INQUIRY QUESTION
How can an understanding of biomechanics help improve sports performance?
Biomechanics is the field of sports science that applies the laws of mechanics and physics to human performance in order to gain a greater understanding of performance in physical activity. It is the study of forces and the effect of those forces on and within the human body.

**KEY KNOWLEDGE**
- Biomechanical principles for analysis of human movement including:
  - angular and linear kinetic concepts of human movement: Newton’s three laws of motion, inertia, mass, force, momentum and impulse
  - angular and linear kinematic concepts of human movement: distance, displacement, speed, velocity, acceleration and projectile motion (height, angle and speed of release)
  - equilibrium and human movement: levers (force, axis, resistance and the mechanical advantage of anatomical levers), stability and balance (centre of gravity, base of support and line of gravity)

**KEY SKILLS**
- Analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills in a coaching context

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**Biomechanical properties**

- Angular and linear kinematics
  - Distance and displacement
  - Speed and velocity
  - Acceleration
  - Projectile motion (height, angle and speed of release)
  - Equilibrium and human movement (levers, stability and balance)

- Angular and linear kinetics
  - Newton’s laws
  - Inertia
  - Mass
  - Force
  - Momentum
  - Impulse
2.1 Introduction to biomechanics

KEY CONCEPT There is a vast array of biomechanical principles that, when understood and applied, can be used to improve movement skills in a coaching context.

There are many ways in which an athlete can gain an advantage over competitors. These include the adoption of appropriate dietary and hydration techniques, using appropriate training and recovery methods, and working with coaches and specialists on acquiring higher levels of skills, tactical nous and mental strength required for optimal performance. Many athletes also analyse their own human movement in order to promote even higher levels of performance. To do so, an understanding of the principles that govern movement is required.

For many years, athletes, coaches and sports scientists have applied biomechanical principles to analyse human movement. The term biomechanics is derived from the Ancient Greek terms bios meaning ‘life’ and mechanike meaning ‘mechanics’.

It refers to the study of the mechanical principles that govern human movement. In exercise, play, recreation and sport, biomechanics contributes to the description, explanation and prediction of movement. Biomechanical principles are also used to determine optimal techniques in sport, with the aim of optimising human performance, in addition to developing and sustaining healthy movement patterns.

This chapter explores a range of biomechanical principles used for analysis of human movement. Working through this chapter you will learn about a branch of biomechanics called kinetics, which is the study of the forces that cause motion and also the forces resulting from motion. Forces cause changes in motion and a change in motion cannot occur without force. Forces cannot be created unless two or more bodies interact. Another branch of biomechanics called kinematics is the study of movement with reference to time, distance, displacement and velocity.

In the study of biomechanics, it is also important to look at the relationship between equilibrium and human movement, focusing on the use of levers and study of stability and balance.

Biomechanics is the study of the mechanical principles that govern human movement.

Kinetics is the study of forces that cause motion.

Kinematics is the description of motion.

TEST your understanding
1. What does the term ‘biomechanics’ refer to?
2. Explain the benefits to coaches and athletes of having an understanding of biomechanical principles.

APPLY your understanding
3. There are two main branches of biomechanics. Name these and explain the differences between them.
A key branch of biomechanics, referred to as kinetics, involves the study of the forces that contribute to motion. The term **motion** refers to a body’s change in position in relation to time. Motion is typically described as linear or angular (or a combination of these) and relates to both living (animate) and non-living (inanimate) bodies. A human body or body segments are both animate bodies, while a baseball is an example of an inanimate body.

**Linear motion**, also commonly referred to as translation, takes place either in a straight line or curved path. Movement in a straight line is referred to as rectilinear motion, where all parts of a body travel the same distance, in the same direction, at the same time. Movement over a curved path is referred to as curvilinear motion.

**Angular motion**, also commonly referred to as rotation, occurs when a body moves along a circular path at the same angle, in the same direction, at the same time. Angular motion occurs around some type of axis, which can be either external or internal. An example of an external axis in sport is a gymnast rotating around a high bar, while an internal axis would be a joint in the body around which a body part rotates.

**FIGURE 2.2** A gymnast rotating around a high bar would be using an external axis to promote angular motion.

In sport, true linear motion is rarer than angular motion, as movement is typically generated by angular motion of body parts or equipment. Far more common, however, is the combination of the two types of motion, referred to as general motion. An example of general motion is the running in a straight line seen in a 100-metre sprint caused by the angular rotation of the arms and legs.
Understanding angular and linear kinematic concepts of human movement

There are a range of angular and linear kinematic concepts of human movement. These include the concepts of:
- mass
- inertia
- force
- momentum
- impulse
- Newton’s three laws of motion.

Mass

The term mass is used to described the quantity of matter found within a particular body. Mass is typically measured in kilograms. A person with a large mass is composed of large quantities of matter, while a person with a small mass is composed of a small quantity of matter. There is a direct relationship between the amount of mass and inertia. A ball with a small mass has less inertia and therefore is easier to move than a ball with large mass and large inertia. Similarly, once moving, the ball with large mass and inertia will be much more difficult to slow down or stop than the ball with small mass and small inertia. Think of the challenges if you were asked to both throw and catch a shotput instead of a tennis ball.

Inertia

Inertia is a term that describes the reluctance of a body to change its state of motion and, as highlighted in the section on mass, the terms mass and inertia are closely linked. This includes a body at rest reluctant to move, and a body moving reluctant to change its direction or velocity. Examples of static inertia include the reluctance of a heavy piece of sports equipment to be moved, such as a barbell with weights on it, or the reluctance of a static wrestler to be shifted from their position in a contest. An example of dynamic inertia is the reluctance of a rugby player running quickly with the ball to be stopped (change of direction and velocity).
Force

Force is an effect on one body that results from the interaction of a second body. Inanimate and animate bodies are either in a state of rest (not moving) or a state of motion (moving). To change the state of a body, a force must be applied to it. A force can have either a pushing or pulling effect on a body with mass, causing it to accelerate (speed up), decelerate (slow down) and/or change direction.

Although forces have the capacity to alter motion, they need to be sufficient enough to overcome the inertia of a body. For example, a heavy barbell on the floor in a weightlifting competition will only be lifted if sufficient force is created to overcome its inertia.

Forces can be defined in relation to the body of interest, as internal (interactions inside) or external (interactions outside). There are different types of internal and external forces that act on bodies. In sport, the force generated by the contraction of
2.2 Using kinetic concepts studied in biomechanics for analysis of human movement

the skeletal muscles would generally be classified as an internal force. External forces include gravity, air resistance and friction.

The unit of force is called the Newton (N). It is the amount of force required to shift a 1 kg mass (1 unit of mass) to accelerate at 1 m/s$^2$ (1 unit of acceleration).

\[ 1 \text{N} = 1 \text{m} \times 1 \text{a} \]

**Momentum**

The term **momentum** describes the quantity of motion a particular body of mass has. It is a combination of mass and velocity: mass (measured in kilograms) multiplied by velocity (measured in metres travelled per second).

This is written as:

\[ \text{momentum (p)} = \text{mass (m)} \times \text{velocity (v)} \]

If an object has zero velocity (not moving), then it has zero momentum. The higher the mass and the higher the velocity, the greater the momentum will be. An example would be to compare athletes running in a 100-metre sprint, as shown in table 2.1. The product of the mass and velocity of the athlete in lane 3 means that he/she would possess the largest momentum of the four athletes.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Athlete’s mass (m)</th>
<th>Athlete’s peak velocity (v)</th>
<th>Athlete’s peak momentum (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80 kg</td>
<td>10 m/s</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>80 kg</td>
<td>9 m/s</td>
<td>720</td>
</tr>
<tr>
<td>3</td>
<td>90 kg</td>
<td>10 m/s</td>
<td>900</td>
</tr>
<tr>
<td>4</td>
<td>90 kg</td>
<td>8 m/s</td>
<td>720</td>
</tr>
</tbody>
</table>

In many ways, the momentum of the athletes above is irrelevant to their performance as the runner simply needs to get to the finish line first to win the contest. However, what if the aim of the competition was to stop each runner from moving when they are at peak (highest) velocity? In this case, the momentum is highly relevant as the athlete with the highest momentum would be the hardest to stop. This would be athlete in lane 3, who has a momentum of 900 kg/m/s due to the combination of high mass and high velocity.

**Conservation of momentum**

Whenever two bodies collide, the combined momentum of the two bodies is conserved (stays the same). This is referred to as the principle of conservation of momentum. An example of this is in ten-pin bowling. The momentum of the bowling ball and pin when combined are the same pre- and post-collision. The bowling ball when thrown has significant momentum due to its combined mass and velocity. The pin, however, has zero momentum due to its zero velocity. Once the bowling ball hits the pin, a significant quantity of momentum is transferred from the bowling ball to the pin, causing the pin to increase in velocity. The bowling ball will reduce its velocity. The combined momentum, however, will be the same.
**Force summation**

The principle of conservation of momentum is important in any sport that requires the transfer of momentum from one body part to another or the transfer of momentum from a body part to an inanimate object such as a ball, bat or racquet. **Force summation** is a vital ingredient of human movement where the correct timing and sequencing of body segments and muscles through a range of motion is evident. Experienced athletes spend countless hours practising the range of movements required in their sport to ensure the desired quantity of force is generated. In many instances, maximal force production is the aim, such as in throwing events like javelin or when kicking a penalty as hard as a player can in soccer. There are, however, many times where sub-maximal force is required, such as putting in golf or taking a free throw in basketball. Controlling the quantity of force generated is therefore often important.

**FIGURE 2.7** A golfer aiming to propel the ball as far forward as possible will aim to apply maximal force when teeing off.

**FIGURE 2.8** Players shooting for a free throw in basketball will only apply submaximal force during a shot.
Simultaneous force summation is the use of multiple body parts at the same time to produce force.

Sequential force summation is the activation of body parts that are used in sequence to produce force.

In some sporting examples, there are times when body parts are moved at the same time to perform an action. This is known as **simultaneous force summation**. Simultaneous summation of force occurs in athletics when a sprinter explosively moves multiple body parts at the same time at the start of the race. Other examples include a long jumper or high jumper propelling their body in the air after a run up.

Far more common in sport is **sequential force summation**, where body parts move in a sequence to produce the desired degree of force. Adopting a technique that enables sequential force summation enables greater force to be developed. Sequential force summation is more successful, and produces the maximal amount of force, if a number of principles are adhered to. These include:

- **Activating the stronger and larger muscles first**
- **Using as many body parts as possible, enabling force to be generated over a greater time**
- **Transferring momentum from one body part to another when at maximum velocity**
- **The presence of a stable base for maximal acceleration of body parts to occur so that momentum can be transferred successfully from one body part to another**
- **Ensuring appropriate follow-through is used to prevent unnecessary deceleration of body parts.**

**Activating the stronger and larger muscles first**

Activating the larger and stronger muscles first enables these muscles to generate a large amount of force that can be passed onto other body parts. These large body parts (with high mass and low acceleration) transfer momentum to smaller body parts (low mass and high acceleration). A golfer teeing off who is trying to hit the ball with maximal force will recruit the larger muscles of the lower body first, followed by the muscles of the torso, then the shoulders and finally the smaller muscles of the arms and hands.

**The use of as many body parts as possible, enabling force to be generated over a greater time**

Greater momentum can be produced by applying force over a longer period of time. By recruiting more body parts in sequence, the total time where momentum can be generated is increased, which can then be transferred to the desired action. Think of two athletes starting a race. Runner A decides to crouch and wait for the starter's gun to be activated, while...
runner B uses blocks. Runner A on hearing the gun pushes back and down to enable the full extension of the grounded leg and subsequent propulsion in the air. The runner would therefore leave the starting line quite quickly. Compare this to runner B who has their legs flexed more significantly at the knee joint. Once the starting gun goes off, the athlete takes longer to push down and back to enable the propelling leg to fully extend, therefore starting the race more slowly. The benefit to runner B, however, is that they are able to generate force over a longer period of time, resulting in greater momentum from the start. All other factors being equal, the runner with greater momentum (runner B) will end up performing better than runner A. For more details, see the section on *impulse* (page xx).

Transfer of momentum from one body part to another when at maximum velocity

If momentum is transferred at the wrong time, performance will be compromised. People often describe athletes with great skill as having terrific 'timing', a term that means that the athlete appears to sequence the movement of body parts just ‘at the right time’. Athletes who do not have good sequencing ability are likely to either transfer momentum from one body part to another too early (before momentum is at its maximum) or too late (when the momentum drops due to a drop in velocity). The correct sequencing and timing of the transfer of momentum is also important when releasing or striking a projectile. A good example is a fast bowler in cricket who has to get their timing right to produce maximal force. If a bowler has too short a run-up, then less momentum is developed by the bowler for transfer to the ball, creating a slower speed of release. The bowler on the other hand who takes too long a run-up will experience a drop in momentum if velocity drops (due to a reduction in the speed of energy supply due to energy system limitations).
A stable base must be present for maximal acceleration of body parts to occur so that momentum can be transferred successfully from one body part to another.

Technique is a vital aspect of a successful motor skill. A stable base must be in place for the development of efficient acceleration of body parts. Think of a golfer who needs to have a strong trunk and torso to enable successful sequencing and timing of the transfer of momentum from one body part to another and then onto the ball. A stable base in this example refers to the player's lower body. Another example is a 100-metre sprinter who has a strong and stable core, where the arms and legs rotate around this base.

Ensure an appropriate follow-through is used to prevent unnecessary deceleration of body parts.

Many younger and inexperienced athletes fail to generate full power during activities that require a transfer of momentum to a projectile. A common reason is the inability to maintain acceleration during a movement. Many slow their movements down either prior to or at the time of impact, resulting in a drop in performance (due to inefficient movement patterns and subsequent drop in the execution of the skill). Athletes in all sports that require successful transfer of momentum are encouraged to ‘follow through’ with their action. This enables the performer to maximise the force generated.

Angular momentum

Like linear momentum, there are some principles that guide our understanding of how momentum is both conserved and transferred when angular motion is involved. Angular momentum is a product of moment of inertia and angular velocity. This can be expressed as:

$$ H = Iω $$

Moment of inertia is a measure of an object’s resistance to change in its rate of rotation. It is based on Newton’s first law of motion, which describes a rotating body or object’s reluctance to change. The moment of inertia is dependent on both the:
- mass of the rotating object or body and
- the distance the weight is distributed from the axis of rotation.

Angular momentum is greater if the mass is larger and the further that mass is distributed from the axis. When rotating a baseball bat, for example, angular momentum can be increased by increasing the mass of the bat, as well as the length of the bat (that increases the distance the weight is distributed away from the axis). The greater the angular momentum, the greater the transfer of momentum to the ball. What each athlete needs to do, however, is to select an appropriate bat to meet the demands of the situation. Generating angular momentum is useless if the speed of the baseball pitch, for example, is too quick for the batter to react. The batter may elect to reduce the weight of the bat to enable it to be swung more quickly, sacrificing overall momentum for increased angular velocity.

Instead of changing bats, there are other ways to alter an object’s moment of inertia. This includes

**Figure 2.12** In this example, angular momentum is a product of the angular velocity multiplied by the bat’s moment of inertia (product of the mass of the bat and the distance the weight is distributed away from the axis).

**Figure 2.13** If the bat is turned around, the mass is closer to the axis (point of rotation; in this example, the wrists). This would reduce the moment of inertia and, in turn, the bat other way around angular momentum.

**Figure 2.14** When running, the angular momentum in each leg is conserved throughout the action. When the leg is bent, the moment of inertia drops but angular velocity in that leg increases to conserve momentum.
altering how the striking implement is held. By holding the striking implement higher up (using the above example, the baseball bat), the moment of inertia is decreased as the distance between the centre of the bat’s mass and axis of rotation is decreased. This is sometimes referred to as ‘choking’ the grip. This technique increases the ability to swing the bat more quickly, due to the drop in inertia. Children will often do this to gain greater control.

Modified equipment is another way of reducing the moment of inertia, promoting the ability to move the equipment with more ease. However, this also reduces the overall angular momentum. Cricket and tennis are two of many examples in which modified equipment is encouraged for ease of use.

**FIGURE 2.15** Once the diver leaves the diving board, angular momentum will be conserved. However, the diver can alter the moment of inertia and angular velocity by moving body parts into different positions. During the tuck, the moment of inertia is reduced significantly, which, in turn, increases angular velocity (degree of rotation) that conserves the momentum. The opposite occurs coming out of a tuck, where velocity decreases due to an increase in the moment of inertia.

**FIGURE 2.16** The baseballer pictured here is maximising the potential to generate angular momentum by ensuring that the bat is held at a point that maximises the moment of inertia.
2.2 Using kinetic concepts studied in biomechanics for analysis of human movement

**TEST your understanding**

1. Explain what the term ‘inertia’ means. Provide one example of static inertia and one example of dynamic inertia in a sporting context.
2. Describe the difference between animate and inanimate objects.
3. List four sequential force summation principles that should be adhered to so that maximum force production can occur.
4. Write the formula for angular momentum.

**APPLY your understanding**

5. For the following biomechanical terms, provide the symbols used for each listed; momentum, force, velocity and acceleration.
6. An athlete who has a mass of 75 kg reaches a peak velocity of 4 m/s during a 400-metre run. What is their peak momentum?
7. The table below shows some data relating to the mass and velocity of two athletes in a sprint.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Athlete’s mass (m)</th>
<th>Athlete’s peak velocity (v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 kg</td>
<td>8 m/s</td>
</tr>
<tr>
<td>2</td>
<td>60 kg</td>
<td>7 m/s</td>
</tr>
</tbody>
</table>

Calculate each athlete’s peak momentum during the sprint, highlighting whether the athlete in lane 1 or lane 2 generates the most.

8. A rugby player receives a pass from a team mate while stationary. Immediately after receiving the ball, he is tackled by an opposition player. Explain, using the principle of transfer of momentum, what would happen next.

9. **Practical activity**
   As a class, each complete six discus throws, three using the standing throw and another three using the one-and-a-half turn technique. Measure each throw and come up with a class average for each type depicted.

**EXAM practice**

10. Draw on a graph the flight path (trajectory) of an optimal throw for distance, where the release height and landing height are the same. You need to:
   - draw and label both the x- and y-axis
   - draw the shape of the flight path
   - label the angle of release.
Isaac Newton first compiled his three laws of motion in 1687. These laws describe the relationship between a body and the forces acting upon it. They also explain how these forces affect the motion of a body as a consequence.

**Newton's first law of motion**

Newton's first law of motion is commonly referred to as the law of inertia. This law states that:

‘An object will stay at rest or continue to travel in the same direction at a constant velocity unless acted on by an unbalanced force.’

In other words, objects will not move from their state of being unless forces acting on them become unbalanced. This can be referred to as a body having uniform motion. To shift from a state of uniform motion, a force must be applied to disrupt the balance and hence accelerate an object. The higher the mass of a body, the greater the inertia and therefore more force is required to overcome this inertia. This is true both for objects that are static and those that are moving.

**Newton's second law of motion**

Newton's second law of motion states that:

‘The rate of acceleration of a body is proportional to the force applied to it and in the direction in which the force is applied.’
From a mathematical point of view, this presents as force = mass × acceleration or $F = ma$.

Force therefore is a product of mass and acceleration. To produce maximal force, mass and acceleration should be at their highest. Think of a baseball bat. The higher the mass and the more it is accelerated, the higher the overall force that can be transferred to the baseball. However, from a practical perspective, athletes need to find a balance between mass and acceleration. Using the same example, it is counterproductive to select a very heavy baseball bat if the person swinging it cannot accelerate it quickly enough to hit the ball. There is an inverse relationship between the mass of an object and its acceleration, using the formula $F = ma$. This means that as mass is doubled, the acceleration is halved with the same amount of force generated, and conversely, when the mass is halved, the acceleration is doubled.

Newton’s third law of motion

Newton’s third law states that:

‘For every action, there is an equal and opposite reaction.’

To elaborate on this point, this law means that when one body applies a force against a second body, the second body applies an equal force in the opposite direction on the first. Consider the same individual jumping three different times. If the individual aims to jump directly in the air and land on the same spot, then in order to go directly up, the force must be applied directly down. In the second jump, the athlete aims to propel themselves up and forward. To do this, the force must be applied down and back. In the last jump, the person wants to jump up but backwards. The force to enable this jump to succeed is to push down and forward. In all three jumps, the magnitude (size) of the force dictates the force applied back to the person jumping. The greater the force, the greater the propulsion.

Consider other examples in sport. A basketball hitting the backboard at an angle bounces off on an angle with similar force to that with which it was thrown. A
soccer player aiming to move sideways to their left to change direction must apply a sideways force to their right. Again, the greater the force applied to the ground (action), the greater the force that the ground applies back to the soccer player (reaction).

Looking at Newton’s third law in isolation tends to be confusing. This is because the effects of these equal and opposite forces are visibly very different. The ground clearly doesn’t move but the person jumping does. The basketball clearly rebounds off the backboard but the backboard doesn’t visibly shift. Newton’s second law helps explain this phenomenon. In the case of the individual jumping, the force applied (in accordance with Newton’s second law) by the individual is their mass multiplied by their acceleration \( F = ma \). The earth responds with the same force. Considering the enormous mass of the earth, its acceleration is miniscule (so tiny it is not detected by the human eye).

In the other example, where the basketball hits the backboard and bounces off, the backboard can be shifted if the force of the ball is strong enough. In this case, you may see or hear the backboard move (accelerate from a stationary position). Due to its higher mass than the basketball, its acceleration will be much smaller than that observed in the basketball.

**Impulse**

There is an impulse-momentum relationship that can be described by the formula:

\[
\text{Impulse} = \text{force} \times \text{time} \quad \text{or} \quad \text{Impulse} = F \times t
\]

The greater the impulse, the greater the momentum generated. For this to occur, the force (via a combination of mass and acceleration) should be applied over the longest period of time. The term ‘time’ in this formula refers to the length of time force is applied to an object. An example of the impulse-momentum relationship includes when a tennis player uses a racquet with loose strings instead of very tight strings. When a tennis ball hits a racquet with tight strings, the amount of time the ball is in contact with the racquet is quite small. However, when hitting looser strings, the ball stays in contact for a longer period of time, resulting in greater impulse and subsequent momentum. Other sports such as throwing and racquet activities utilise techniques and equipment that increase the impulse.
2.3 Newton’s laws of motion

Impulse can also be used to absorb force over a longer period of time to reduce the impact. Examples of equipment being used for this purpose include high jump mats and cricket pads. Techniques can also be adopted to use the principle of impulse to absorb force over time. If a person receives a catch over a period of time, the force is absorbed over a longer distance, over a longer time. This is generally done by bending the elbows and moving the arms in the direction that the ball is travelling rather than keeping the arms straight.

TEST your understanding

1. Name the Newton’s law that is often referred to as The Law of Action and Reaction.
2. According to Newton’s second law, the force produced is a product of what two variables?
3. A bike rider quickly puts on their front brake to avoid a collision but, as the bike slows down, the cyclist is thrown over the handlebars and becomes airborne. Explain, using Newton’s first law, why this occurs.
**APPLY your understanding**

4. There are two wrestlers, one with a larger mass than the other. Explain, using Newton’s first law of motion, why the wrestler with the larger mass would be harder to move than the wrestler with smaller mass, all other factors being equal.

5. Explain how impulse can be used for success in sport.

6. **Practical activity**
   As a class, each complete six discus throws, three using the standing throw and another three using the one-and-a-half turn technique. Measure each throw and come up with a class average for each type depicted.

Discuss the results in relation to the impulse-momentum relationship.

**EXAM practice**

7. (a) Explain what is meant by the term ‘Newton’s third law of motion’.
   (b) Using Newton’s third law, explain how a runner can propel themselves forward and up during a race.
2.4 Using kinematic concepts studied in biomechanics for analysis of human movement

**KEY CONCEPT** Kinematic biomechanical concepts can help analyse human movement.

**Displacement** is the difference between the initial position and final position of an object.

Kinematics is the study of movement with reference to time, distance, displacement and velocity. It studies things such as how fast bodies move and how far bodies move, without being interested in what causes these objects to move the way they do (covered by kinetics). By using kinematic concepts, coaches and athletes can better understand human movement and develop techniques to maximise performance.

**Linear distance and displacement**

Although distance and displacement measure the extent of motion of a body, there are significant differences between these two terms in biomechanics. Distance refers to how much ground an object travels throughout its motion, while displacement refers to an object’s overall change of position from one point in time to another. An example outlining the difference between distance and displacement is the difference in distance and displacement in the following swimming events: a 50-metre swim where a swimmer starts at one end of the pool and finishes at the other end, and a 100-metre swim where a swimmer starts at one end of the pool, swims to the other end, turns around and swims back to the starting position.

<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Total distance travelled</th>
<th>Total displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-metre swim</td>
<td>Swim from one end of a 50-metre pool to the other</td>
<td>50 metres</td>
<td>50 metres</td>
</tr>
<tr>
<td>100-metre swim</td>
<td>Swim from one end of a 50-metre pool to the other, turn around and swim 50 metres back to starting position</td>
<td>100 metres</td>
<td>0 metres</td>
</tr>
</tbody>
</table>

Even though the second swimmer covered 100 metres in total, the displacement was 0. Another way to understand displacement is to ask ‘how far out of place’ an object is from one point in time to another. Seeing that the swimmer was in the same position between start and finish of the 100-metre swim then they were ‘not out of place’.

Consider another example. The same swimmer completes the first 50 metres, turns around and can only complete 30 metres before having to stop. The accumulated distance travelled is 80 metres. What is the displacement? To calculate this, you need to consider how far the person is away from the original starting position. In this instance, they are 20 metres away from the starting position, therefore they are 20 metres out of place between start and finish. Hence the displacement is 20 metres.
Angular distance and displacement

The concepts covered in the section on linear distance and displacement can be transferred to angular motion. When a body rotates from one position to another, it experiences angular motion. The angular distance is the total of all angular changes that result from an object or body part angle between the starting and finishing position. Consider the example of a ten-pin bowler swinging their arm during the bowling action. If the bowler moves their arm two-thirds of a full rotation (a full rotation is 360 degrees), the angular distance covered would measure 240 degrees. The angular displacement, however, is the difference in degrees between the object or body part's initial and final positions. It is measured by the smaller of the two angles. In this particular example, the angular displacement would be 120 degrees. Angular displacement has both size (magnitude) and direction. Typically, clockwise movements are referred to as positive and anti-clockwise as negative.

Note there are typically three units used to measure angular motion. These include revolutions (one revolution is a full circle), degrees (where 360 degrees is a full circle) and radians. Although commonly used in engineering and physics, the degree is a more common way it is measured in sports coaching and biomechanics.
Linear speed and velocity

Similar to distance and displacement, speed and velocity are common terms used interchangeably to describe the rate with which an object moves from one location to another, but are in fact not the same.

The average speed of a body refers to the distance covered divided by the time taken. The velocity formula for this is represented by:

\[ S = \frac{l}{t} \]

Where:
- \( S \) = speed
- \( l \) = length of path (distance)
- \( t \) = time

Velocity however measures the displacement an object experiences over time. The formula for this is represented by:

\[ V = \frac{d}{t} \]

Where:
- \( V \) = velocity
- \( d \) = displacement
- \( t \) = time

Using the example of the distance and displacement of the 50-metre and 100-metre swimmers, we can see the differences in speed and velocity of the swimmers in these two events.

<table>
<thead>
<tr>
<th>Swim event metres (m)</th>
<th>Description</th>
<th>Total distance travelled (l)</th>
<th>Total displacement (d)</th>
<th>Time of swim (t)</th>
<th>Average speed ( S = \frac{l}{t} )</th>
<th>Average velocity ( V = \frac{d}{t} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Swim from one end of a 50 metre pool to the other</td>
<td>50 metres</td>
<td>50 metres</td>
<td>25.00 seconds</td>
<td>2 m/s</td>
<td>2 m/s</td>
</tr>
<tr>
<td>100</td>
<td>Swim from one end of a 50 metre pool to the other, turn around and swim 50 metres back to starting position</td>
<td>100 metres</td>
<td>0 metres</td>
<td>50.00 seconds</td>
<td>2 m/s</td>
<td>0 m/s</td>
</tr>
</tbody>
</table>
Angular speed and velocity

The term angular speed refers to the angular distance covered divided by the time taken. For example, a rotating object that completes two full revolutions (full circles) per second would have an angular speed of 720 degrees per second (360 degrees × 2).

The angular velocity is measured by dividing the angular displacement by the time taken.

Written as a formula:

\[ \omega = \frac{\theta}{t} \]

\( \omega \) = angular velocity = initial angle – final angle / time (and specifying the direction)
\( \theta \) = angular displacement
\( t \) = time

Linear acceleration

Another key kinematic concept is that of acceleration. Acceleration refers to the rate of velocity change experienced by an object over time. This is represented by the following formula:

\[ a = \frac{v_f - v_i}{t} \]

\( a \) = acceleration
\( v_f \) = final velocity
\( v_i \) = initial velocity
\( t \) = time

If the velocity increases over the period of time measured, then the object will experience acceleration that is positive; that is, it speeds up. If the velocity doesn’t change over time, then the body will be travelling at the same velocity and therefore zero acceleration occurs. If the final velocity is slower than the initial velocity, the object is said to have negative acceleration. It is normal for the term ‘deceleration’ to be used to describe this.

An example of an athlete experiencing positive, zero and negative acceleration during an event is a 100-metre runner. When watching a 100-metre sprint, the observer sees the athletes explode from the blocks and accelerate to maximum velocity to compete for the win. The reality however is that the athlete does indeed accelerate but typically reaches maximum velocity at approximately the 40- to 50-metre point in the race, where the same velocity is held (zero acceleration), but will decrease their velocity to varying degrees over the last half of the race, experiencing negative acceleration (deceleration) during this time.
Gravity exerts downward forces and therefore can influence an object’s acceleration as it moves through the air. The size of the acceleration due to gravity is about 9.81 m/s$^2$.

**Angular acceleration**

The angular acceleration is the rate of change of angular velocity (final velocity – initial velocity) over time. 

\[
\alpha = \frac{\omega_f - \omega_i}{t}
\]

- $\alpha$ = angular acceleration
- $\omega_f$ = final velocity
- $\omega_i$ = initial velocity
- $t$ = time

A gymnast rotating around a high bar who speeds up from 100 degrees/s to 300 degrees/s in 0.5 seconds has an angular acceleration of 400 degrees per second. This is written as:

\[
\alpha = \frac{300 \text{ degrees/s} - 100 \text{ degrees/s}}{0.5 \text{ s}} = 400 \text{ degrees/s}^2
\]

**Projectile motion**

As soon as an object or body is released into the air, it becomes a projectile and is automatically under the influence of two external forces, gravity and air resistance.

Air resistance is a force working against motion. It acts horizontally on a projectile as it moves through the air. Drag forces are created which then cause the projectile to slow down and reduce its flight time and the resultant distance it travels. There are many factors that impact on the amount of air resistance a projectile experiences. (Note that air resistance also acts on other bodies that are not airborne, such as bike riders and skaters).

The following factors influence a projectile’s motion:

- velocity; the higher the velocity, the greater the air resistance
- mass; the lower the mass, the greater the air resistance
- shape; objects considered streamlined will experience less air resistance than those that are not. Streamlined shapes allow air to flow over them with less drag.
- surface area; the greater the surface area, the greater the air resistance. The surface area refers to the area of an object which is exposed to the air. A good example of an object that has significant surface area exposed to the air is a badminton shuttlecock.
- nature of the surface area; smooth surfaces decrease drag and are therefore less affected by air resistance, while rough surfaces are slowed more readily.

**FIGURE 2.28** A badminton shuttlecock has many openings and gaps to help create a large surface area that air can act against.
Gravity acts against motion by pulling the object back towards the ground, acting as a vertical force on a projectile. In addition to the external forces that determine the flight path (trajectory) of a projectile, so do a number of other factors such as speed of release, angle of release and height of release.

**Speed of release**

The force applied to the projectile will have a large impact on its motion. The force can vary in amount as well as its direction of application. The greater the
force applied to the projectile, the greater the speed and the further it will travel, all other factors being equal. A technique to increase force is to use as many body parts as possible; for example, a bowler in cricket (as discussed in the section on summation of forces).

**Angle of release**

In most sporting situations where maximal distance of a projectile is desired, there needs to be an optimal angle of release, to minimise the effects of both gravity and air resistance. In these instances, the desired angle of release is 45 degrees. Any deviation from this optimal angle (above or below) will result in reduced distance.

Some sporting situations require that the angle of release will be higher or lower than 45 degrees. For instance, in events where the ideal trajectory (flight path of the projectile) is low, then the angle of release will be well below 45 degrees. An example would be a tennis forehand from the baseline where the ball should be kept as low as possible when going over the net. The opposite would occur in a volleyball dig, where the aim is to achieve height so the ball reaches a player's teammate with height. The angle of release therefore should be higher than 45 degrees.

A person can easily alter the angle of release by moving body parts in different ways. In a sport such as golf, there are special clubs designed for different purposes. A putter, designed to release the ball to travel along the ground, is flat and therefore the ball comes off the face of the club at 0 degrees. Other clubs such as a 3-iron release the ball at about 23 degrees, while a sand wedge is closer to 55 degrees.

The human body can be manipulated to change the angle of release. Consider an Australian Rules footballer kicking the ball as far as they can. Their leg will be positioned at such an angle to maximise distance, aiming for a release height of approximately 45 degrees. Compare this to a player kicking a short pass where the aim is to get the ball to a teammate with a flatter trajectory. The leg will be positioned so the release angle is much lower than 45 degrees.

**FIGURE 2.31** The optimal angle of release is determined by the needs at any given time. This graph shows some examples of typical angles of release that would be deemed ideal in a variety of contexts.
Height of release

Another factor which may affect the distance a projectile will travel is the height of release. If the angle and speed of release are constant, an object released from a higher point will travel further than one released from a lower level. A taller athlete who naturally releases a ball when throwing would therefore have an advantage over a shorter athlete.

FIGURE 2.32 All other factors being equal, the higher the release, the further the projectile will travel due to having greater time in the air.

TEST your understanding
1 Explain what the term ‘projectile’ means when discussing biomechanical principles.
2 What is the difference between the terms ‘distance’ and ‘displacement’ when discussing movement?
3 An athlete who is neither accelerating nor decelerating is said to have a constant what?
4 There are three units used to measure angular motion. List the three different units and highlight the one commonly used in sports coaching and biomechanics.

APPLY your understanding
5 You are a coach of two junior athletes. One of your athletes, Fiona, is positioned 1 km away in a straight line from where you are, while another, Sally, is next to you. Fiona runs to you, taking five minutes to get there. You instruct Sally to run two full laps of an oval with a distance of 500 metres per lap, finishing where she started.

Using the information above, calculate the average speed and average velocity of Fiona and Sally. Compare the results.

6 Practical activity
You kick a soccer ball from the ground into the air at an angle of 30 degrees. It lands 20 metres away.
(a) Describe how the ball is impacted on by external forces once in the air.
(b) For the next kick, your objective is to kick the soccer ball further. Describe three things that you could do to achieve this.

Table 2.3 indicates the velocity experienced by a 100-metre sprinter at different stages, including prior to the start at the starting line and at each 20-metre interval of the race thereafter.

TABLE 2.3

<table>
<thead>
<tr>
<th>Sprinter’s position</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting line</td>
<td>0</td>
</tr>
<tr>
<td>20-metre point</td>
<td>7</td>
</tr>
<tr>
<td>40-metre point</td>
<td>11</td>
</tr>
<tr>
<td>60-metre point</td>
<td>10</td>
</tr>
<tr>
<td>80-metre point</td>
<td>8</td>
</tr>
<tr>
<td>100-metre point</td>
<td>7</td>
</tr>
</tbody>
</table>

(a) At what point of the race did the sprinter experience the greatest velocity?
(b) What is the unit that velocity is measured in?
(c) The sprinter finished the race in 11 seconds. Using the correct formula, what was the average velocity from start to finish?

EXAM practice
8 Below are the results of a video analysis of a gymnast performing a full somersault from a static position, landing one metre ahead of the take-off position. Use the data below to answer the following questions.
### TABLE 2.4

<table>
<thead>
<tr>
<th>Angular displacement</th>
<th>Angular distance</th>
<th>Angular speed</th>
<th>Linear displacement</th>
<th>Linear distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degrees</td>
<td>360 degrees</td>
<td>720 degrees per second</td>
<td>x</td>
<td>y</td>
</tr>
</tbody>
</table>

(a) What is meant by the term ‘angular distance’? 1 mark

(b) Analyse the data in the table above to calculate the time it took the gymnast to perform this somersault. Explain how you worked out the answer. 2 marks

(c) Use the information in the stem above the table, what was the gymnast’s linear displacement (x) and linear distance (y)? 2 marks

x = ____________________________

y = ____________________________

(d) To ensure a stable landing, there are some techniques that the gymnast can adopt to land safely. Describe the relationship between stability and centre of gravity, and the relationship between stability and base of support. 2 marks

(e) Describe in practical terms how the gymnast would aim to land to promote the best possible landing position, using the terms ‘centre of gravity’ and ‘base of support’. XX marks
2.5 Using principles of equilibrium, levers, stability and balance for analysis of human movement

**KEY CONCEPT** The principles of equilibrium, levers, stability and balance can help analyse human movement.

**Levers**

The term *leverage* refers to a beam or rigid structure that rotates around a fixed point, commonly referred to as an axis (some sources use the terms 'fulcrum' or 'pivot point'). The term 'leverage' describes the action or advantage of using a lever. From a sporting perspective, levers are used to improve performance, via the use of equipment in addition to body parts that can be moved to create anatomical levers. Anatomical levers can provide a mechanical advantage where a small amount of force can be used to move a larger force.

![Figure 2.33](image1) People can create short and long anatomical levers by moving their body parts to different positions, as shown here by the young soccer player.

There are many examples in and out of sport where equipment is used to enable human beings to generate force or speed more easily. Crowbars, wheelbarrows and scissors are examples of such equipment. There are three common components of levers:

- The axis is the turning point of the lever.
- The force is the point where force is applied.
- The resistance is the weight of whatever a person is trying to move (either the force of objects or the weight of body parts).

![Figure 2.34](image2) This tennis serve shows the three components of a lever system: the axis, force and resistance.
Lever types

Levers are classified depending on the location of the axis, force and resistance in relation to each other. They are categorised as either a first class, second class or third class lever.

- **First class levers** have the axis as the central component that separates the force and resistance.
- **Second class levers** have the resistance as the central component that separates the axis and force.
- **Third class levers** have the force as the central component that separates the axis and resistance.

**First class levers**

An often used example of a first class lever is a simple see-saw. At either end of the see-saw are the force and the resistance, with the axis in the middle. The force comes from the person attempting to apply force to move the position of the person at the other end. The resistance is the weight of the person being moved.

There are limited instances of the human body acting as a first class lever. One example is your head and neck. To prevent the weight of your head bringing it forward, your neck muscles that sit posteriorly apply a force against the head (resistance). This enables the head to rotate back to an upright position.
Second class levers
Similar to first class levers, there are a few examples of the body acting as a second class lever. Second class levers have the resistance situated between the axis and force. A wheelbarrow is a second class lever, where the wheel acts as the axis, the load within the wheelbarrow is the resistance and the force is the pressure applied to the handles by the person moving the wheelbarrow.

An example of a human second class lever is when a person shifts their weight from having feet flat on the ground to standing on the balls of their feet (combination of the metatarsals and phalanges at the metatarsophalangeal joint). The metatarsophalangeal joint acts as the axis at one end of the lever. The resistance is the weight between the axis and the force applied to the heel bone by the two muscles at the back of the lower leg, the gastrocnemius and the soleus.

Third class levers
Third class levers are the most regularly used type of lever in the human body and when executing skills in sport. Whenever we kick a ball or strike an object with the hand or a racquet, the resistance is the weight of the object being struck and therefore is at one end of the lever system. To move a body part, a force needs to be applied by the muscles to change the angle of a joint (that acts as the axis). To enable this movement to occur, the muscles exert force to the bone via attachment to a tendon, which crosses the joint and applies force between the axis and resistance, hence becoming a third class lever.

Another example of a third class lever is the use of a fishing rod. The resistance is the weight of the fish (or anything caught instead of the desired fish!), where the force is applied to the rod itself and the axis is the end of the fishing rod that will rotate when trying to move the load.
Dynamic equilibrium is the state in which a body is in motion with a constant velocity.

Static equilibrium is the state in which a body has zero velocity and zero acceleration. A body is in equilibrium when the sum of all forces and the sum of all moments acting on the body are zero.

Using lever systems

Levers can have a significant mechanical advantage when used correctly. The actual advantages are often dependant not only on the type of lever used but on other factors, including the length of the force arm and the length of the resistance arm. The force arm refers to the distance between the force and the axis. The resistance arm is the distance between the axis and the resistance.

To determine the mechanical advantage over the use of the lever, the force arm is divided by the resistance arm.

\[
\text{Mechanical advantage} = \frac{\text{force arm}}{\text{resistance arm}}
\]

If the force arm is longer than the resistance arm, then the mechanical advantage is deemed to be greater than 1, where the force that is needed to move the load is less than the force of the resistance. In other words, less effort is required to move the resistance.

Equilibrium

Equilibrium is a term commonly used in sport. It refers to a state in which there is a balance of forces or influences in opposition to each other. Equilibrium is seen when all parts of a body are at rest, such as a ball stationary on the ground or a gymnast holding a handstand. This is an example of a body experiencing static equilibrium. Equilibrium can also be seen when all parts of a body are moving with the same constant velocity created by balanced forces. This refers to dynamic equilibrium.
**Stability and balance**

*Stability* and *balance* are important in many sports, particularly where force is required to move another human body, such as in a rugby scrum (or force is required to resist movement, such as the rugby player not wanting to be shifted). The term ‘stability’ refers to the degree to which a body resists changing its equilibrium. Balance on the other hand is the ability to control the state of equilibrium. This balance can refer to a person being in control of their body position while stationary, such as a gymnast holding a steady handstand. This is an example of static balance. Dynamic balance, on the other hand, relates to a person in control of their body position while moving. An example would be a squash player or netballer moving with speed and control on the court.

**FIGURE 2.40** Dynamic equilibrium

**Stability** refers to the degree to which a body resists changing its equilibrium.

**Balance** is the ability to control the state of equilibrium.

**FIGURE 2.41** Netballers use both static and dynamic balance on court: they need to be in control of their bodies while still and moving.
Some important stability definitions

The centre of gravity (COG) is the central point of an object, about which all of its weight is evenly distributed and balanced. This point shifts with every movement of the body.

The line of gravity is an imaginary line which passes through the centre of gravity and continues down into the centre of an object’s base of support.

The base of support refers to the area of an object that is in contact with the surface supporting it.

Tips for increasing stability and balance

- Lowering an object’s centre of gravity
- Ensuring the line of gravity is over the base of support
- Increasing the size of the base of support
- Increasing the friction between two or more bodies
- Increasing the mass of an object
- Extending the base of support in the direction from which a force is coming

There is a performance issue with being stable: the more stable an object or person is, the harder it is to shift. Think of a cricketer (a person batting) facing a fast bowler, or a 100-metre sprinter. In both of these instances, the person’s ability to move quickly is diminished if their body is in a stable position. Instead, people adopt body positions where there is a degree of stability but from which they can easily shift their body to an unstable (but controlled) position, allowing for quick movement. The cricketer, for example, will reduce their base of support by removing their heels from the ground. This also raises their COG and shifts their line of gravity closer to being outside their base of support.
FIGURE 2.44 By removing the front leg from the ground, the sprinter creates quick angular motion that enables him to accelerate out of the blocks. This is due to the line of gravity moving to well outside the base of support (back foot on the blocks) when the front leg is lifted.

Tips for reducing stability and balance to promote agility
- Raising an object's COG
- Shifting the line of gravity outside the base of support
- Narrowing the base of support
- Decreasing the friction between two or more bodies
- Decreasing the mass of an object

FIGURE 2.45 Consider the two tennis players in this picture. The player in the red shirt has a wide base of support, which increases stability but negates agility. The player in the white shirt, on the other hand, has positioned his legs closer together, which promotes agility but reduces stability.
In many sporting instances, there is a need to promote angular motion. This is produced by a force that does not act throughout a body’s COG. This is applied via an eccentric force that results in an object rotating, which in many sports is referred to as spin. This rotation is caused by torque, often referred to as the ‘moment of force’.

Torque is dependent on two different factors:
- size of the applied force
- length of lever/moment arm (the distance that the force is applied away from the axis of rotation).

If two equal eccentric forces are applied in two opposing directions, then the object will rotate without moving from its position in space.

![Figure 2.46](image.png) An eccentric force causes an object to undergo angular motion.

**TEST your understanding**

1. Define the term ‘lever’.
2. There are three classes of lever. Explain the difference between these.
3. Dividing the force arm by the resistance arm gives you what measurement?
4. Explain what is meant by the terms ‘static balance’ and ‘dynamic balance’. Give an example of each in gymnastics.

**APPLY your understanding**

5. You are a sumo wrestling coach. Your task is to explain to your sumo wrestler how he can increase his stability and balance using the terms ‘centre of gravity’, ‘line of gravity’ and ‘base of support’.
6. A tennis player serves with great velocity, using a racquet as a lever. At the point of impact, describe where the axis, resistance and force are. Use this information to identify the class of lever.

7. The optimal angles of release for the three different sports are as follows: high jump — 60 degrees, a throw for distance — 45 degrees, a javelin throw — 30 degrees. Draw a graph to visually represent this information. You must label both axes and include all necessary information.

**EXAM practice**

8. Anatomical levers are used by athletes to promote performance.
   (a) Define the term ‘lever’. (1 mark)
   (b) There are three classes of levers. Name the type of lever that is most common in the human body. What is the central component of this type of lever? (2 marks)
   (c) Describe the difference between an anatomical lever and a non-anatomical lever. Use an example of each to help in your explanation. (3 marks)
KEY SKILLS

- Analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills in a coaching context.

UNDERSTANDING THE KEY SKILLS

To address these key skills, it is important to remember the following:
- Analyse and interpret information provided in a variety of formats that includes graphs, visuals (such as pictures) and digital media.
- Apply knowledge acquired in a graphical or visual manner.
- Answer structured questions that draw on primary data or secondary data that analyses a movement skill using biomechanical principles.

PRACTICE QUESTION

1. A golfer chooses to hit with a 7-iron using maximal force off a tee, but the ball falls well short of the desired target. The golfer’s playing partner suggested using a longer club, such as a 5-iron, which strikes the ball closer to its centre and therefore creates a reduced angle from the ground. The weight of the two golf clubs and their angular velocity at the time of impact are the same.

   a. Explain why, using correct biomechanical terms, a longer golf club such as a 5-iron compared to a 7-iron would result in the golf ball travelling a longer distance.

   b. Draw the likely differences in vertical and horizontal displacement between two golf shots, one using a 5-iron and one using a 7-iron struck, both struck with maximal force.

   c. Name the predominant external force that impacts on the vertical displacement of the ball.

   d. Name the predominant external force that impacts on the horizontal displacement of the ball.

HOW THE MARKS ARE AWARDED

- 1 mark: for highlighting that angular distance is the overall distance travelled in degrees over a given period of time.
- 1 mark: for identifying that the full somersault would take 0.5 seconds.
- 1 mark: for explaining that given the angular speed of the somersault was 720 degrees per second and considering that only 360 degrees was covered (1 full rotation) the time to do this would be half the speed measured.
- 1 mark: for identifying that \( x = 1 \) metre.
- 1 mark: for identifying that \( y = 1 \) metre.
- 1 mark: for identifying that there is a relationship between a lower centre of gravity and increased stability.
- 1 mark: for identifying that there is a relationship between a larger base of support and increased stability.
- 1 mark: for explaining that the gymnast would lower their centre of gravity prior to landing by bending their knees.
- 1 mark: for explaining that the base of support would be widened by spreading their feet apart.
SAMPLE RESPONSE

a. The main reason why the 5-iron would make the golf ball travel further than the 7-iron would is due to the increased angular momentum that can be generated by using a longer club. Angular momentum is a product of angular velocity multiplied by the moment of inertia (mass of the object x distance the weight is distributed from the axis of rotation). In this case, the angular velocity and the mass were the same but the weight of the longer 5-iron would be distributed further away from the axis of rotation (shoulders) so therefore greater momentum could be generated and transferred to the ball.

b. 

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 iron (longer)</td>
<td>7 iron (higher)</td>
</tr>
</tbody>
</table>

c. The predominant external force that impacts on the vertical displacement of the ball is gravity.

d. The predominant external force that impacts on the horizontal displacement of the ball is air resistance.
CHAPTER SUMMARY

- Application of biomechanical principles can assist coaches and athletes to improve performance.
- Kinetics is a branch of biomechanics that studies the forces that cause motion.
- Kinematics is a branch of biomechanics that describes motion.
- Motion is typically described as angular, linear or a combination of these.
- Inertia is the resistance of a body to a change in its state of motion.
- Sufficient force must be applied to overcome inertia, having either a pushing or pulling effect on an object.
- Forces include those generated by the contraction of skeletal muscles, air resistance, gravity and friction.
- Momentum is the product of mass and velocity.
- Conservation of momentum occurs when two bodies collide or when momentum is transferred from one body part to another.
- Angular momentum is the product of angular velocity x moment of inertia (a measure of an object's resistance to changing its rate of rotation).
- Force summation involves the correct timing and sequencing of body segments and muscles through a range of motion.
- Newton's three laws of motion are used to describe the relationship between a body and the forces acting upon it.
- There is an impulse-momentum relationship where the greater the impulse, the greater the momentum.
- There is a distinct difference between the terms 'distance' and 'displacement' in biomechanics.
- Displacement is the difference between the initial position and the final position of an object.
- Speed is the rate of motion (distance/time), while velocity is displacement/time.
- Acceleration refers to the rate of change of velocity over time.
- As soon as an object or body is released into the air, it becomes a projectile and is automatically under the influence of two external forces: gravity and air resistance.
- Other factors that influence the trajectory of a projectile include: height of release, angle of release and speed of release.
- The term 'lever' refers to a beam or rigid structure that rotates around a fixed point, commonly referred to as an axis.
- Levers are classified depending on the location of the axis, force and resistance in relation to each other. They are categorised as either a first class, second class or third class lever.
- Levers aim to provide a mechanical advantage to improve performance.
- Stability and balance are important in many sports, particularly where force is required to move others.
- There are a range of ways in which stability and balance can be altered to benefit performance.

EXAM PREPARATION

MULTIPLE CHOICE QUESTIONS

1. The study of the mechanical principles that govern motion is called
   (A) kinetics.
   (B) kinematics.
   (C) biomechanics.
   (D) dynamics.

2. Spin and rotation are common terms for which of the following types of motion?
   (A) Curvilinear
   (B) Angular
   (C) Linear
   (D) General

3. The correct unit of force is
   (A) Newton.
   (B) kilogram.
   (C) metres per second.
   (D) metres per second squared.
4. The correct formula for impulse is
   (A) Force × Momentum.
   (B) Force × Velocity.
   (C) Force × Inertia.
   (D) Force × Time.

5. A gymnast on a high bar spins one and a half full rotations. Her displacement is
   (A) 180 metres.
   (B) 180 degrees.
   (C) 1.5 revolutions.
   (D) 540 degrees.

6. In a 400-metre run, an athlete covers the first 50 metres in five seconds. The average acceleration would be
   (A) 10 m/s
   (B) 10 m/s²
   (C) 50 m/s
   (D) 50 m/s²

7. A badminton shuttle experiences greater air resistance than a tennis ball, primarily due to its
   (A) mass.
   (B) surface area.
   (C) inertia.
   (D) momentum.

8. Which of the following is an example of an anatomical lever?
   (A) Throwing a shotput
   (B) A smash in tennis
   (C) A badminton volley
   (D) A table tennis serve

9. When a person is running, the prime resistance in a lever system is
   (A) air resistance.
   (B) gravity.
   (C) friction.
   (D) mass of body part being moved.

10. The most stable body position would be
    (A) running.
    (B) lying down.
    (C) standing with legs spread.
    (D) sitting.
TRIAL EXAM QUESTIONS

Brooke Stratton set a new Australian women’s long jump record in Perth during 2016 with a jump of 7.05 metres. Describing this achievement, a sports scientist said Brooke’s jump was outstanding as she first had to overcome inertia and develop enough force during the run up to propel herself into the air for this performance.

a. Describe what the term ‘inertia’ means. 1 mark

b. Prior to Sally moving, she has to overcome her static inertia. What is this static inertia directly proportional to? 2 marks

c. After Sally propelled herself into the air, she was confronted by two external forces that prevented her from jumping even further. Name these two forces.
   For each of these forces explain how they acted on Sally. 2 marks

d. Describe what Newton’s third law of motion states. 1 mark
   Use Newton’s third law to describe how Sally was able to run down the long jump track prior to her jump, explaining what the terms ‘equal’ and ‘opposite’ mean in this context. 1 mark