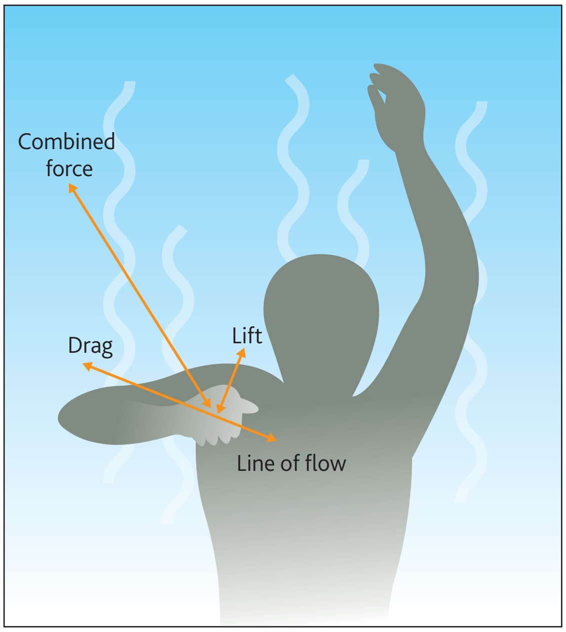

Figure 3.53 The combined forces of lift and drag allow swimmers to propel themselves through the water.

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To understand the effects of drag on a swimmer, let's look at its effects on a swimmer's arm as it moves through the water. A swimmer's arm goes through five stages: the pitch (entry), catch, pull, push and recovery. During the catch phase, swimmers pull (or push, in the case of butterfly) their hand back towards their body. Water builds up on the palm side of the hand, leaving a cavity on the knuckle side that water rushes into. The trapped water molecules on the palm side of the hand create a high-pressure zone. Conversely, the water that rushes past the hand and into the cavity on the knuckle side moves at a high speed, creating a low-pressure zone. In the same way that water flows from high- to low-pressure zones, the hand, which is caught between pressure zones, is sucked into the low-pressure zone on the knuckle side of the hand, which allows the swimmer to exert a holding or grabbing force on the water, from which they can pull and push themselves past.

This suction effect is what differentiates drag force from lift force.

Which swimming stroke is your strongest? What are the relative contributions of drag and lift in that stroke?

Fluid resistance

Swimming is a relatively unnatural action for humans; our body shape, body density and surface (skin) make us inefficient swimmers when compared with water animals.

Our ability to propel ourselves through the water is significantly reduced by three types of resistance: **skin resistance**, **turbulence resistance** and **wave resistance**. Before looking at these concepts, it is important to become familiar with the following terms:

- **water displacement**—the shifting or spreading of water in order for an object to move through it
- **laminar flow**—smooth-flowing water of a low pressure
- eddies—water that is moving in a different direction from the main current, usually in a circular whirlpool motion
- **streamlining**—the act of making the body as 'thin' as possible, reducing the amount of surface area displacing the water

How do you streamline your body when swimming? How do you lift your head when you have to breathe? What phases of your stroke could be better streamlined?

Skin resistance

When a swimmer moves through the water, the fluid that comes in direct contact with their body forms what is called a boundary layer. This layer of fluid grips on tightly and interacts with the next layer of water, and so on, creating a frictional force that resists forward movement. There is very little that humans can do to reduce skin resistance other than keep their skin smooth and wear tight-fitting swimwear.

Turbulence resistance

Undisturbed water has a laminar flow, which is disrupted when a swimmer moves through it. As this occurs, a high-pressure zone develops in front of the swimmer where some of the water accumulates. In addition to this build-up at the front, some of the displaced water slips past the swimmer, crashing into the space the swimmer has just left and creating a low-pressure wake full of eddies behind the swimmer. As water flows from high- to low-pressure zones, the pressure differential causes a suction effect, which resists forward motion.

Turbulence resistance is often referred to as profile drag, because swimmers' profiles (shape in the water) determine the amount of turbulence they create. If a swimmer is streamlined—with their hands, shoulders, hips, knees and feet aligned—a relatively small amount of water will be displaced; this, in turn, will minimise the suction effect. On the other hand, when swimmers' techniques are inefficient—with the hips, knees and feet sinking—more water is displaced in front of them; this increases the eddies formed and the suction effect.

For example, in breaststroke it is essential that swimmers avoid drawing their knees up towards their chest during the kicking action, as doing so increases their profile through the water and results in increased resistance.

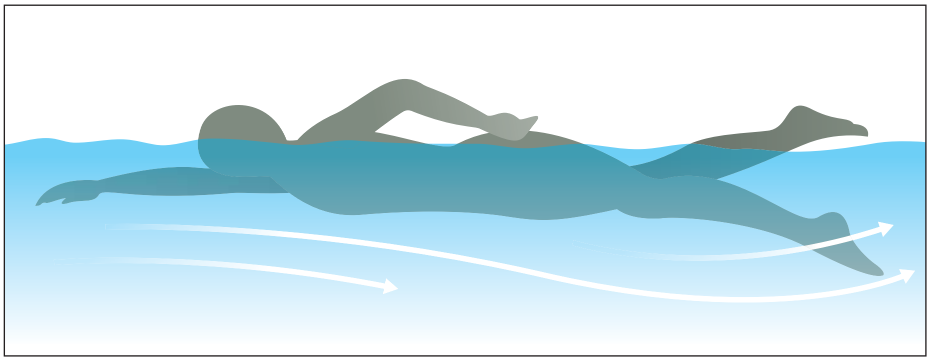

Figure 3.54 To minimise turbulence and resistance, good swimmers streamline their bodies in the water.

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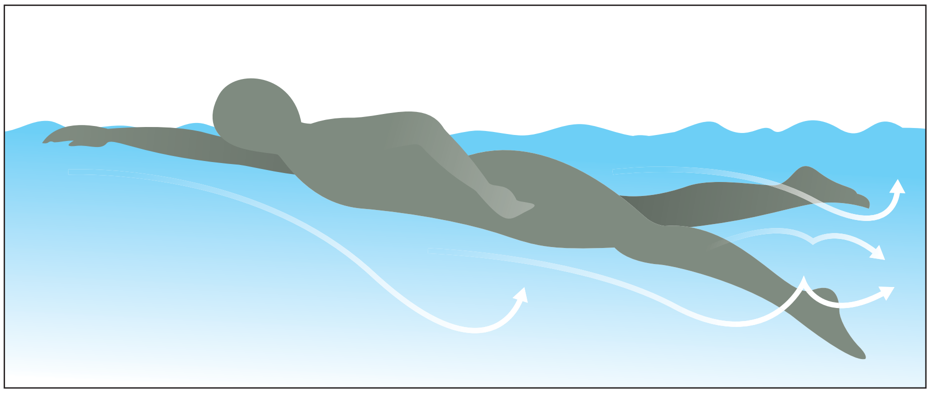


Figure 3.55 A bigger profile in the water displaces more water and results in greater resistance.

Wave resistance

When a swimmer moves through the water, waves build up in front of them, creating a high-pressure swell that exerts a resistance. This wave is often referred to as a wall of water that acts to block the swimmer's path.

The faster a swimmer travels through the water, the larger the wave generated and the greater the resistance. With speed, the second factor that increases the size of the wave formed is the amount of water being displaced. It is essential, therefore, to use streamlining techniques to displace less water when moving at high speed.

ACQUIRE

1 What determines whether an object will float or not?
2 Why does a shot-put sink when thrown in a pool when a rubber ball floats?
3 What does Bernoulli's principle explain?
4 What forces are at work when a swimmer moves through the water?
5 What is drag also known as?
6 List reasons why humans are inefficient swimmers when compared with water animals.

The principles of fluid mechanics and performance

The scientific study of the principles of fluid mechanics has influenced the performances of our elite athletes. Science has influenced the design of sports clothing, equipment and competitions, and changed training techniques.

In swimming, controversy has surrounded the use of fast skin swimsuits and the number of world records that have fallen since they were first introduced. The suits' revolutionary design decreased drag, increased buoyancy and resulted in an unprecedented improvement in performance for elite swimmers. After the 2008 Olympic Games, the international swimming body, FINA, investigated and regulated the use of high-tech suits to ensure the technology provides no unfair advantage.

The focus of training for elite athletes has changed too. Athletes can spend as much as 50 per cent of their time refining the technical aspects of kicking, pulling, breathing and positioning the body to try to reduce drag, maximise lift and move more efficiently. The ability to video and analyse stroke count, splits, turns and take-offs has resulted in athletes developing a better understanding of the relationship between force and their own performance.

Swimming pools and equipment have also changed to counteract the negative effects of fluid mechanics, such as preventing excessive wave motion. Olympic pools are now ten lanes wide, keeping the two outside lanes free. Pool edges feature gutters that are flush with the water surface, and the plastic buoys that divide lanes are designed to direct water downward and not outward.

Figure 3.56 Australian swimmer Stephanie Rice models the Speedo LZR Racer bodysuit at the Sydney launch.

NEWS

Swimmers happier in someone else's skin

The body parts that make up men and women are a real drag for elite swimmers, slowing their performances by fractions of a second.

'This especially applies to girls,' said Bruce Mason, a biomechanist at the Australian Institute of Sport in Canberra and consultant to swimsuit manufacturer Speedo.

'The fat layer of the leg moves like a wave down their leg. One of the things the suit is intended to do is cut that movement down to avoid the drag,' Mason said of the new Speedo bodysuit that's causing ripples in swimming circles.

Very simply, drag occurs when the water grabs swimmers, slowing them in their progress. It's caused by the surface of the swimmer—their skin or the material of their swimsuit—and their shape.

That's why the LZR Racer suit was designed to compress bulging groins, breasts, legs and abdomens. Internal panels streamline a swimmer's shape and built-in stabilisers act like a corset to keep a swimmer in a more efficient position during a race.

Speedo claims its paper-thin designer fabric cuts surface drag. So too does the orientation of seams, to follow the contours of the body, which are bonded smoothly to the fabric. The zip is also bonded to the suit to streamline the swimmer's shape.

Mason agreed that seams were important because they increase turbulence and, therefore, drag if they cut across the flow of water.

But as Tim Langrish, a Sydney University engineer with expertise in fluid dynamics, noted, no matter how good a suit looks technically, swimmers must be able to wear it and swim in it.

'It's a trade-off between physics and biology,' Langrish said.

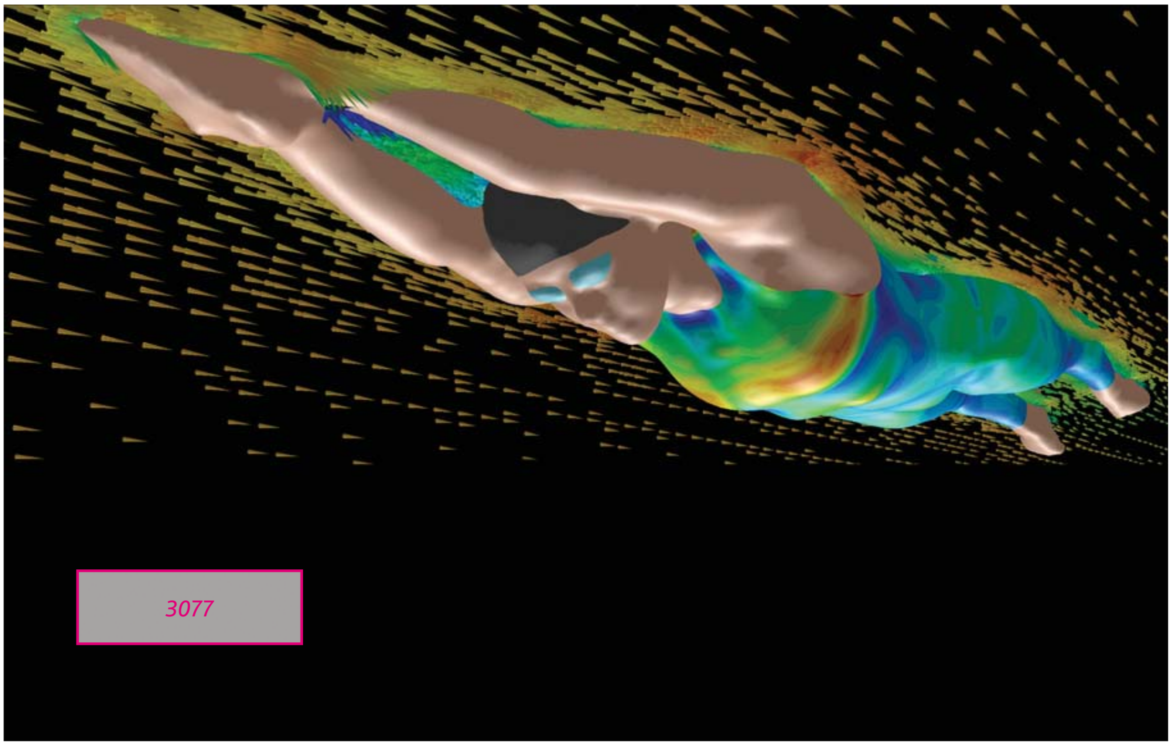


Figure 3.57 The new fast suits dramatically improve streamlining.

Swimmers happier in someone else's skin (*cont ...*)

According to Mason, that was precisely the problem with prototypes of the new supersuit. After testing the fabric, running computer simulations and trialling the suits with mannequins pulled through the water, Speedo asked the Australian Institute of Sport to put them on human swimmers.

'We discovered problems,' he said.

'If (the suit) restricted movement around the shoulders, reducing drag, it also reduced the ability to increase propulsion.

'It's also no good being so tight, it takes two hours to get into ... these are the trade-offs. That's why it takes so long to develop (a suit).'

But the results, Speedo claims, offer a winning edge over previous high-performance suits, reducing drag, increasing turning, sprinting and start times, and enhancing oxygen flow, so-called venous return.

While uncertain of the suit's impact on venous return, Mason said the suit definitely affected something vitally important—attitude.

'Psychologically, a swimmer has on something new,' he said.

'They're performing with something different and they believe that something will give them an advantage.'

As a sponsor of Australia's swim team, Speedo has provided about 120 Olympic hopefuls with this advantage. The remaining stock is on sale to the public for $800 each.

Australia's head swimming coach, Alan Thompson, believes the spate of world records, which are being attributed to the new technology, has just begun as other leading countries prepare to hold their Olympic trials.

Thompson does not credit the fast times to the new swimsuits despite thirteen world records in six weeks since they were launched.

'We are having great performances here (at the Australian Olympic Team Swimming Trials) and, in Europe, we saw a lot of world records broken over the last six days, Thompson said.

'I think it's a great performance of swimming and I think we have more to look forward to ... this is the Olympic year and that's what we expect.'

Source: Leigh Dayton and Nicole Jeffery, *The Australian*, 26 March 2008

Have you ever competed in a swimming race? Would it be fair if some competitors could afford high-tech swimsuits and others could not?

APPLY AND EVALUATE

1. The tumble turn is used by all competitive swimmers as it is more effective than the basic 'touch and turn' method. One of the major reasons for its effectiveness is that it allows the swimmer to turn well under the surface of the water.
   Use your understanding of wave resistance to explain why a swimmer can significantly reduce their turn time using a tumble turn.
2. With a partner, select one of the sports in Table 3.2 (page 118) and explain how each of the selected biomechanical principles applies.
3. Suggest biomechanical reasons why swimming world records seem to be being broken at an ever-increasing rate.

Table 3.2—Biomechanical principles, as they *most dominantly* relate to individual sports

		Volleyball	Softball	Swimming	Golf	Athletics			Tennis	Gymnastics
						Track	Throws	Jumps		
Motion	Linear (rectilinear) motion	✓	✓	✓		✓		✓	✓	✓
	Curvilinear motion			✓						✓
	Velocity and speed		✓	✓		✓		✓		✓
	Acceleration		✓	✓		✓		✓		✓
	Newton's first law of motion—inertia	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Newton's second law of motion—acceleration	✓	✓		✓		✓		✓	
	Newton's third law of motion—action and reaction	✓	✓	✓	✓	✓	✓	✓	✓	✓
Balance and stability	Base of support	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Centre of gravity	✓	✓	✓	✓	✓	✓	✓	✓	✓
Force	Force production	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Summation of forces	✓	✓	✓	✓		✓		✓	✓
	Momentum		✓	✓		✓		✓		✓
	Transfer of momentum	✓	✓		✓		✓	✓	✓	✓
	Impulse	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Absorbing force	✓	✓						✓	
	Accuracy	✓	✓		✓		✓		✓	
Rotary forces	Concentric and eccentric forces	✓	✓	✓	✓				✓	✓
	Rotational momentum	✓		✓		✓	✓		✓	
	Conservation of rotational momentum									✓
	Centripetal and centrifugal forces					✓	✓	✓		✓
	Levers	✓	✓	✓	✓		✓		✓	
	Sweet spot		✓		✓				✓	
Projectile motion	Angle of release		✓		✓		✓			
	Height of release		✓		✓		✓			
	Speed of release		✓		✓		✓			
	Fluid resistance (air)	✓	✓		✓		✓		✓	
	Magnus effect	✓	✓		✓				✓	
Fluid mechanics	Buoyancy			✓						
	Centre of buoyancy			✓						
	Propulsion			✓						
	Fluid resistance (water)			✓						

Note that most biomechanical principles relate to most sports. This table shows only the most relevant and strongest links.

03: SUMMARY

- Biomechanics is the study of the body as a machine.
- Linear (or rectilinear) motion occurs in a straight line; curvilinear motion follows a curved path.
- Speed describes only how quickly the body is moving; velocity describes both how quickly and in which direction.
- Newton's laws of motion explain that:
  - a still object continues to be still, and a moving object continues to move in the same direction at its current velocity, unless an external force acts on the object
  - the sum of the force that moves an object is equal to the object's mass multiplied by the acceleration
  - for every action, there is an equal and opposite reaction.
- Balance and stability are related to the base of support and centre of gravity.
- Force is anything that causes or has the potential to cause or change movement.
- The summation of force principle explains that the force produced during the movement of one body segment will be added to the force produced by the next body segment, and so on.
- Rotary forces are forces that cause an object to turn or rotate.
- A force that produces a rotating or twisting motion is known as torque.
- Every lever has a point at which force (or power) is applied, a point of resistance and a fulcrum (or axis).
- The flight of a projectile is influenced by the angle of release, height of release and speed of release.
- Fluid mechanics is used to explain the forces of buoyancy and propulsion.

NOW THAT YOU HAVE FINISHED ...

1. Define biomechanics
2. How might the science of biomechanics have influenced the sport you are currently studying?
3. Describe the difference between linear (rectilinear) and curvilinear motion.
4. Explain Newton's three laws of motion. How might they be used to explain the action of a long jumper from the start of the run-up to landing in the pit?
5. Give three examples in athletics of action and reaction forces.
6. Using Newtown's second law, answer the following question. If a 15 newton force is applied to a 1.5 kilogram discus, what is the acceleration of the discus?
7. Discuss how a gymnast's centre of gravity may change throughout a routine.
8. Outline three ways an athlete can maximise force production.
9. Outline three ways the body can apply or absorb force.
10. Explain the difference between concentric and eccentric forces.
11. List the two factors that determine rotational momentum.
12. Identify the principle that causes a rugby union goal-kicker's left arm to rotate forward, across the body when their right foot kicks a ball through the uprights.
13. Explain the term 'sweet spot'.
14. Identify five factors that affect the trajectory of a thrown ball.
15. Explain how you would find a person's centre of buoyancy.
16. Describe the types of resistance that exist in fluid environments.

a ASSESSMENT TASKS

3061

3060

Task 1— Skill acquisition

Genre: Report
Word limit: 800–1000 words

Preamble

The rate of learning can be plotted as a learning curve.

In your study you will create your own learning curve graph, plotting your performance in several skills. You will then evaluate the graph and use it as the basis of a report.

Learning requirements

To successfully complete this task you will need to:

- participate in the physical activity currently being studied
- identify your stage of learning in that activity
- create a learning curve graph to record your learning
- evaluate your learning curve, reflecting on what it means about your progress.

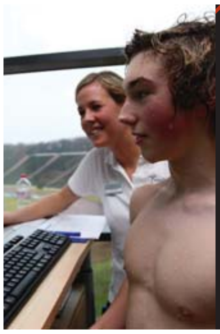
Click to access learning curve templates.

Task

Evaluate your personal learning curve graph and use your findings to write a report in which you *justify* your self-assigned stage of learning. In your report, use your findings to *recommend* appropriate practice methods (including the timing and frequency of training sessions) that will help you to progress in the activity.

Additional information

- You will need to use appropriate headings and subheadings in your report.
- All tables, graphs and other images referred to in the body of your report are to be placed in an appendix.
- You will need to provide a reference list and correctly use in-text referencing to acknowledge the sources of your information.



Task 2— Sports psychology and accountability in team sports

Genre: Essay
Word limit: 600–800 words

Preamble

Every time your team played a match in the round-robin tournament this term, statistics were recorded for a variety of skills. These statistics were collated and you were ranked based on percentages. At the end of the competition, the player with the best aggregate ranking received a reward and public recognition.

Learning requirements

To successfully complete this task you will need to:

- set short-term and progress goals for the unit. Your short-term goals should be what you wish to achieve by the end of the unit. Progress goals should detail each week's desired improvements
- participate in a round-robin competition
- keep a match journal, in which you discuss performance strengths and weaknesses, and the effectiveness of any sports psychology methods used during each match
- record individuals' statistics from every match, documenting the success rate of fundamental skills as a percentage.
- display match statistics so that students are accountable for their performance
- rank students based on overall percentages.

Task

Justify which sports psychology method was most effective to improve your performance. Use publicly displayed statistics and journal entries to support your justification.

Additional information

- You will need to bring in your journal entries, statistics sheets and rankings from the round-robin tournament.

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Task 3—Biomechanical analysis

Genre: Speech and PowerPoint presentation (multimodal)
Time limit: 6 minutes

Preamble

If you can understand how biomechanical concepts interrelate and govern physical activity, you will be better able to analyse your performance and adapt it to improve. You will video your performance and analyse it to determine what modifications need to be made to your technique.

Learning requirements

To successfully complete this task you will need to:

- arrange video recording of the physical activity you are currently studying
- analyse the video footage, using motion-analysis software, if available
- edit the footage (in class).

Task

Evaluate the video footage taken of your performance in your current physical activity and identify one major weakness in your technique. Select two biomechanical principles to *justify* why this is a weakness. *Recommend* a drill that would help to remedy the problem. Explain your findings in a speech, accompanied by a PowerPoint presentation.

Additional information

- Both video footage and stills should be used and referred to during your speech to support your conclusions. Edit footage to include both normal-speed and slow-motion footage to support your points.
- Any video footage and stills used should be embedded in PowerPoint slides.
- Use palm cards when presenting your speech.