CHAPTER 2

Efficiency of movement — biomechanics

In chapter 1 the way in which an individual is able to learn physical skills and improve performance was examined from a skill acquisition perspective. This chapter investigates how the development and improvement of motor skills is also dependent on the individual's ability to acquire, apply and evaluate knowledge and understanding about biomechanical principles. As individuals strive to improve performance, they look to the biomechanist for advice on technique, style, development and refinement of equipment and analysis of performance.

This chapter examines biomechanical principles and concepts that influence the development and refinement of basic movement patterns and motor skills such as force and momentum, impact, transfer of momentum, inertia, balance, action and reaction, pushing and pulling, and other aligned biomechanical principles. Teachers and students should select a range of these principles when investigating the development and refinement of basic movement patterns.

The focus of this chapter is on learning through practice and students are provided with a range of laboratory activities and practical examples to assist in the application of major concepts and key understandings to basic movement patterns, motor skills and sporting activities.

Assessment tasks

Assessment tasks	Topics	Page
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After completing this chapter, students should be able to:

- explain the application of biomechanical principles when investigating how basic movement patterns and motor skills are developed and refined
- describe biomechanical principles using the correct terminology
- perform, observe, analyse and report on practical and laboratory exercises related to biomechanics
- evaluate the efficiency of movement techniques using biomechanical principles
- compare and contrast the impact of different techniques on performance.

Biomechanics

Biomechanics is the sport science field 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 effects of those forces on and within the human body. The general role of biomechanics is to understand the mechanical cause–effect relationships that determine human motion. Biomechanics contributes to the description, explanation, prediction and improvement of the mechanical aspects of human movement, exercise and sports performance.

Biomechanists are involved, among other things, in:

- human performance analysis
- the analysis of forces in sport and physical activities
- how injuries occur in sport
- injury prevention and rehabilitative treatment methods
- the design and development of sporting equipment.

Figure 2.1: *Biomechanists use a range of sophisticated equipment, such as this swimming flume, to analyse performance.*

Performance analysis

Biomechanics plays a key role in the area of **performance analysis**, along with other disciplines such as exercise physiology, skill acquisition and physical therapy. Performance analysis links the information and insights provided by these disciplines to enable coaches and athletes to develop better practices. Performance analysis can occur during either training or competition. Regardless of the environment, performance analysis involves the following aspects:

- a permanent record of performance is made, for example, a videotape of an athlete executing a particular skill
- the systematic observation of the performance
- an analysis of selected aspects of the performance
- the provision of quantitative and qualitative information about the performance.

Coaches can use this process to compile objective and reliable observations of performance that can then be used to promote learning and develop and improve performance.

The biomechanist's equipment

Biomechanists use a range of technologies and equipment in their field of study. Examples of modern day techniques include:

- cinematography, which includes video, high speed photography, slow motion analysis, 3-dimensional motion analysis and computerised video analysis
- computer and digital analysis, which is used to investigate concepts such as the centre of gravity of an object, speed and the range of motion of body parts
- force platforms, which measure force application, impulse, acceleration and deceleration during activities such as shot put, sprint start, high jump take-off and discus spin
- wind tunnels, which are used for streamlining body position and equipment in sports such as cycling, downhill skiing and tobogganing
- resistance pools or swimming flumes, which can be used for refining swimming stroke technique, and measuring swimming performance (figure 2.1).
- electromyography, which enables measurement of muscle force and action throughout a movement or activity (figure 2.2).

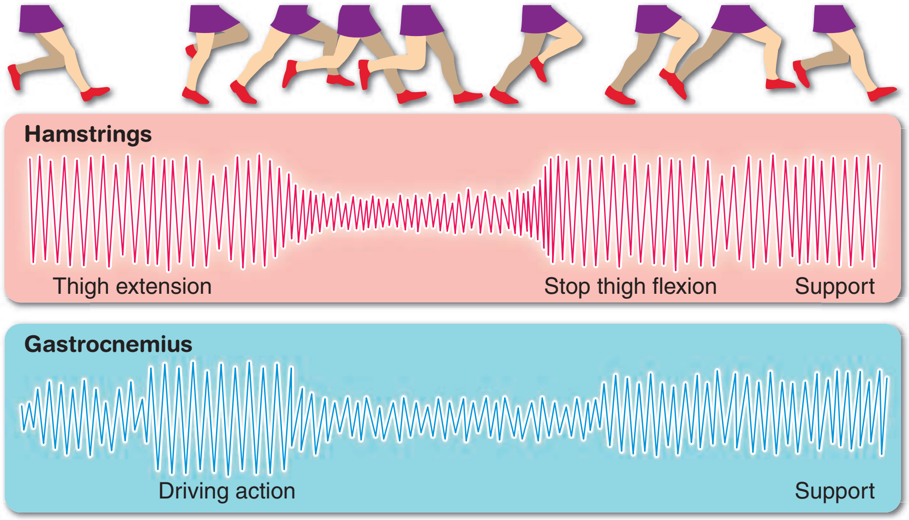


Figure 2.2: *Electromyographic recordings of hamstrings and gastrocnemius muscles during running*

The benefits of biomechanics

Understanding biomechanics can produce the following benefits for athletes and sportspeople:

- optimisation of sports performance by developing the most efficient and effective technique
- prevention and reduction of injuries through an understanding of injury causes and the development and application of proper technique
- the design and development of improved equipment and materials to maximise sports performance
- the development and modification of sports equipment to widen participation, for example, junior size equipment to allow participation at a younger age; and cheaper and more durable equipment to reduce costs to participants and thereby provide greater access to participation.
- the transference of skills from the practice field to the playing field, for example, batting tees, ball-throwing machines; swimming flumes, and video software that allows athletes to enhance technique in practice and apply this in competition.

It is clear that biomechanics forms an integral part of the total performance package in the pursuit of skill development and improvement. Table 2.1 shows that the biomechanist has a leading role to play in developing best technique and equipment to produce optimal performance.

Table 2.1

Developing best performance

Physical preparation	Technique development	Mental preparation
• Training/fitness • Sports medicine/injury • Nutrition/diet • Anatomy/build • Training principles • Ergogenic aids	• Biomechanical analysis • Equipment design • Environmental factors – wind – rain – playing surfaces	• Mental rehearsal • Psychologists • Motivation • Personal goals • Pride in performance • Mental toughness
• Coach (fitness)	• Coach (technique)	• Coach (motivation)

All have input into optimal performance

To utilise biomechanics to enhance skill learning and physical performance it is necessary to have an understanding of the biomechanical principles that underlie human movement and the execution of sporting skills. What follows is a selection of the key biomechanical principles that are essential in terms of this understanding. These principles include:

- force production
- application of force including the concepts of inertia, momentum, impulse, accuracy and force reception
- Newton's three laws of motion
- transfer of momentum and conservation of momentum
- leverage
- motion including human motion and projectile motion
- impact and friction
- balance and stability.

Force production

Force is defined in simple terms as 'any pushing or pulling activity that tends to alter the state of motion of a body'. Therefore, through the application of a force, a body at rest can be made to move and a body in motion can be stopped, slowed, have its speed or velocity increased, or have its direction of motion altered. The body could be a human body, a ball, a discus, a javelin, a racquet or a bat. The forces that can be applied to these bodies may be external forces, and they include: gravity, friction, air resistance and water resistance. Each of these forces is discussed later in this chapter.

Forces on the human body can also be internal, generated by the action of muscles and tendons on the skeletal system.

Types of forces

Force without motion — isometric force

Muscular contractions may or may not create movement while applying a force. If the muscle length does not change, then an **isometric contraction or force** is being applied — for example, pushing against an immoveable object, or gripping a racquet or bat.

Force with motion — isotonic force

An **isotonic force** is sufficient to change the state of motion of the object, for example, pushing out of the blocks in a 100-metre sprint, shot-putting, accelerating a hockey ball with a push pass, or decelerating a football by marking it on your chest.

Sub-maximal force

Force application must be graduated or optimal for successful performance, but the optimal force in some activities is less than maximum, for example, putting in golf, using a drop shot in badminton, doing a lay-up in basketball and trapping the ball in soccer. These skills require the performer to use a limited number of muscle motor units and to apply biomechanically sound techniques.

Maximal force

Perfect timing, maximal muscle contraction and excellent technique achieve maximal force, for example, throwing for distance, shot-putting, high jumping and serving in tennis. When maximum force development is required the desired movement is usually the result of a combination of a number of forces. The summation of these forces is required to produce the maximal force.

Force summation

Force summation can be achieved:

- simultaneously, where an explosive action of all body parts occurs at the same time, for example, a high jump take-off and a gymnastic vault take-off
- sequentially, where body parts are moved in sequence to generate great force. This technique is used in gross body actions such as throwing, striking and kicking (figure 2.3).

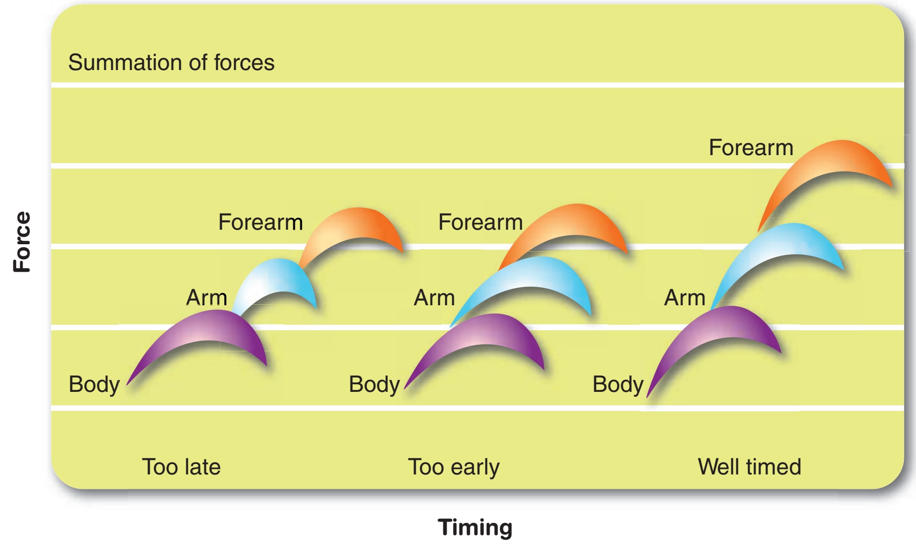


Figure 2.3: *Timing of sequential summation of forces when throwing for distance*

Sequential force summation requires the following techniques.

1. Use as many body parts as possible.
2. Use the largest body parts and muscle groups with the greatest mass first, such as legs and quadriceps (figure 2.3).
3. Sequentially accelerate each body part so its momentum optimally passes onto the next body (figure 2.3).
4. Sequentially stabilise each body part so the next body part accelerates around the stable base (a joint or body segment) and receives the optimal momentum developed by the previous body part.

Fast bowling in cricket is a good example of how the sequential summation of force is used to generate the delivery. In the delivery action, there is a sequence of body movements beginning with larger, heavier body parts (such as legs and trunk) and finishing with smaller, lighter body parts (such as wrist and hand):

- The first part of the delivery action is the step forward onto the front foot.
- This provides a stable platform for the rotation of the hips and trunk.
- Momentum is then transferred to the shoulder and the arm swing followed by wrist flexion and the release of the ball from the hand and fingers.

Figures 2.4 and 2.5 illustrate the concept of sequential summation of force in bowling.

Figure 2.4:
The delivery action in fast bowling in cricket showing the sequential summation of force

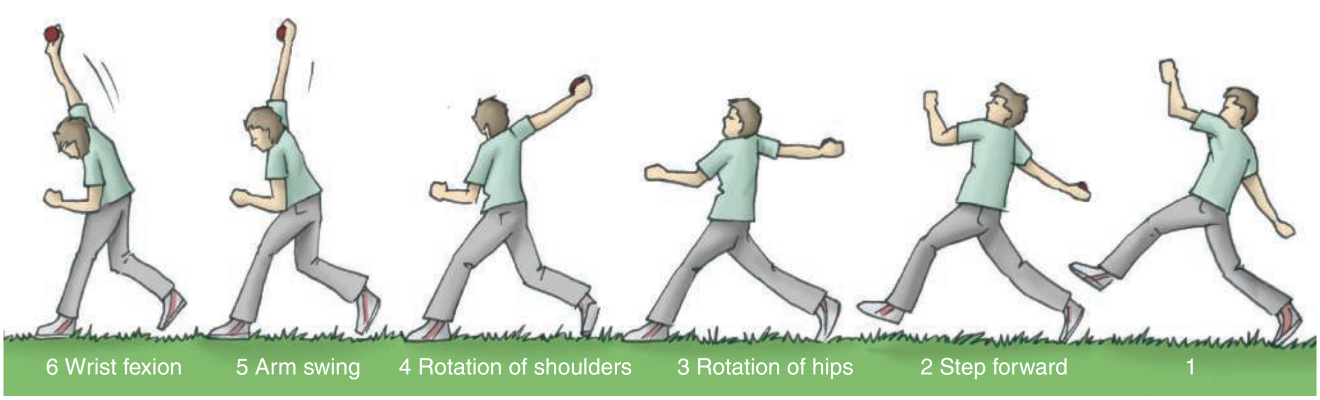


Figure 2.5:
To achieve maximum force in fast bowling in cricket, release should occur when maximum force has been developed through the sequential summation of force.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 1 Laboratory report

Summation of force

This laboratory activity investigates the concept of sequential summation of force as applied to the overarm throwing technique.

To complete this activity you will need to work as part of a group of three.

Equipment

- tennis ball
- tape measure
- hoop

Method

The task requires one person within your group to throw a tennis ball for maximum distance, using an overarm throwing technique under a number of different conditions. The second person in your group should measure and record each distance obtained using a table similar to table 2.2 (see p. 57). The third person is required to stand a few metres in front of the person throwing and hold the hoop in such a way to ensure that the angle of release is approximately the same (45º) for each throw under each condition. Perform two trials (throws) for each condition.

Condition A

The thrower takes up a long sitting position, against a wall or fence as shown in figure 2.6. Shoulders and hips must remain tight against the wall. Throw the ball for maximum distance using the arm only.

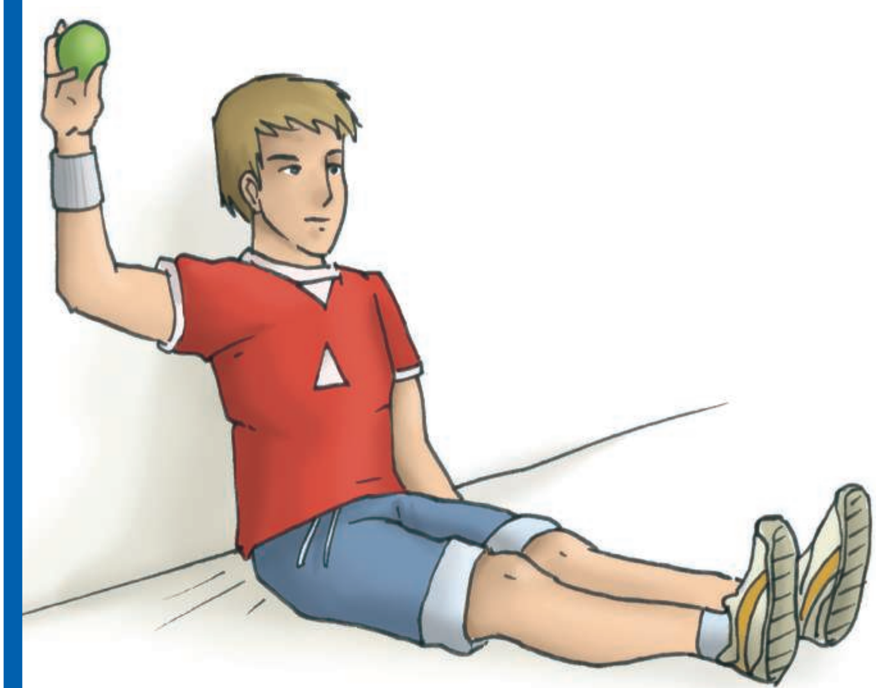


Figure 2.6:
Diagram of long sitting position for condition A

continued ➤

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 1 *continued*

Condition B

The thrower moves 1 metre forward from the wall or fence, but remains in a long sitting position as shown in figure 2.7. Throw the ball for maximum distance by rotating the shoulder and arm back as far as possible, but **do not** lean back. Throw using the shoulders and arm only.

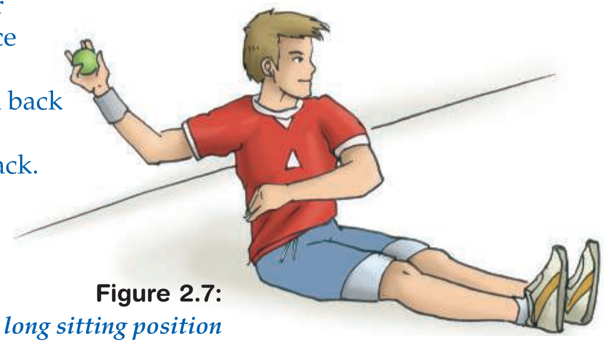


Figure 2.7: *Diagram of long sitting position for condition B*

Condition C

The thrower can now stand up and move 2 metres forward of the wall or fence. Throw the ball for maximum distance by rotating the hips and shoulders as far back as possible, but the thrower's feet must remain in contact with the ground and must not twist around (see figure 2.8). Throw the ball using the hips, shoulders and arm only.

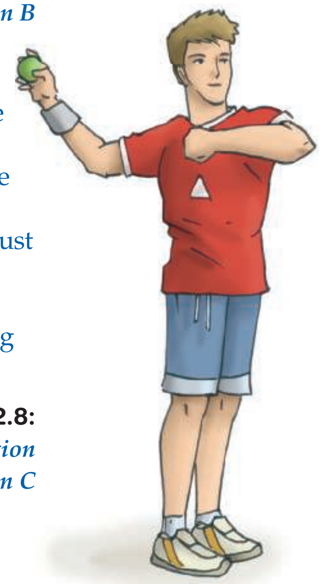


Figure 2.8: *Diagram of standing position for condition C*

Condition D

The thrower retains the position 2 metres away from the fence, but can now stand side-on to the direction of throw, with the feet shoulder width apart as in figure 2.9. Throw the ball for maximum distance by stepping forward onto the front foot and by rotating the hips and shoulders. Throw the ball using a step forward, the hips, shoulders and arm.

Figure 2.9: *Diagram of standing position for condition D*

Condition E

The thrower is now allowed to throw for maximum distance by taking a run-up and throwing using the side-on position.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 1 *continued*

Results

- Record your group's results in a table similar to table 2.2.
- Obtain the maximum distance the ball was thrown for each condition by each of the other groups in your class. Use this information to calculate the class average maximum distance thrown for each condition (use a table similar to table 2.3 to record this information).
- Construct a graph to show a comparison between the maximum distance thrown for each condition by the person in your group and the class average maximum distance for each condition.

Table 2.2

Condition	Trial 1	Trial 2	Best
Condition A			
Condition B			
Condition C			
Condition D			
Condition E			

Table 2.3

Condition	Class average maximum distance
Condition A	
Condition B	
Condition C	
Condition D	
Condition E	

Discussion questions

1. Do the results for your group and for the class as a whole show a consistent increase from one condition to the next?
2. List the order in which body parts should be utilised in the overarm throwing technique.
3. In keeping with the concept of force summation, what observation can be made regarding the mass of the body parts used in the overarm throwing sequence?
4. What is meant by sequential stabilisation of body parts? How is this achieved in the overarm throwing technique?
5. What common errors do beginners make in throwing overarm that are contrary to the principle of sequential summation of force?
6. How might these technique errors of beginners be rectified? What simple coaching points might you give a beginner?
7. From a sport or physical activity of your choice, select a skill that relies on sequential force summation and explain the techniques required to perform this skill successfully.

Applying an effective force

To understand this principle, it is necessary to understand the biomechanical concepts of:

- inertia
- momentum
- impulse
- accuracy
- force reception.

Inertia

Inertia is the term used to describe a body's resistance to a change in its state of motion. It is easiest to understand as an object's resistance to beginning movement; it can also refer to a body's resistance to changing its state of motion (such as a cricket ball bowled towards a batter). The heavier the object, the greater its inertia and therefore the greater the force required to move it or change its state of motion.

Momentum

The **momentum** of an object or body is equal to its mass or weight multiplied by its velocity.

Momentum = mass × velocity

Therefore, an object can only have momentum if it is moving. The greater its momentum, the further it may travel and the harder it is to stop or slow the object. To increase momentum, an object must either increase its mass or increase its velocity.

Impulse

The concept of impulse and the impulse–momentum relationship is best described by the following formula:

Impulse = force × time

where force equals the object's mass multiplied by its acceleration, and time equals the length of time for which the force is applied to the object. The longer a force can be applied and the greater the force applied, the greater the object's impulse or change of momentum.

Impulse and particular sports

Impulse is important in many sports, including the start of the 100-metre sprint in athletics, leaving the blocks in swimming, pitching in softball and baseball, the discus throw and performing the push pass in hockey (figure 2.10). For example, in throwing events, the best techniques for developing impulse are those in which the maximum muscular force is exerted for the longest possible time. In the discus it is beneficial to perform a circular spin before releasing the discus rather than throwing from a standing position, to be able to provide greater time for the generation of muscular force (figure 2.11).

In the 100-metre sprint, two techniques are used at the start of the race to generate greater impulse:

- pushing from the blocks to maintain a strong forward force for as long as possible
- taking short sharp steps over the first 10–20 metres, allowing the feet to push repeatedly against the track and magnifying the force applied.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 2 Written report

Impulse

Examine figures 2.10 and 2.11 and answer the following questions.

1. What positions constitute the period of 'impulse'?
2. What is one body technique that the player has used to increase the time over which the forces are applied?
3. How could the players optimise force? How could they optimise accuracy? List only one suggestion for each.
4. What other sport relies on a similar technique?

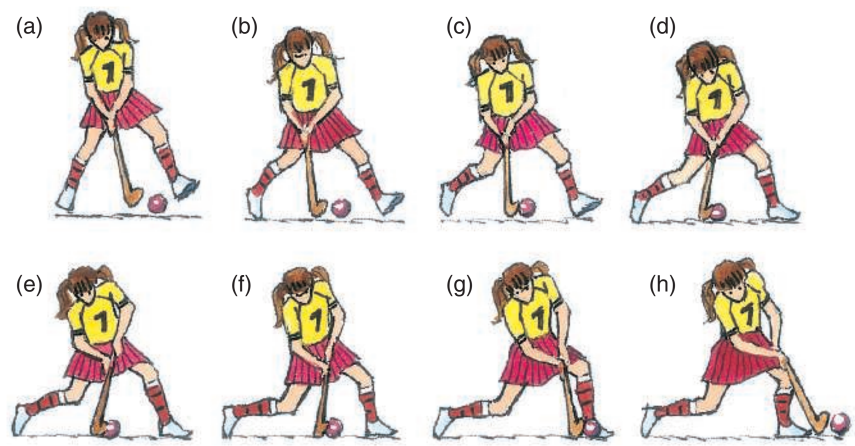


Figure 2.10:
This push pass in hockey shows the techniques used to increase the impulse between the stick and the ball.

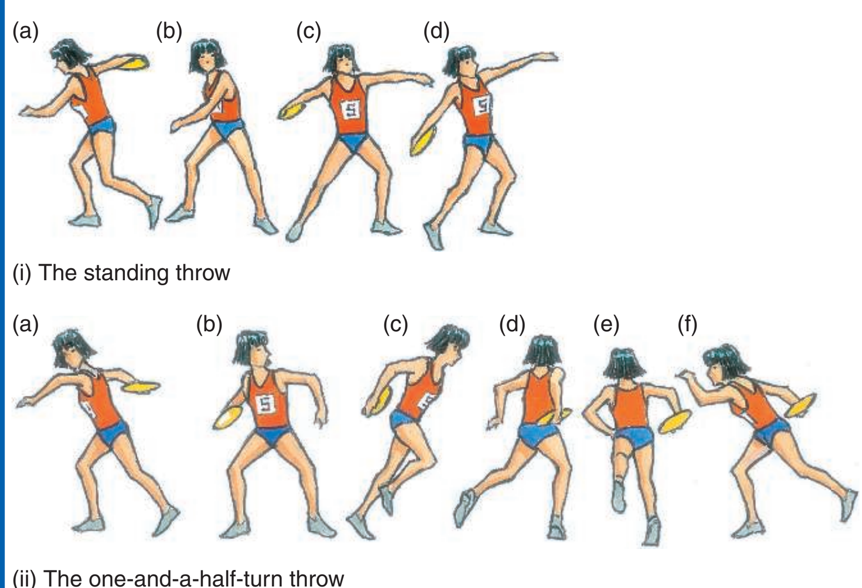


Figure 2.11:
Two styles of throwing the discus

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 3 Multimedia presentation

Impulse–momentum

1. Describe a sport technique of your own choice that illustrates the impulse–momentum relationship.
2. Take a series of photographs or make a video that clearly illustrates this relationship. Show it to the class.
3. Describe and evaluate two styles or techniques in the sport action that will result in different impulses.

Impulse and accuracy

Certain techniques in sport allow longer contact with a ball when throwing or hitting. This increased contact time provides greater force application (when required) and also increased accuracy. However, sometimes increased accuracy requires a decrease in the force applied.

Flattening the swing arc

This technique is applicable to many throwing and striking activities such as serving in tennis, underarm pitching in softball, bowling in cricket, push passing in hockey and the basic golf swing. Biomechanists and coaches assist athletes to develop techniques that create a zone of flatline motion at some stage in the performance. This flat zone allows a greater distance over which force can be applied in the desired direction of travel. It also allows a greater time over which the athlete can release or hit the ball and still reach the desired target zone.

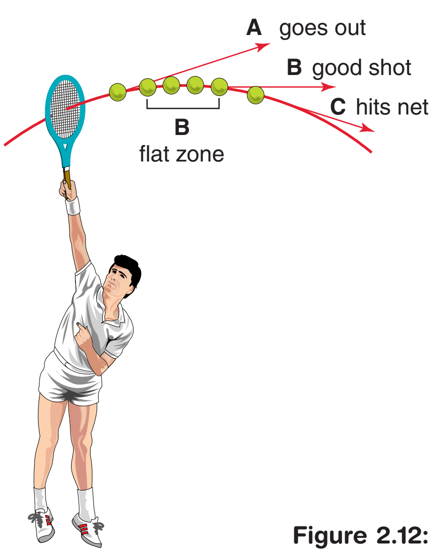


Figure 2.12: *Flattening the arc of the swing in a tennis serve improves accuracy. The correct trajectory is obtained by striking the ball at B.*

Flattening the arc in throwing and striking

Flattening of the arc in throwing activities is achieved by moving the axis of rotation (the shoulder joint) forward in the direction of the throw just prior to the time of release of the ball. When a player serves in tennis (figure 2.12), he or she creates a flattened arc of the racquet head by the shift of bodyweight forward and the rotation of the body prior to the moment of contact. When a player hits a softball, the arc is flattened due to the rotation of the trunk that moves the shoulders forward, and the transference of weight onto the front leg just prior to contact.

Follow-through

This is also an extremely important part of any striking, throwing or kicking activity. The **follow-through** must be in the required direction of travel, and it ensures that the maximum force is applied to the object by avoiding deceleration before contact with or release of the ball.

Force reception/absorption

When a ball is travelling at speed towards the catcher, or when a player is trying to crash through opponents, the force (momentum) of the ball or player must be absorbed or received over a distance to slow it and stop it. Correct catching technique requires the momentum of the ball to be absorbed over a distance or over a short period of time. An example of **force**

reception in sport is when a fielder catches a ball in cricket. As the ball makes contact with the hands it is important for the fielder to 'give with the hands' slightly to allow the force of the ball to be absorbed over a longer distance and period of time. Another example is when a gymnast lands on the mat after performing a vault. Upon landing on the mat, the gymnast executes a deep knee bend to absorb the force of landing.

Figure 2.13: *Correct catching technique. At the point of contact it is important to 'give with the hands' to absorb the force of the ball.*

Newton's laws of motion

The major concepts or principles of force production can be investigated by discussing Newton's three laws of motion.

Newton's first law of motion — inertia

'An object whether at rest or in motion will continue in that state unless it is acted upon by a force strong enough to change its state of motion or rest.' This is called the law of **inertia** because the size of the force required to change the object's state of motion depends on the object's weight or mass The heavier the object, the greater its inertia and the greater the force required to shift it. A weight-lifter, for example, must exert a very large force through muscular contraction to lift a 100-kilogram barbell above their head.

Newton's second law of motion — acceleration/momentum

'The acceleration of an object is directly proportionate to the amount of force applied and takes place in the direction in which the force is applied.' A chest pass in netball, for example, will accelerate at a rate directly proportional to the force applied by the player. If the netball was replaced by a heavy medicine ball, the player would not be able to apply the same amount of acceleration to the ball and its speed or velocity will be decreased.

Newton's third law of motion — action and reaction

'For every action there is an equal and opposite reaction.' When a runner pushes against the ground he or she exerts a downward and backward force against the ground (action force). At the same time the ground exerts the same (equal) force upwards and forwards (in other words in the opposite direction) against the runner's foot (reaction force). As a result, the runner moves forward (figure 2.14). The effect of the action force on the Earth is not evident because of the Earth's great mass. This law encompasses the concepts of **transfer of momentum** and **conservation of momentum**.

Conservation of momentum

This principle states that the total momentum of two objects before impact or contact will equal the total momentum after impact. The momentum of an object is never lost, but rather transferred on contact with other objects. In billiards, for example, if a red ball is struck by the white and takes off with the same velocity and momentum as the white, then the white must now be still after having transferred all its momentum to the red.

Conservation of momentum can vary, for example, when the white ball hits the red ball at an angle and continues in a different direction, and the red moves at a slower pace. Another example occurs when a soccer player takes a penalty kick. The player's lower leg and foot hit the ball, transferring momentum from the leg to the ball; the ball explodes away while the lower leg and foot rapidly decelerate. There is an equal and opposite reaction occurring between the foot and the ball.

Figure 2.14: *Newton's third law of motion. The runner's foot pushes backwards against the starting block (action). The block pushes forwards against the runner's foot with the same amount of force (reaction).*

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechancial principles**

Key skills

- **Describe biomechanical principles using correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.**

Activity 4 Report on participation in physical activity

Newton's laws of motion

As a class, participate in a team game of the class's choice.

1. Give one example of Newton's first law of motion from the game.
2. Give one example of Newton's second law of motion from the game.
3. Give one example of Newton's third law of motion from the game.
4. Explain each law in three to five sentences.
5. Explain two forces opposing motion in one aspect of the game.

Levers

Levers are rigid bar-like objects that turn about a fixed point called a **fulcrum**, **pivot** or axis of rotation and to which forces are applied at two other points (effort force and resistance or load force). We use levers every day to make tasks easier to perform. Scissors, wheelbarrows, bottle openers, and crowbars are all examples of levers. The human body is also made up of levers in the form of bones, with the joints acting as the fulcrum or axis of rotation.

The use of levers allows humans to apply increased force and to generate greater speed in executing sporting activities and everyday chores about the home and in the workplace.

Types of levers

All **levers** have three main elements:

1. a force arm
2. an axis, fulcrum or pivot point
3. a resistance arm.

The arrangement of these elements, and the point of application of the effort force and resistance force, determines the class or type of lever, and its mechanical advantage or function. There are three classes or types of levers — first class, second class and third class. The two main functions of levers are to:

1. increase or magnify the force applied. This occurs when *the force arm is longer than the resistance arm.*
2. generate increased speed of movement. This occurs when *the force arm is shorter than the resistance arm.*

*Some types of levers are better su*ited to force magnification while others are best suited to increasing speed of movement.

First class levers

Figure 2.15 shows the three elements as they appear in a first class lever. In a first class lever, the axis is located between the resistance and the point of force application. Everyday examples include a crowbar, see-saw and scissors. They are effective at magnifying the force applied.

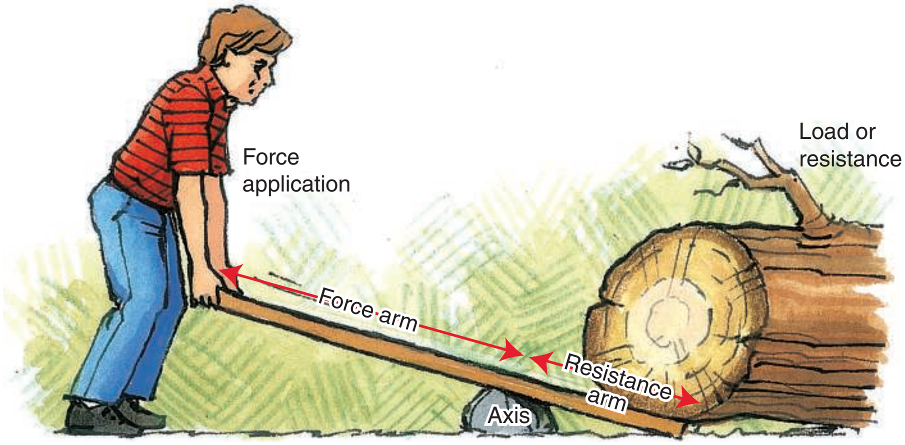


Figure 2.15: *The first class lever is being used to generate great force to overcome the large resistance of the tree log.*

First class levers can also be used to generate great speed. This is achieved by moving the axis of rotation closer to the point of application of force: if the force arm is long, greater strength or force can be applied (as with a jemmy or a crowbar); if the resistance arm is long, greater speed will be developed (as with the oar in rowing or a catapult).

Figure 2.16
A wheelbarrow is an example of a second class lever system.

Second class levers

Second class levers are used to increase the strength that humans apply to objects. These levers always have the resistance or load between the fulcrum and the force, and the force arm is always longer than the resistance arm. Two everyday examples are a wheelbarrow and a bottle opener (figure 2.16).

Third class levers

The levers within the body are mostly third class, and they have a short force arm and a long resistance arm (with the force being applied between the fulcrum and the resistance). This leads to a speed advantage. Humans are built for speed rather than strength (figure 2.17).

Levers in sport

Humans use a range of different levers to increase the amount of momentum imparted on objects. Athletes increase the length of external levers by using racquets, clubs or bats (figure 2.18), or maximise the length of their body levers by using correct technique such as overarm bowling in cricket or kicking in football.

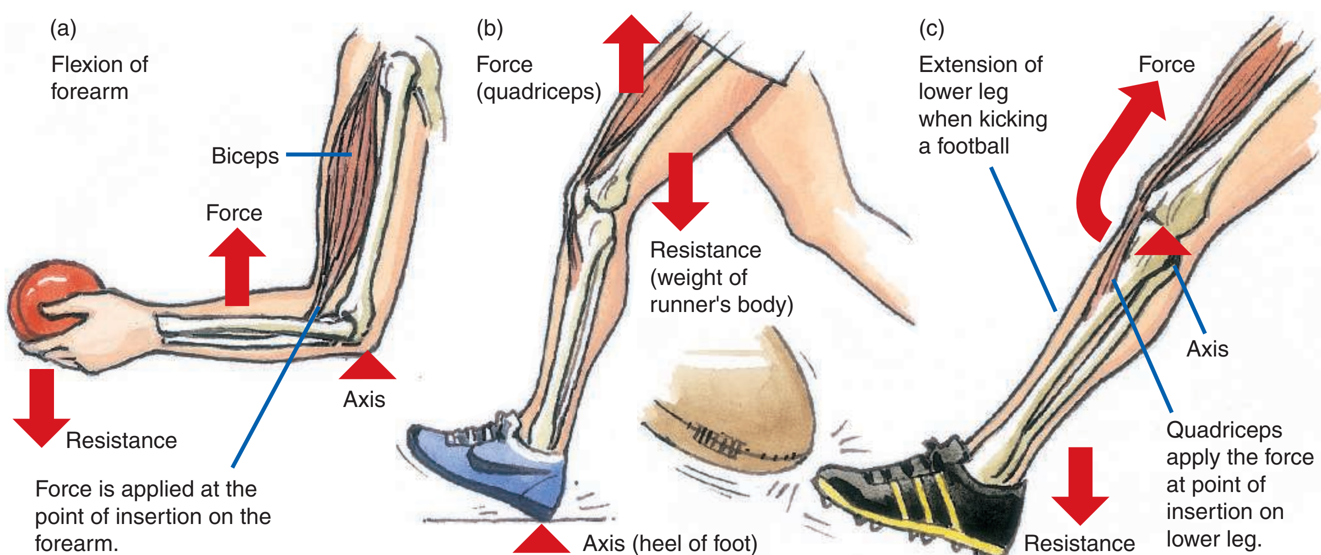


Figure 2.17:
Examples of third class levers

The principle of leverage

This principle is based on the fact that velocity is greater at the end of a long lever than at the end of a short lever. The longer the lever, the greater the velocity at impact and the greater the momentum developed by the object. Golf drivers and long irons have longer shafts than the short irons. In tennis, the server reaches up high during the contact phase of the serve to maximise lever length formed by the arm and racquet. A performer can only use the principle if they are capable of controlling the longer club or racquet. Children have difficulty swinging full sized racquets or bats, and they require shorter equipment to achieve a controlled swing.

Sometimes, athletes combine the use of long and short levers to maximise performance. For example, in soccer the kicking leg acts as a lever. The leg begins its forward swing with the knee flexed to achieve greater acceleration of the body part at the beginning of the movement. Just prior to contact with the ball, the leg is straightened, increasing the lever length and therefore increasing the velocity at its terminal point (the foot), which makes contact with the ball (figure 2.19).

Figure 2.18:
An example of how long levers are used in sport to generate a powerful throw of the ball in lacrosse

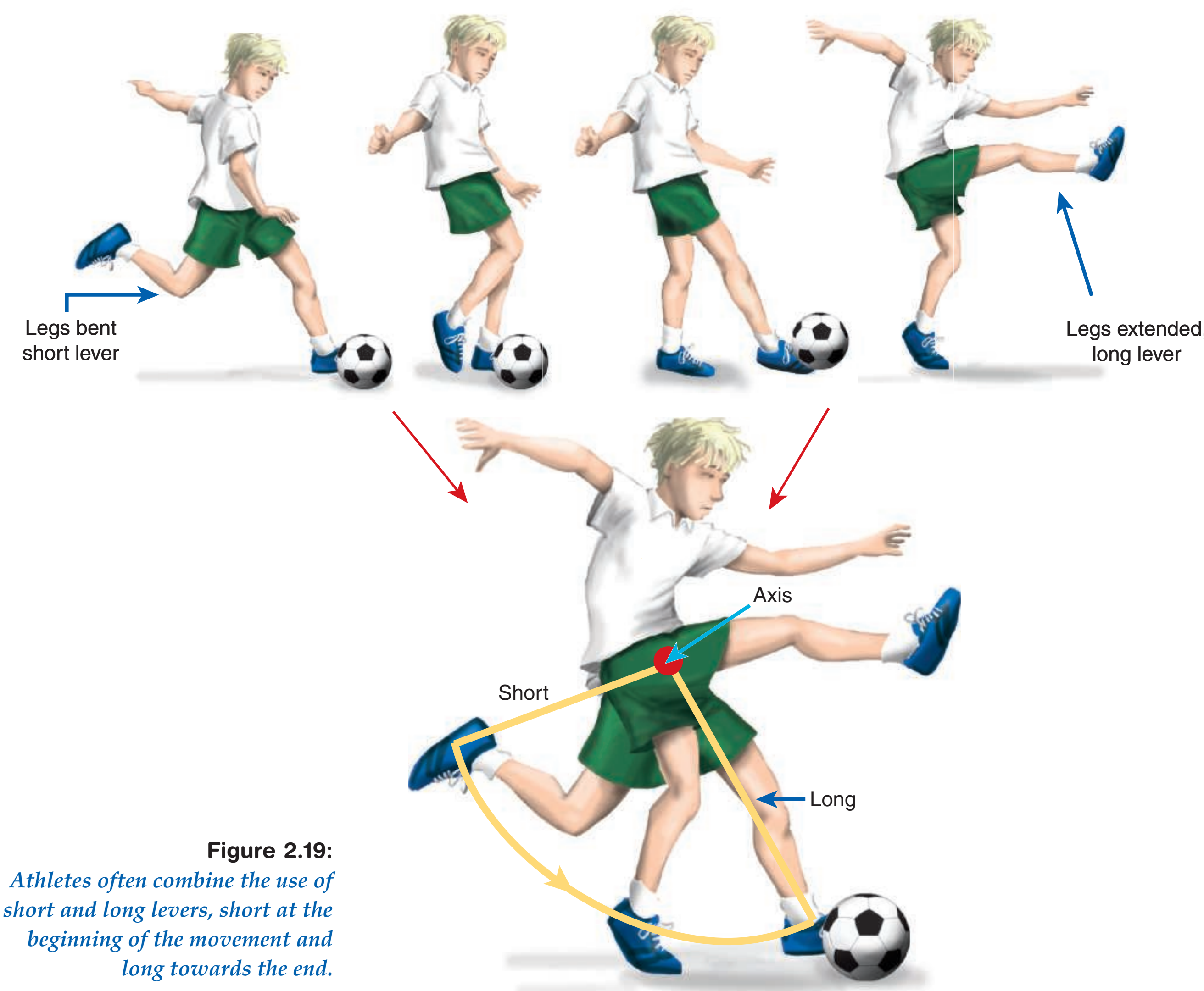


Figure 2.19:
Athletes often combine the use of short and long levers, short at the beginning of the movement and long towards the end.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 5 Laboratory report

Levers in sport

This laboratory activity investigates the concept of leverage. In particular, it explores the principle that velocity is greatest at the end of a longer lever than at the end of a shorter lever.

To complete this activity you will need to work with a partner.

Part A

Equipment

- two softballs
- a 2-metre long stick, similar to a broom handle
- tape measure

Method

1. Set up the two softballs and the 2-metre long stick as shown in figure 2.20.

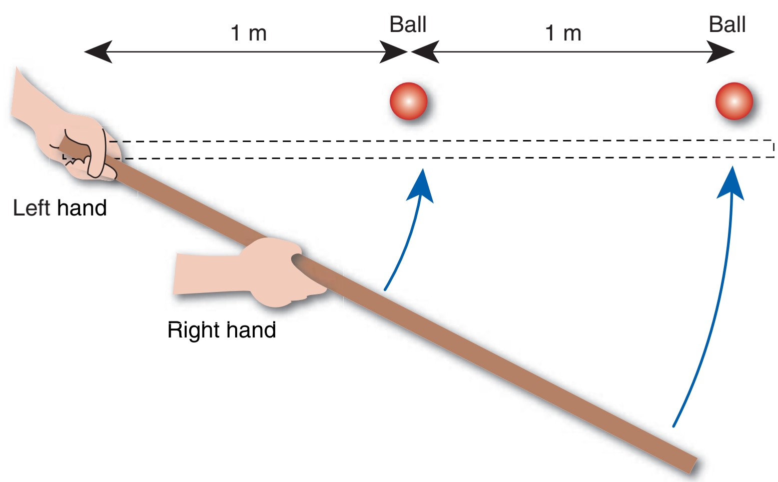


Figure 2.20

2. One partner should use his or her left hand to keep a steady pressure on the pivot point of the stick, while with the right hand, push on and move the stick in a sweeping motion towards the two softballs.
3. The stick should impact with the two balls at the same time.
4. The second partner should observe and measure the outcome of the impact of the stick on the two balls. Note should be taken of the velocity of the two balls immediately after impact (e.g. faster, slower) and measurement using the tape measure should be taken of the distance travelled by the two balls after impact.
5. Three trials should be performed.

Results

- Observations and measurements should be recorded in a table similar to that shown in table 2.4.
- Obtain the average results for the distance the two balls travelled from the other student pairs in your class. Calculate the class average result.
- Draw up a graph to show and compare your results and the class average results for the distance travelled by the two balls.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 5 *continued*

Table 2.4

Results table	Ball A distance travelled (m)	Ball B distance travelled (m)	Ball A velocity after impact (faster/ slower)	Ball B velocity after impact (faster/ slower)
Trial 1				
Trial 2				
Trial 3				
Average				

Discussion

1. According to your observations, which ball, A or B, had the highest velocity after impact?
2. According to your average results and the class average results, which ball, A or B, travelled the furthest after impact?
3. Using the principles of leverage, explain why the velocities and distance the balls travelled would be different.

Part B

Equipment

- digital camera
- variety of sports equipment

Method

1. Working with your partner, have one person perform the following activities while the other person uses the digital camera to take 'action shots' at the point of ball release or contact:
   - overarm throw
   - tennis serve
   - golf drive
   - soccer penalty kick
   - football drop punt
2. Print out the photograph 'action shots' that were taken.
3. On each of the photographs, draw on and label the following features of levers:
   - the fulcrum or axis of rotation
   - the resistance
   - the resistance arm
   - the point of force application
   - the force arm
4. Indicate the class of lever you have drawn in each case.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 6 Written report

Leverage

Read the article in figure 2.21 and then answer the following questions.

1. What are the advantages of playing with the long body racquet?
2. How can the concepts of levers and impulse be applied to the information in the advertisement?
3. Find some biomechanically debatable claims by the manufacturer in the article.

Discover what an extra inch or two can do for your performance

You don't have to be Michael Chang to experience the benefits that Prince® LongBody™ racquets bring to your game.

This major Prince design breakthrough that helped make Michael Chang one of the world's top players is now available to you.

Until now, the added performance benefits that extra racquet length could provide were always offset by weight and reduced playability. By applying advanced materials technology and extensive testing, Prince has totally re-engineered racquet standards, adding up to two inches in length . . . making Prince® LongBody™ racquets lighter and more maneuverable than traditional length models.

Now with three new Prince® LongBody™ racquets to choose from, you too can experience the ultimate in tennis performance, as you take your game to greater lengths . . . with more power, more control, more of everything!

More power

A longer, lighter racquet lets you swing through the ball, generating increased racquet speed. With each additional inch of Prince® LongBody™ racquet, your power increases by 10 per cent . . . automatically adding this power to your regular stroke. With two extra inches that a Prince LongBody racquet can provide, you'll add 20 per cent more power. Imagine what a Prince® LongBody™ racquet can do for your game!

More spin

Spin is a direct result of higher racquet speeds. The extra speed that a Prince® LongBody™ racquet produces increases spin up to 10 per cent. Your topspin ground strokes drive harder and deeper, underspin shots stay lower, kick services bounce higher and slice serves go wider.

More reach

The extra inches provided by a Prince® LongBody™ racquet automatically increase your court coverage by up to 13 per cent. This expanded coverage, up to 13 per cent in all directions, lets you reach shots that were once impossible . . . suddenly returning them with ease. Instantly, you become 13 per cent harder to pass, and 13 per cent harder to lob over.

More control

Prince® LongBody™ racquets increase spin on the ball and allow you to place all of your shots with more control. For example, on a serve the added length provides a 13 per cent larger serving angle. As a result, first serve percentages dramatically increase, double faults decrease and aces soar by your opponent.

More comfort

Prince LongBody racquets are specially designed to allow more vibration to be absorbed throughout the racquet — instead of your arm. This improved vibration dampening effect allows you to play longer, play better and play harder without making it harder on your body.

Figure 2.21:
The advertising information from Prince clearly describes the biomechanical principles claimed in the design of the 'long body' racquet.

Source:
Pacific Leisure Australia Pty Ltd.

Motion

Types of motion

There are three basic forms of motion: **linear motion**, **angular** or **rotary motion**, and **general motion**.

Linear motion

Linear motion occurs when all the parts of an object travel over the same distance at the same time, for example, a speed ice skater gliding down the back straight after finishing a race. The centre of gravity of the object may trace either a straight line or a curved line, but in both cases all body parts travel the same distance at the same time. If a curved line is evident, it is called **curvilinear motion**; if a straight line is evident, it is called straight line motion.

The flight path or trajectory of a projectile (such as a ball, a javelin or a long jumper) is called a parabola; this is an example of curvilinear motion. Projectile motion is discussed later in this chapter.

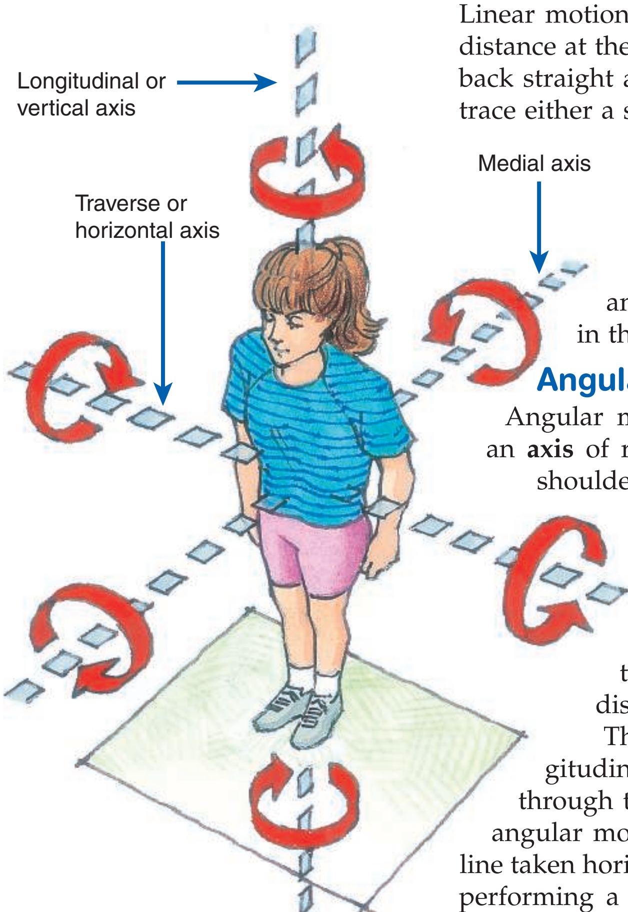


Figure 2.22: *The three axes of the human body*

Angular motion

Angular motion is evident when the body or an object turns about an **axis** of rotation. The axis may be a fixed point — for example, the shoulder joint in a throw, or the centre of gravity of an object or human. In this case, the body parts closest to the axis of rotation move less distance than do the body parts furthest from the axis of rotation. Not all body parts move the same distance, and those furthest from the axis move much more quickly than those closer to the axis. This is a concept used to great advantage in hitting or bat sports, and it has been discussed in greater detail in the section on levers (page 63).

The human body has axes about which it can rotate. The longitudinal or vertical axis is the line taken from head to toe vertically through the centre of gravity: an ice skater spinning is an example of angular motion about this axis. The transverse or horizontal axis is the line taken horizontally from hip to hip through the centre of gravity: a diver performing a triple front somersault demonstrates angular motion about this axis. The medial axis is also a horizontal axis taken from the navel to the small of the back through the centre of gravity: a gymnast performing a cartwheel demonstrates angular motion about this axis (figure 2.22).

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.

Activity 7 — Multimedia presentation

Angular motion

1. Videotape friends or class members performing a range of activities that demonstrate rotation about each of the three axes — for example, doing a forward roll, cartwheeling, spinning on a swivel chair, pirouetting. Play the tape to the whole class and describe the activity and the axis of rotation.
2. Alternatively, tape activities from the television and replay them to the class.
3. Record the activity and the axis of rotation in an appropriate table.

General motion

Angular motion or rotation tends to be far more common in sports than linear motion. However, most sporting activities use a combination of both types of motion. This is known as general motion. General motion may be described as linear motion of the whole body that is achieved by the angular motion of some parts of the body. For example, in running the 100-metre sprint the whole body moves in a straight line as a result of the rotary motion of the legs about the hip joint. A cyclist pedalling along a road also demonstrates general motion, as does as kayaker paddling down a river (figure 2.23).

Figure 2.23: *General motion — the body of the kayaker and the kayak move in linear motion as a result of the rotary motion of the arms and shoulders.*

Key skill

- **Describe biomechanical and skill acquisition principles using the correct terminology.**

Activity 8 **Multimedia presentation**

Types of motion

Use magazines, newspapers or the Internet to locate photographs showing linear, curvilinear, angular and general motion. Display these images either as a poster or as a PowerPoint presentation.

More about angular motion

Newton's three laws of motion also apply to angular motion.

- first law (inertia — see page 61): for example, a place kick in Rugby spins through the air only after it has been kicked;
- second law (acceleration — see page 61): for example, a diver spins rapidly in a tuck position only after they have pushed hard into the diving board;
- third law (equal and opposite reaction — see page 61): for example, a spinning ball hits the ground and its amount of spin is reduced by the opposite action applied by the ground.

Forces that create angular motion

A rotational force is called an **eccentric force.** This occurs when the force is applied away from the **centre of gravity** of an object. If only one eccentric force is applied, then both linear and angular motion will occur.

However, if one end of the body is fixed, an eccentric force will produce a turning effect only. No linear motion will occur in such a situation. For example, when a gymnast performs a giant swing on the horizontal bar, the axis of rotation (the hands grasping the bar) is fixed and only rotation occurs.

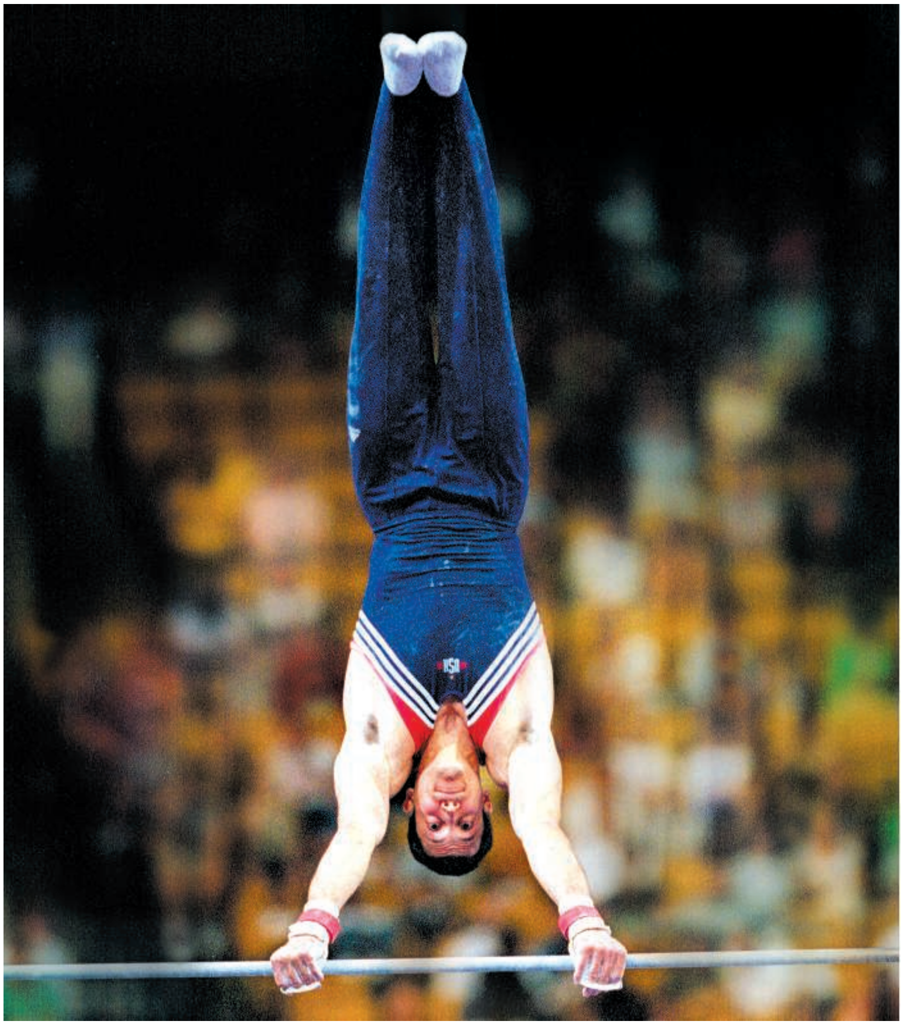


Figure 2.24: *A gymnast performing a giant swing on the horizontal bar*

The amount of rotation produced by an eccentric force depends on:

- the magnitude of the force — the greater the force applied, the greater the **angular velocity**
- the distance between the point of force application and the axis of rotation (the **moment arm**)

The product of these is called the **moment of force.**

Moment of force = applied force × moment arm.

The greater the moment of force, the greater is the resulting rotation. In order to increase the moment of force, the athlete may either increase the force applied, or simply apply the force at a greater distance from the axis of rotation.

Force couples

When two equal but opposite eccentric forces are applied at the same distance from, but on opposite sides of the centre of gravity of an object, the object will simply rotate in a fixed position. No linear motion will occur. This situation is referred to as a **force couple.**

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical and skill acquisition principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**

Activity 9 Laboratory report

Angular motion (rotation)

This laboratory activity explores angular motion (rotation), and in particular, the concepts of moment of force and force couple.

Part A

Equipment

- a ruler (30 cm)

Method

Step 1

- Place the ruler flat on a table.
- Use your finger to apply a force on the side of the ruler through the centre of gravity of the ruler.
- Observe and record what happened.

Question

What name is given to a force that produces this effect?

Step 2

- Place the ruler flat on a table.
- Use your finger to apply a force on the side of the ruler through a point 2 centimetres along from the centre of gravity of the ruler.
- Repeat the above but applying the force at 5, 10, and 15 centimetres from the centre of gravity of the ruler.
- Observe and record what happens in each case.

Questions

1. What name is given to a force that produces this effect?
2. What effect, if any, did applying the force further from the centre of gravity of the ruler have on the motion produced?
3. Explain the meaning of the following terms — moment arm and moment of force.

Part B

Equipment

- a basketball

Method

Step 1

- Bounce the basketball vertically down onto the floor, so that it rebounds straight back up to you. Make sure your hand is positioned directly on top of the ball as you bounce it.

Questions

4. Did the ball travel with linear and/or rotational motion? Explain your answer.
5. In which direction is the force applied, in relation to the centre of gravity of the ball, in order to produce this effect?

Step 2

- Place the basketball on the floor. With one hand on either side of the ball, apply an equal force with each hand so that the ball rotates (spins) on the spot.

Questions

6. Draw a diagram to indicate the direction of force application required to produce this effect?
7. What name is given to the forces that produce this effect?

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical and skill acquisition principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.

Activity 9 *continued*

Step 3

- You will need to work with a partner to complete this step.
- Stand 3 metres from your partner. Bounce the basketball to your partner giving the ball heavy topspin (i.e. the top of the ball rotating away from you).

Questions

8. Draw a diagram to indicate the direction of force application required to produce this effect.

9. In which direction are the forces applied, in relation to the centre of gravity of the ball, to produce this effect?

Moment of inertia

The **moment of inertia** is an extremely important concept for sport and reflects Newton's first law. The moment of inertia of a rotating body or object is its resistance to change, particularly resistance to beginning angular motion or rotation. In linear motion, the object's weight or mass determines its inertia. In angular motion, an object's inertia or moment of inertia has two components: its weight or mass, and the distance that the weight of the object is distributed away from the axis of rotation.

The closer the mass is distributed to the axis of rotation, the easier it is to rotate. For example, it is easier to rotate the arm about the shoulder joint (axis of rotation) when the arm is bent as opposed to when the arm is straight (figure 2.25).

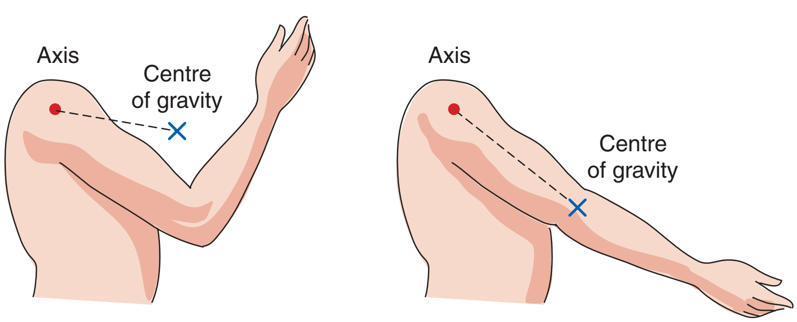


Figure 2.25:
With a bent arm, the moment of inertia is decreased — that is, there is less resistance to rotation.

Figure 2.26:
A young child gripping the handle of a baseball bat to decrease the moment of inertia.

Moment of inertia in sport

The concept of moment of inertia and its application in sporting situations can best be illustrated through some specific examples.

1. Baseball

Younger children will tend to, or should be instructed to, 'choke up' on a baseball bat — that is, grip the bat further up the handle. By doing so they reduce the bat's moment of inertia by reducing the distance between the mass of the bat and the axis of rotation, thereby making the bat easier to swing (figure 2.26).

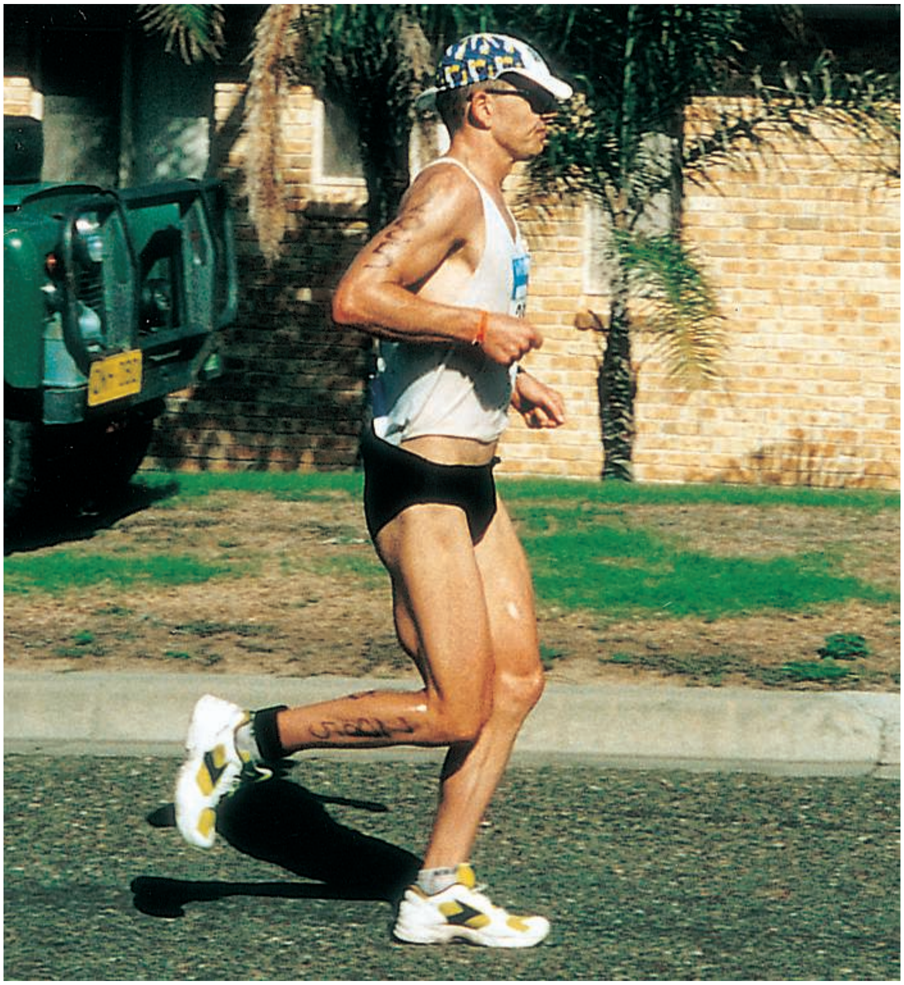


Figure 2.27:
A runner showing normal stride — elite Australian triathlete, Adam Deacon, finishing the 1998 Hawaii Triathlon. Note the hamstring flexing which occurs each time the running foot leaves the ground. This flexing decreases the leg's moment of inertia and allows it to swing through much more efficiently to then stretch out for the landing phase of each running stride.

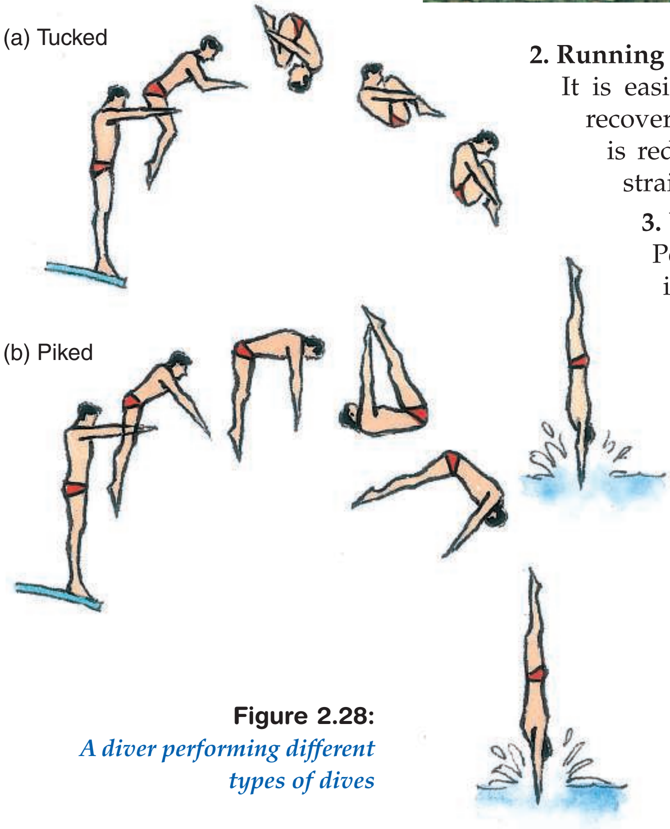


Figure 2.28:
A diver performing different types of dives

2. Running

It is easier to run by flexing the leg at the knee during the recovery phase, because the moment of inertia of the leg is reduced when it is bent as opposed to when the leg is straight (figure 2.27).

3. Diving

Performing a front somersault dive in a tucked position is easier than performing the same dive in a piked position, because when tucked the mass of the body is close to the axis of rotation and the moment of inertia is small. Rotation and angular velocity when in the tuck position are rapid. However, when in the pike position the body mass is further from the axis of rotation and the moment of inertia is increased. Rotation is twice as slow as in the tucked position (figure 2.28).

Reducing the moment of inertia is the main reason why younger children should be provided with junior-sized equipment such as racquets and bats. With junior-sized equipment both the mass and the distribution of the mass relative to the axis of rotation are decreased, therefore reducing the bat or racquet's moment of inertia, and making it easier for the child to swing and control.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.
- Compare and contrast the impact of different techniques on performance.

Activity 10 Laboratory report

Moment of inertia

This laboratory activity explores the concept of moment of inertia. The moment of inertia of a body equals the mass of the body multiplied by the square of its distance from the axis of rotation (radius of rotation).

The moment of inertia will be increased when the radius of rotation of the body is increased. This will result in a decreased angular velocity of the body. The moment of inertia will be decreased when the radius of rotation of the body is decreased. This will result in an increased angular velocity of the body.

Work in pairs to complete the following tasks:

Task A

Equipment

- roman rings

Method

- Hold onto the roman rings with two hands and have your partner slowly turn you around so that you wind up the cables of the rings.
- Have your partner release you, and as you unwind and rotate, vary the position of your legs as shown in figure 2.29.
- Have your partner observe and record what happens, and then change over roles.

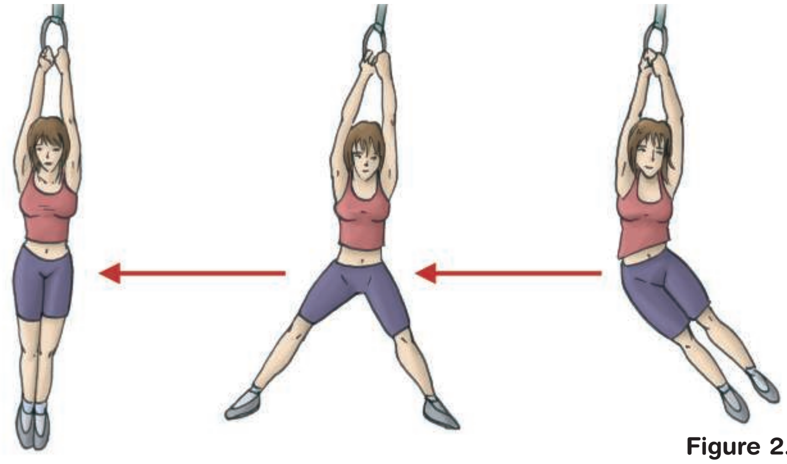


Figure 2.29

Task B

Equipment

- swivel chair
- two shot-puts
- gym mats laid out on floor around the chair for safety reasons.

Method

- Sit in the swivel chair and have your partner push you so as to spin you around while seated (figure 2.30).
- As you are spinning around, alternate your legs between tucked in and extended.
- Have your partner observe and record what happens, and then change over roles.

Figure 2.30

continued ➤

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 10 *continued*

- Repeat the spinning around in the chair, but this time hold the two shot-puts in your hands and alternate between holding the arms folded across the body and extending the arms out to the sides while holding the shot-puts (figure 2.31).
- Have your partner observe and record what happens, and then change over roles.

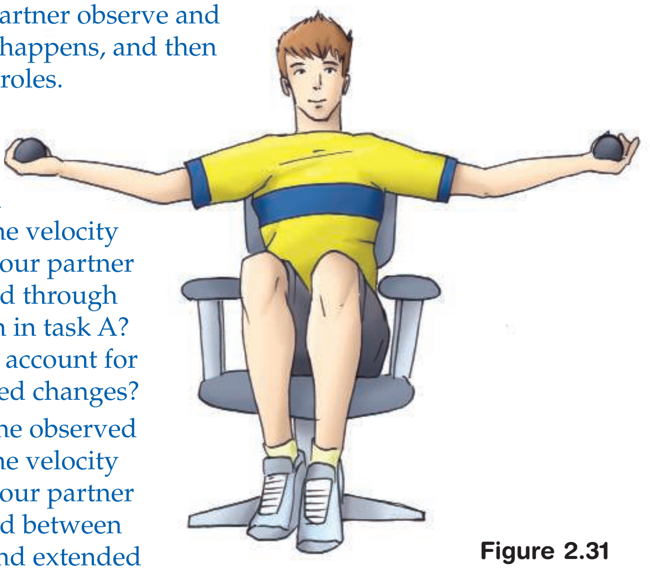


Figure 2.31

Questions

1. What were the observed changes in the velocity of you and your partner as you moved through each position in task A? How do you account for these observed changes?
2. What were the observed changes in the velocity of you and your partner as you moved between the tucked and extended leg position in task B? How do you account for these observed changes?
3. What were the observed changes in the velocity of you and your partner when you moved between the arms folded and arms extended positions in task B? How do you account for these observed changes?
4. A baseballer continually hits the ball into foul territory before first base. Using the principle of moment of inertia, what advice could you give the batter to help increase his or her chances of hitting the ball into fair territory? Explain the advice you provide.
5. Figure 2.32 shows a trampolinist performing a skill known as a barani. Using the principle of moment of inertia, explain when in the movement sequence it would be most appropriate to initiate the twist rotation. Give reasons for your answer.

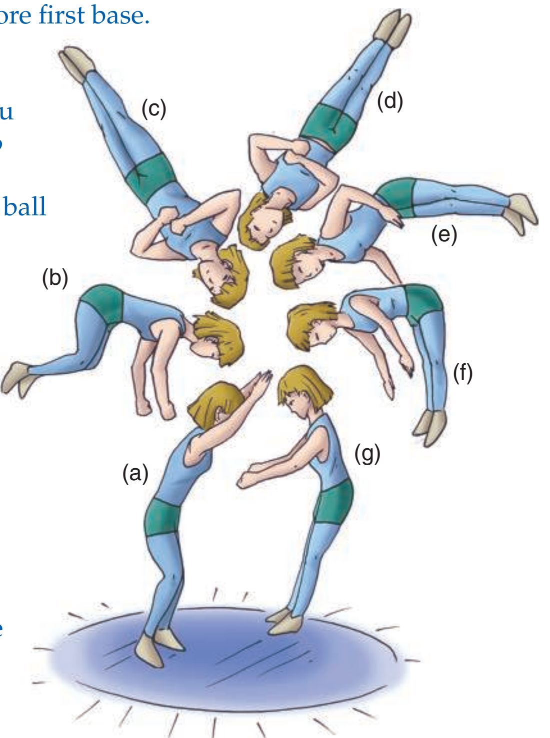


Figure 2.32

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Compare and contrast the impact of different techniques on performance.

Activity 11 Written report

Moment of inertia

1. Visit a sports store and note the length of the racquet shaft and handle in junior tennis racquets. Using biomechanical concepts, explain why junior racquets are shorter in the handle.
2. Describe the diver's 'angular velocity' and 'moment of inertia' in figure 2.28 for each method of diving:
   (a) tucked (b) piked.
3. What do you think happens to the diver's 'angular momentum' after take-off until they enter the water?
4. Give three sporting examples, other than those used in this chapter, of how an athlete changes body position or shape to increase rotational speed.

Angular momentum

Remember that in linear motion, momentum equalled mass times velocity. **Angular momentum** depends not on mass and linear velocity but on moment of inertia and angular velocity.

Angular momentum = moment of inertia × angular velocity.

The conservation and transfer of angular momentum

The **conservation of angular momentum** is based upon Newton's first law of motion. As applied to angular motion this law states that 'a rotating body will continue to rotate about its axis of rotation with constant angular momentum, unless acted upo[illegible]al force'. Given this definition it follows that if angular mo[illegible]ns constant, then moment of inertia and angular velocity are inversely proportional — as one increases, the other must decrease and vice versa.

A simple sporting example that illustrates this principle can be observed in diving (see figure 2.28). Angular momentum in diving is gained at the point of take-off from the board and is conserved until the diver enters the water. If, during the dive, the diver adopts a tucked position he or she will rotate faster than when in a piked or layed-out position. This is because in a tucked position the diver's moment of inertia is decreased. Given that the diver's angular momentum must remain constant, the decrease in moment of inertia must result in an increase in angular velocity — in other words the diver rotates faster.

The concept of conservation of angular momentum also includes the notion that angular momentum can be transferred from one body part to another. This is the principle of **transfer of angular momentum.** For example, when sitting on a swing, a person uses the action of the legs swinging forwards and backwards to get the swing in motion. The angular momentum produced by the forwards and backwards movement of the legs is transferred to the upper body causing the swing to move. Figure 2.33 shows a gymnast transferring momentum from the legs to the upper body as she performs a kip movement on the high bar. Parts II, III and IV show the legs being forcefully kicked downwards, thus transferring momentum to the upper body which is then able to rise above the bar. This also demonstrates Newton's third law of motion — equal and opposite reaction.

The concept of sequential summation of force to develop maximum force production is based on the transfer and conservation of angular momentum from one body part to the next.

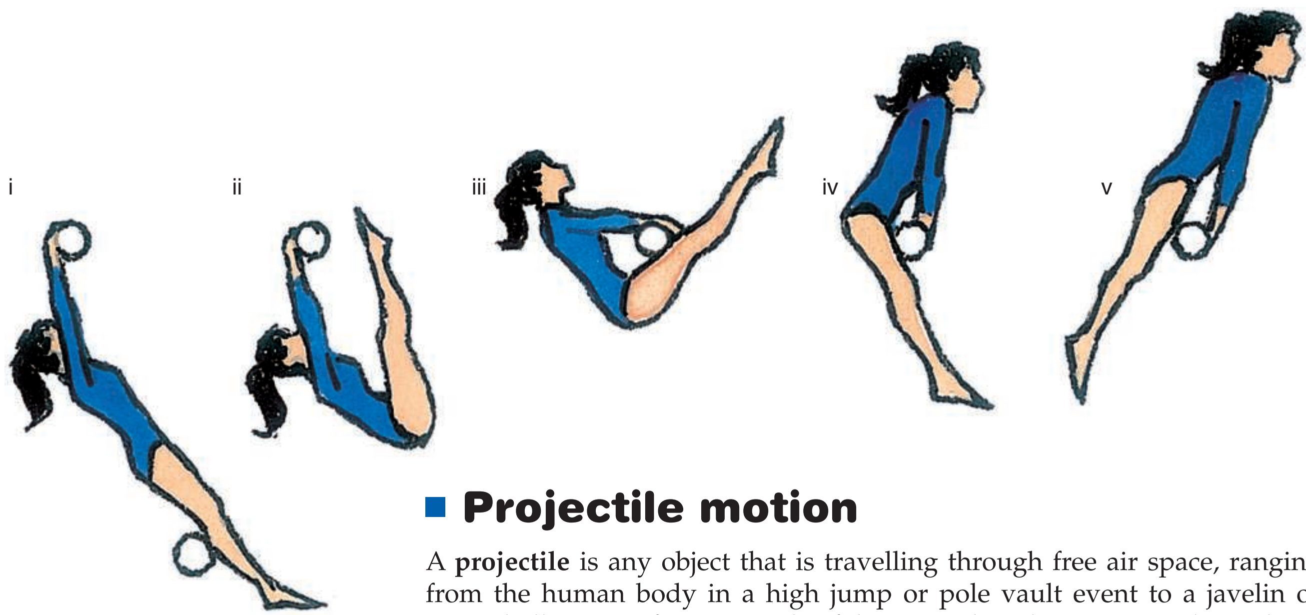


Figure 2.33: *Kip on the high bar*

Projectile motion

A **projectile** is any object that is travelling through free air space, ranging from the human body in a high jump or pole vault event to a javelin or tennis ball passing from one side of the net to the other. A projectile can have a range of different **trajectories** or flight paths depending on the nature of the activity (figure 2.34).

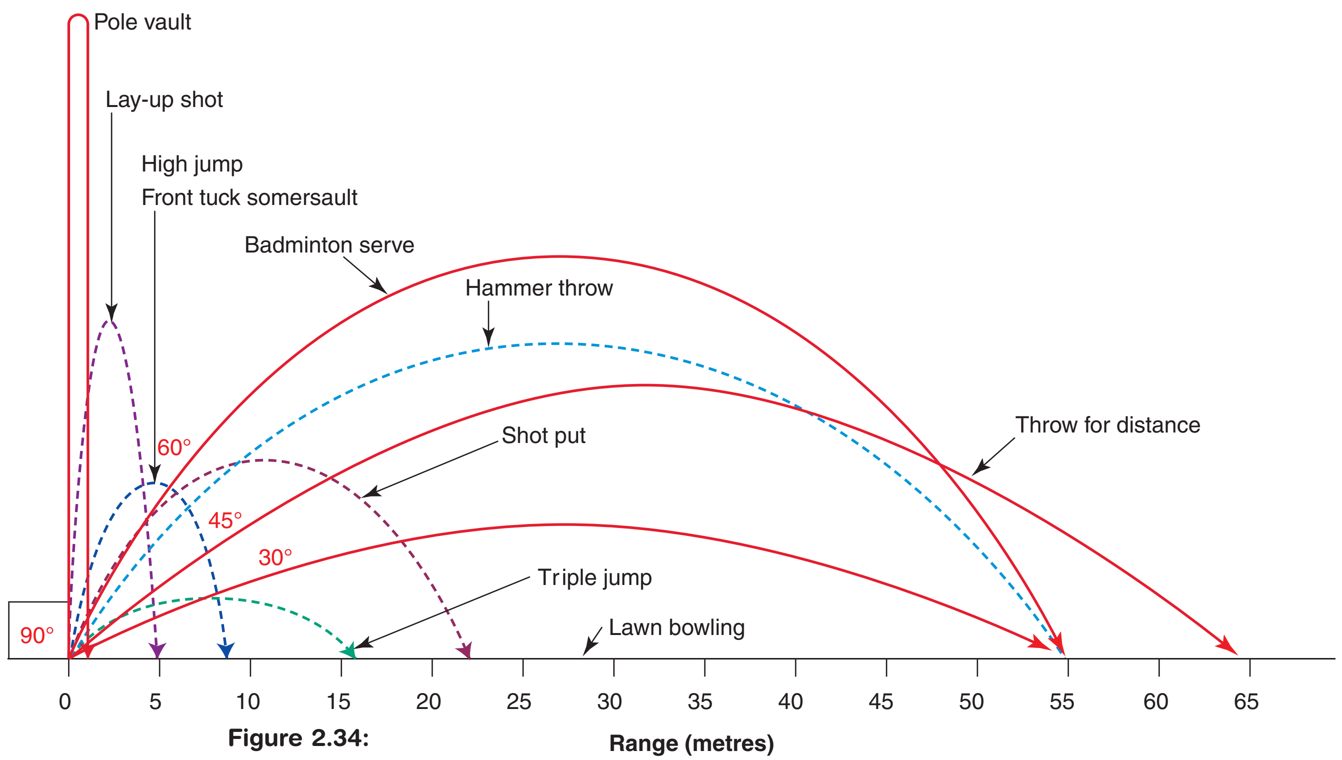


Figure 2.34: *The range of trajectories for various events involving projectiles*

Factors affecting the flight of projectiles

A projectile's trajectory is influenced by a number of factors including:

- speed or velocity of release
- angle of release
- height of release
- gravity
- air resistance
- spin.

Speed or velocity of release

Speed or **velocity of release** is the single most important factor for achieving maximum distance of a projectile. Basically, the greater the velocity of release, the greater the distance achieved.

Angle of release

When attempting to achieve maximum distance, the theoretical optimal **angle of release** of a projectile is 45 degrees for any given velocity of release. This angle of release provides equal components of vertical and horizontal force. However, this applies only when the height of release and height of landing are the same, and when spin and air resistance are not present. Given that this is rarely the case, the optimal angle of release for achieving maximum distance in most sporting activities is usually less than 45 degrees, with between 35 degrees and 45 degrees being most common.

Height of release

For any given velocity and angle of release, as the **height of release** increases, the distance achieved increases. However, if the height of landing is greater than the height of release, the horizontal range is decreased.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 12 Laboratory report

Projectile motion

The aim of this laboratory activity is to demonstrate the relationship between velocity of release, angle of release and height of release on the trajectory and distance achieved by a projectile.

Equipment

- tennis ball throwing machine or water hose
- tape measure

Method

- Release the ball or water at
  - three different velocities while maintaining the same angle (45°) and height of release
  - three different angles (30°, 45°, 60°) while maintaining the same speed of release and height of release
  - three different heights of release while maintaining the same speed and angle of release.

Results

- Record the distance achieved under each condition in an appropriate table.
- Draw and accurately label the flight path of the ball or stream of water under each condition.

Discussion

1. What effect did varying the velocity of release have on the flight path and distance achieved by the ball or stream of water?
2. What effect did varying the angle of release have on the flight path and distance achieved by the ball or stream of water?
3. What effect did varying the height of release have on the flight path and distance achieved by the ball or stream of water?
4. What combination of variables (velocity, angle and height of release) was the maximum distance achieved?
5. Under what circumstances is the ideal angle of release 45 degrees?
6. Give three examples from different sports where the velocity of a projectile is more important than the distance it travels?

Gravity

Gravity is a constant force which acts on all projectiles by pulling them towards the earth at the rate of 9.8 metres per second. Gravity creates the parabolic trajectory of all projectiles.

Air resistance

Ignoring the effect of **air resistance**, the distance that a projectile would travel in a vacuum is represented by:

Distance = velocity × flight time.

For example, velocity = 50 metres per second, flight time = 10 seconds, distance = 500 metres.

It has been calculated that a soccer ball kicked at 35 metres per second at an angle of 45 degrees would carry 125 metres in a vacuum, whereas the effect of air resistance means that it carries around only 65 metres in reality. Thus, air resistance markedly reduces the distance of a throw or hit; however, it can be used to advantage in many sports, for example, a swing bowl in cricket or softball, and a swerve ball in a soccer corner kick.

A projectile must push through the atmosphere or air. Thus, it disturbs the air, creating a **drag force** behind it; as speed increases, so does drag. This means that the air acts in two ways: first as a frictional force through which the projectile must push, and second as a drag force from which it must escape.

The effect of air resistance on a projectile depends on many factors, all of which are characteristics of the projectile.

Size or surface area of the projectile

The larger the **surface area** of a projectile, the more it is affected by air resistance. Reducing the surface area, particularly the frontal surface area, is an important consideration in the design of objects and equipment that act as projectiles in sport.

The nature of the surface area of the projectile

The nature of the surface covering of a projectile affects the degree of air resistance encountered. Rough textured covering, as opposed to smooth surfaces, increases the amount of air resistance experienced by the projectile during flight. It is differences in the texture of the outer surface of a cricket ball that helps to produce the swing of the ball that many bowlers seek to achieve.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 13 Written report

Secrets of Sultans of Swing

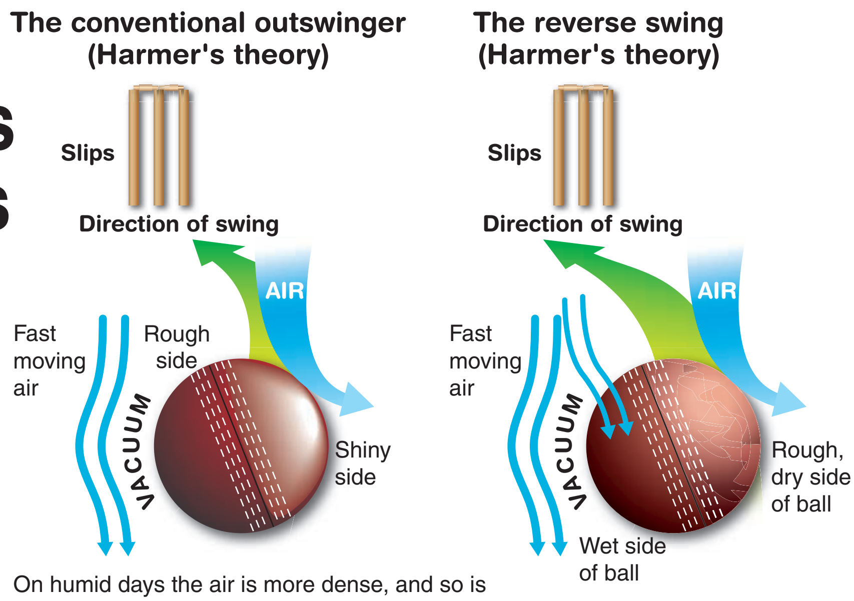
Read the article 'Cricket theorist seeks key to secrets of Sultans of Swing' (figure 2.35) and then complete the following tasks:

1. Outline the conventional theory as to how swing is produced when bowling.
2. Outline the alternative theory proposed by John Harmer as to how swing is produced by a bowler.
3. Explain how 'reverse swing' is achieved according to the theory proposed by John Harmer.
4. Why is it that a cricket ball seems to swing more on humid days as opposed to other days?

Cricket theorist seeks key to secrets of Sultans of Swing

by Greg Baum

Like cures for cancer, explanations for swing bowling are eagerly sought, abundant and mostly suspect. Nothing incontrovertible has been advanced about either.



On humid days the air is more dense, and so is trapped more thickly on the ball, creating a greater pressure difference, and therefore a greater vacuum and more exaggerated movement.

For nine years, John Harmer has applied a cricketer's mind, a scientist's method and an enthusiast's concentration to the mystery, and believes he has unravelled it. He also believes he knows the secrets of the new craze, reverse swing.

Harmer played District cricket for many years and is now coach of Hawthorn. He is also a lecturer in biomechanics at Deakin University, Burwood, and since 1983 has made a meticulous study of bowlers, bowling and balls.

Heretically, Harmer said cricket balls do not swing because of a bowler's action, nor because of any vigorous shining of one side of the ball, but because of certain immutable laws of physics. It is all about air pressure.

'We can't really disturb the laws that the air has, and how it interplays with the ball,' he said. 'If you can change the rate of flow of air around the ball, you will alter the pressure systems on the ball. By doing that, the ball will be sucked to the left or right, depending on where the faster flow of air is.'

The trick, he said, was to release the ball in such a way as to harness these properties. For an outswinger, the upright seam is pointed towards the slips and the shiny side faces to leg. According to conventional theory, the on rushing air is blocked by the rough side of ball, but slips off the polished side, which consequently moves faster through the air and pushes the ball towards the slips.

Harmer disagreed. The rough side, he said, traps the air in pockets on the surface of the ball, like the dimples on a golf ball trap air. Further away from the surface, there is fast-moving air. The difference in pressure between the still air and the speeding air creates a vacuum, which sucks the ball off its original line.

To engineer reverse swing later in the innings, bowlers load the hitherto shiny side of the ball with sweat and whatever other moisture comes to hand. The conventional theory is that this weights the ball and drags it to one side. Again, Harmer demurred. The only effect moistening the ball would have would be to cause it to drop more quickly, he said.

'My understanding is, when you wet the ball, not only does it become a little heavier, but the surface of the ball becomes much more porous, a bit like sandpaper, and it puffs up. It has a pattern of small dimples, like a golf ball.

'The idea is that the air sits inside these little dimples, and that causes the air to adhere to the surface of the ball for a longer period of time than normal. So the air that keeps coming on to the ball is striking air which is already sitting on the ball. Because the air is going faster on one side of the ball, the ball is sucked into the low pressure system that the faster flow of air creates.'

The dimples effect is crucial. Harmer said that before golf balls had dimples, they could be struck no further than 70–80 metres.

Harmer said there was a time in a cricket ball's working life, say between the 30th and 50th overs, when the two effects, orthodox and reverse swing, counterbalanced each other and there was little swing of any sort. This tallies with the experience of the English last summer, who found the Pakistanis were able to swing the ball late, sharply and in contrary directions, after 50 overs.

This does not explain, however, why the Pakistanis have found that the reverse swing effect is dramatically improved by roughing up the other side of the ball to such an extent that they were accused of illegal mutilation in England. None the less, Harmer does not believe reverse swing is a

continued ➤

sinister practice. 'I really don't think it is cheating. It is a technique within the rules, as long as you're not tampering with the ball,' he said.

Harmer said his theory also explained why the ball tended to move more on humid days. The humid air, he said, is more dense, and so is trapped more thickly on the ball, creating a greater pressure difference, and therefore a greater vacuum and more exaggerated movement.

'It's all to do with a combination of surface, speed, density and size of ball,' he said. 'There was the classic case of Bob Massie's wickets in England that day (Lord's, 1972). It was a day when everything was in his favour; the wind was right, the density of the air was right, the speed that he was bowling was right and the surface of the ball was being prepared properly. So you get a more dramatic effect all day.'

Harmer disagreed with former Test captain Richie Benaud's recently advanced theory that what the Pakistanis were employing was swerve rather than swing. Benaud said their technique was borrowed and refined from baseball. A baseball did not have a seam, he said, so pitchers had to use other skills to move it.

A baseball does have a seam, said Harmer, and pitchers use it dextrously to create fast balls, breaking balls and knuckle balls.

Harmer has worked in tertiary education for more than 20 years, as well as playing and coaching cricket, and has advised several AFL clubs on fitness. Nine years ago, he began his own painstaking research into the dynamics of cricket. He would sit at the MCG for days on end, filming Australian bowlers in match conditions, and has on film comprehensive studies of Dennis Lillee, Jeff Thomson, Geoff Lawson, Carl Rackemann and many others.

As well as his commitments at Burwood and Hawthorn, Harmer coaches young cricketers at the Victorian Institute of Sport, is assistant coach of the Australian women's team' and lectures Australian Cricket Board coaches on biomechanics.

Figure 2.35:
The nature of the surface of the ball and how this influences air resistance as the ball is in flight is the key to swing bowling in cricket.

Source:
Greg Baum, *The Age*, 1998.

Key knowledge

- **Developing and refining of basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 14 Report of participation in a practical activity

Swing and seam

The aim of this laboratory activity is to explore and experience swing and seam bowling.

Equipment
- indoor cricket balls
- tennis balls
- insulation tape.

Method
- Using indoor cricket balls in the gym, experiment and see if you can produce swing through the air when you bowl.
- Use the insulation tape to tape one half of a tennis ball, and see if you can produce swing through the air when you bowl this ball.

Results
- Observe and record your observations.

Discussion
1. Were you able to produce any swing through the air using the indoor cricket ball?
2. What techniques did you employ to produce this movement?
3. Were you able to produce any swing through the air using the taped tennis ball?
4. Which way did the taped tennis ball swing — towards the taped side of the ball or away from the taped side of the ball?
5. Explain your results using the theory of how swing is obtained.

The projectile's shape

Blunt-shaped objects passing through the air experience greater air resistance than streamlined tapered shapes. It is for this reason that aircraft are designed so as to have a tapered front, with narrow leading edges and a streamlined fuselage. This also applies to the design of racing cars and, more recently, bicycles.

Figure 2.36: *Aircraft, especially fast-flying military aeroplanes, are designed to reduce the amount of air resistance they experience.*

The projectile's velocity

Air resistance is greater at higher velocities as opposed to slower speeds. A ball thrown at high speed will experience greater air resistance than a ball thrown gently.

The projectile's mass or weight

Air resistance has a greater effect on lighter objects as opposed to heavier objects.

Key knowledge

- Developing and refining basic movment patterns using the correct terminology

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.

Activity 15 Laboratory report

Air resistance

Aim

The aim of this activity is to determine the factors that affect the degree of air resistance experienced by projectiles.

Method

Work in pairs and throw the following objects for distance.
Try to release each object at the same angle and the same velocity.
Leave each object where it lands.

- pateka
- shuttlecock
- squash ball
- table tennis ball
- medicine ball
- nerf ball
- practice golf ball
- soft lacrosse ball

Results

- Rank each object in order of distance thrown, from least distance to greatest distance.

Discussion

1. Using your knowledge of factors affecting the flight of projectiles, discuss your results.
2. Which factor do you believe was most significant in achieving a lot of distance? Or was it a combination of more than one factor?
3. How could you increase the distance you threw the objects?

Spin imparted to the projectile

Spin is created when a ball or any object is subjected to an eccentric force creating a force couple. This generally occurs as the result of an oblique impact between the ball and an implement such as a racquet (figure 2.37) or the ball and the ground.

An oblique impact occurs when objects impact at an angle — for example, a bounce pass in basketball when the ball hits the floor. The bottom of the ball slows down as a result of friction between the ball and floor. The top of the ball keeps going and the ball leaves the floor with topspin imparted.

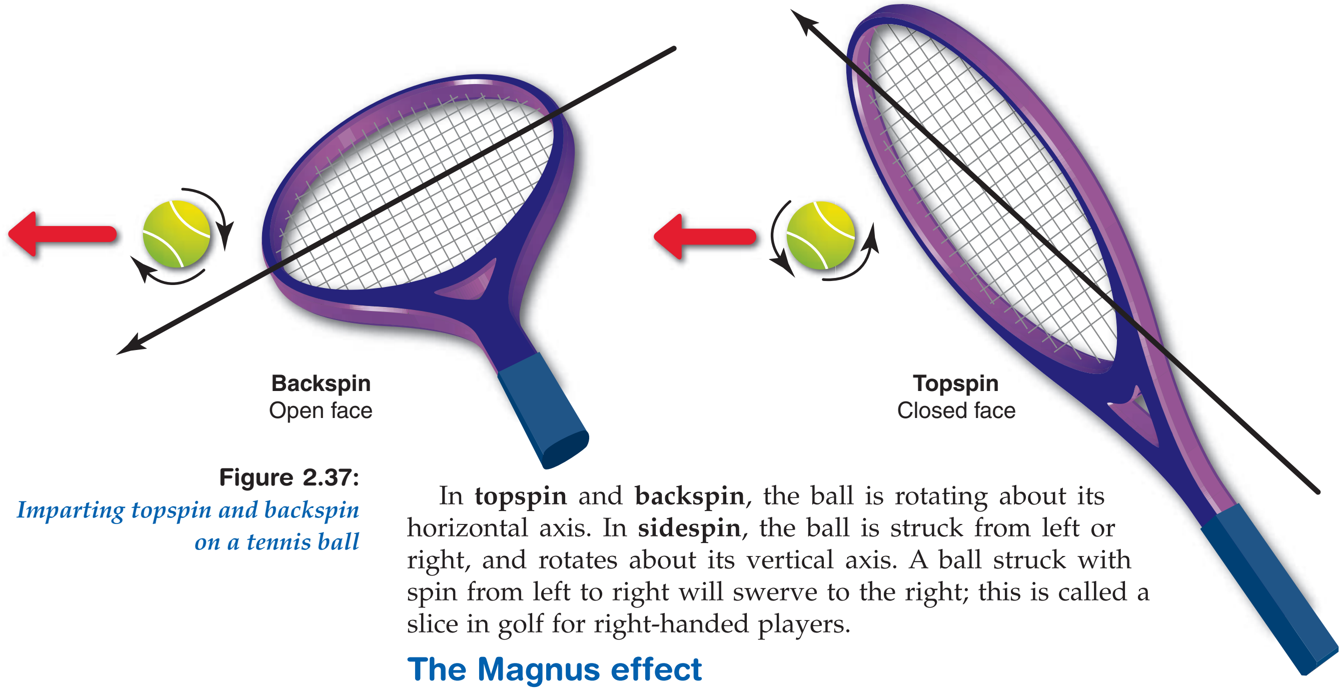


Figure 2.37: *Imparting topspin and backspin on a tennis ball*

In **topspin** and **backspin**, the ball is rotating about its horizontal axis. In **sidespin**, the ball is struck from left or right, and rotates about its vertical axis. A ball struck with spin from left to right will swerve to the right; this is called a slice in golf for right-handed players.

The Magnus effect

The **Magnus effect** explains the deviation of flight paths of balls with spin. Topspin tends to shorten the flight of the ball, which dips sharply at the end of its flight. Backspin also shortens the flight of the ball, which falls more slowly at the end of the flight. Sidespin makes the ball curve left or right in the direction of the spin.

Any ball travelling through the air tends to carry a thin layer of air close to its surface. The less streamlined the surface area of the ball, the more air it will carry with it. The layer of air on the surface of the ball interacts with the oncoming air, creating a disturbance.

When a ball is spinning, one section of its surface area spins in opposition to the oncoming air, while the other section spins in the same direction. This creates a pressure difference, with the opposing section developing a high pressure area. The ball will always move in the direction of the low pressure area (because movement is from high to low whenever pressure differences occur in nature) (figure 2.38).

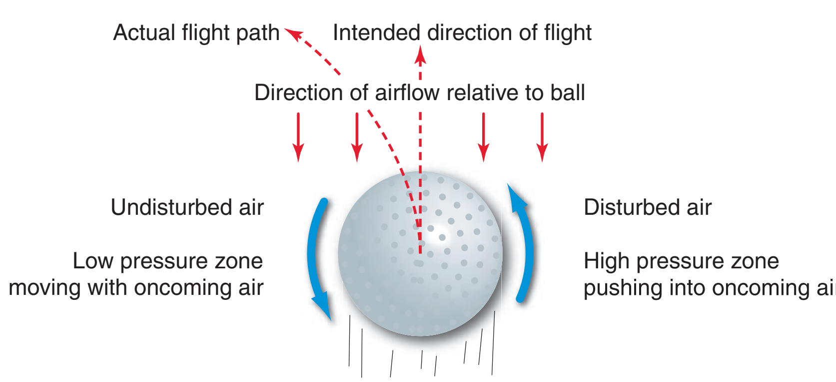
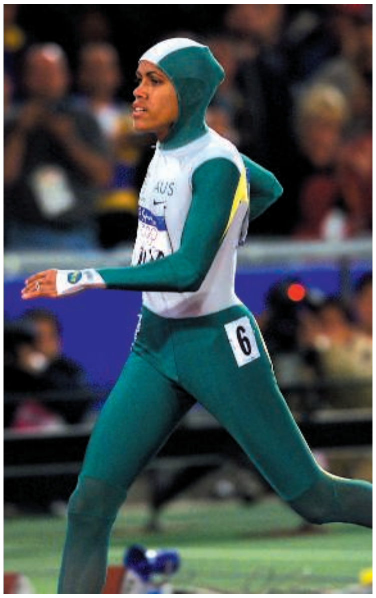


Figure 2.38: *This golf ball has sidespin from right to left which creates a 'hook' for the right-handed golfer.*



Many of the factors that affect the flight of projectiles also apply to the human body as it moves through air and another fluid medium — water. Factors such as the size of the body's surface area, the nature of the surface area (smooth or rough) and the body's shape all influence the amount of resistance the human body experiences as it moves through the air or through the water. Equipment and clothing have been designed and developed to help reduce the amount of air and water resistance opposing the movement of the body through these fluid mediums. Examples include lycra body suits such as the Nike swiftsuit worn by athletes including Cathy Freeman; full body suits worn by swimmers such as Ian Thorpe; and aerodynamically designed bicycles and helmets as used by Australia's gold medal winning 4000-metre team pursuit cyclists at the Athens Olympics in 2004.

Figure 2.39: *Cathy Freeman wearing the Nike swiftsuit during her victory in the 400-metres at the 2000 Olympics*

Figure 2.40: *Ian Thorpe's full-length swimming costume actually reduces the amount of resistance that opposes his movement through the water.*

Figure 2.41: *Australia's 2004 Olympic gold medal winning 4000-metre pursuit team used equipment and clothing specially designed to reduce air resistance.*

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechancial principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.

Activity 16 Report on participation in practical activity

The effects of spin

Aim

To determine the effects of ball spin on the flight path and direction of the ball

Equipment

- table tennis ball
- table tennis bat

Method

- Colour a table tennis ball on one side (so you can see its spin).
- Hit the ball with the following types of spin:
  - topspin
  - backspin
  - slice — left and right
- In each case observe and note (a) the direction and angle of the bat, (b) the type of spin created and (c) the effects on the flight path of the ball. Also draw the flight path in each case.

Discussion

1. Explain the effect (called the Magnus effect) on the flight path in each case.
2. How does the Magnus effect act on topspin, backspin, slice and hook?
3. Explain why the Magnus effect does not work on a torpedo punt in Australian Football or a pass in Rugby Union.

Impact, rebound and spin

A direct impact through the centre of gravity of a ball will not create spin, as demonstrated by a straight drive in cricket or a chest pass in netball. An oblique impact occurs when the ball contacts or is contacted by an object away from its centre of gravity, creating a *force couple* and therefore spin. When a ball has an oblique impact with a fixed object, for example, the ground or a gym floor, the ball will come off the floor with some amount of spin, depending on (a) the friction between ball and floor, and (b) any spin on the ball before landing.

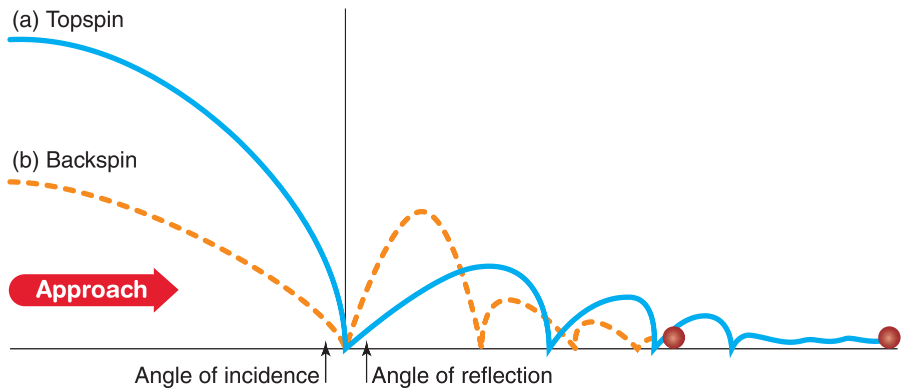


Figure 2.42: *The effect of topspin and backspin on the rebound of a ball*

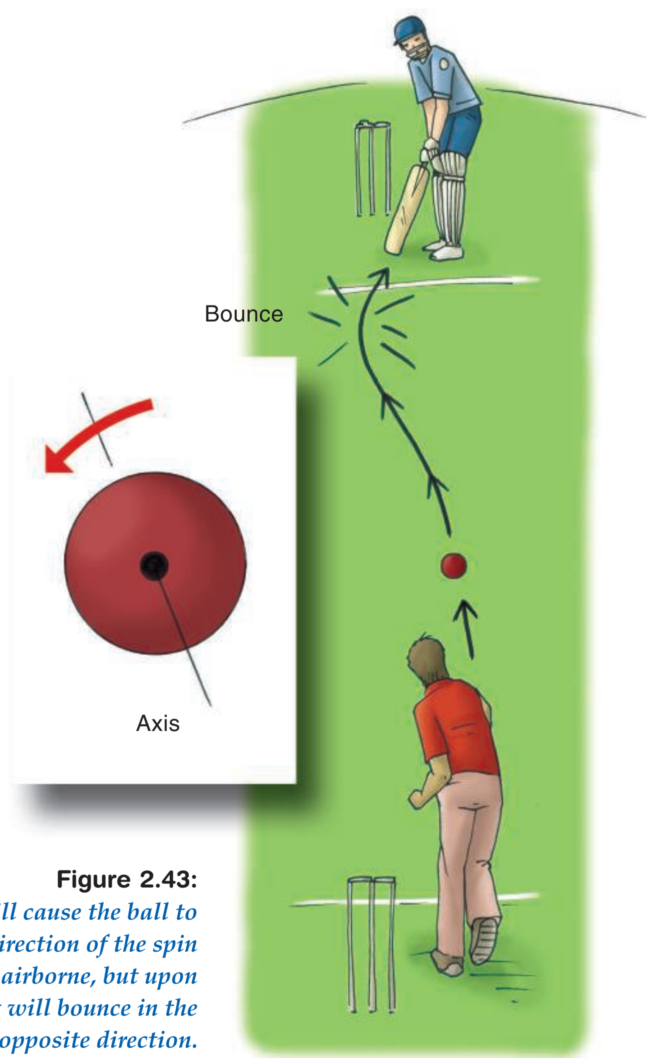


Figure 2.43: *Sidespin will cause the ball to curve in the direction of the spin while it is airborne, but upon landing it will bounce in the opposite direction.*

Figure 2.42 shows that the **angle of incidence** is the angle at which the ball approaches the floor, and that the **angle of reflection** is the angle at which it leaves the floor. This angle in the figure has been measured from the horizontal axis (or the floor).

The principle of transfer of momentum dictates that some momentum from the ball will be transferred to the floor at impact, so the ball will always have a lower angle of reflection. Backspin will increase the angle of reflection while topspin will decrease it.

A ball imparted with sidespin will curve in the direction of the spin while the ball is airborne. Upon landing it will rebound and bounce in the opposite direction (figure 2.43).

Utilising spin in sport

Spin is utilised to great effect in a wide variety of sports, including cricket, soccer, tennis and golf to name just a few.

In cricket, players such as Shane Warne (figure 2.44), the current record holder for the most wickets in test matches, use spin when bowling to deceive batsmen. Leg and off breaks make it difficult for the batsman to determine the flight path and bounce of the ball.

Figure 2.44:
Shane Warne utilises leg spin to capture yet another test wicket.

Soccer players such as David Beckham are skilled at imparting side spin on the ball when taking free kicks close to goal — the kick then curves through the air and into the back of the net.

Tennis players impart both topspin and backspin to the ball. Topspin is used to allow players to hit the ball very powerfully yet still have the ball land in court due to the fact that it drops sharply at the end of its flight.

In golf, the clubs are equipped with club heads of different angles. Drivers tend to impart topspin to the golf ball so that it will travel further and bounce on after landing so that maximum distance is achieved. High irons such as a 9 iron, with its sharply angled club face, tend to impart backspin and are used as the golfer approaches the green to loft the ball onto the putting surface. The backspin prevents the ball from bouncing off the green, and in some cases the ball may even rebound backwards.

The coefficient of restitution

Different types of materials react differently upon impact and rebound at different velocities. An important factor that determines the way an object reacts upon impact with another object or surface is its **elasticity**. Put simply, elasticity refers to the property of an object to regain its original shape after impact. When an object, such as a tennis ball strikes a court surface or when a golf ball is struck by a golf club, some **deformation** of the ball occurs (figure 2.45, page 90). The greater the elasticity of the object, the faster it will return to its original shape and the farther it will rebound after impact.

The **coefficient of restitution (e)** of an object is a measure of its elasticity upon impact with a given surface. In other words, it is a measure of an object's ability to return to its original shape after being deformed at impact. The coefficient of restitution can be determined by dropping a ball from a given height, and then measuring the height of its rebound. The following formula is then applied:

$$e = \sqrt{\frac{\text{height bounced}}{\text{height dropped}}}$$

In all cases the coefficient of restitution will be less than 1.0 because impact creates a transfer of some momentum from the ball to the surface. Also some energy at impact is 'lost' in the form of heat and sound. The higher a ball rebounds or bounces after impact, the greater its coefficient of restitution, and hence the greater its elasticity.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**

Activity 17 Laboratory report

The coefficient of restitution

This laboratory activity allows students to explore the concept of the coefficient of restitution, and to determine the coefficient of restitution of a variety of different balls dropped onto different surfaces. The coefficient of restitution of an object is a measure of its elasticity upon striking a given surface. The coefficient of restitution of any given object (such as a ball) is not fixed. This value can change according to such factors as temperature of the ball and the nature of the impacting surfaces.

Part A

Equipment

- a variety of different balls such as:
  - tennis ball
  - cricket ball
  - basketball
  - volleyball
  - baseball
  - softball
  - lacrosse ball.
- measuring stick.

Method

1. Work in pairs with one person dropping the balls and the other person measuring the height or rebound.
2. Release each of the balls from the same given height, for example off the edge of a table or from a particular joint line in a brick wall, and have them land on a given surface such as a wooden floor.
3. Observe and record the height of rebound of each ball in an appropriate table.
4. Calculate the coefficient of restitution of each ball using the following formula:

$$e = \sqrt{\frac{\text{height bounced}}{\text{height dropped}}}$$

Part B

Equipment

- tennis ball (preferably brand new)
- a variety of floor surfaces such as:
  - wooden floor
  - linoleum floor
  - carpet floor
  - asphalt
  - grass
  - gymnastics mat
  - concrete.
- measuring stick.

Method

1. Work in pairs with one person dropping the balls and the other person measuring the height of rebound.
2. Release the same tennis ball from the same given height, for example, off the edge of a table or from a particular joint line in a brick wall, and have it land on the different surfaces.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.

Activity 17 *continued*

3. Observe and record the height of rebound of the ball in each case in an appropriate table.
4. Calculate the coefficient of restitution of the ball using the following formula:

$$e = \sqrt{\frac{\text{height bounced}}{\text{height dropped}}}$$

Part C

Equipment

- 3 identical (and preferably brand new) tennis balls
- measuring stick.

Method

1. Work in pairs with one person dropping the balls and the other person measuring the height of rebound.
2. Release each of the tennis balls from the same given height, for example off the edge of a table or from a particular joint line in a brick wall, and have it land onto your original surface from part A. Do this utilising a ball:
   - at normal room temperature
   - a ball that has been cooled (place it in a freezer for one hour beforehand)
   - a ball that has been warmed (have your teacher warm the ball in a microwave for a maximum of 15–20 secs).
3. Calculate the coefficient of restitution of each ball using the following formula:

$$e = \sqrt{\frac{\text{height bounced}}{\text{height dropped}}}$$

Results

- All results from parts A, B and C must be recorded in three appropriate tables. Calculated values for the coefficient of restitution must be included in each table.

Discussion questions

1. In part A, which ball had the highest coefficient of restitution? How do you account for this?
2. In part B, what type of surface flooring produced the highest coefficient of restitution of the tennis ball? What type of surface flooring produced the lowest coefficient of restitution of the tennis ball?
3. Based upon your results in part B, what generalisation can be made about the nature of the surface flooring and its effect on the coefficient of restitution?
4. Tennis is played throughout the world on a variety of different surfaces, e.g., grass, clay, asphalt, rebound ace and plexipave. Which of these surfaces would result in higher and lower coefficients of restitution of a tennis ball?
5. In part C, what effect did heating and cooling the tennis ball have on its coefficient of restitution? How is this knowledge relevant to sports such as squash and golf?

Factors affecting the coefficient of restitution

The coefficient of restitution of a ball will vary according to a number of factors.

Nature and condition of the ball

New balls in sports such as cricket, tennis and golf have higher coefficients than older balls. Likewise, balls such as volleyballs , netballs and basketballs that are properly inflated have greater coefficients of restitution.

Temperature of the ball

There is a direct relationship between temperature and coefficient of restitution. As the temperature of a ball increases there is a corresponding increase in the coefficient value. For this reason, golfers often warm their ball up prior to hitting off by keeping it in their pocket, and squash players 'hit up' before a game in order to heat up the ball to its optimum playing temperature.

Surface composition

The composition of the playing surface with which the ball comes into contact also influences the coefficient of restitution. Some surfaces are more or less elastic than others, and as a result, the same ball will rebound somewhat differently from these different surfaces. For example, in tennis the different court surfaces (clay, grass, hard court, rebound ace) affect the height and speed of rebound of the ball. Clay courts, such as those used during the French Open, are generally regarded as the slowest courts because the ball tends to rebound at lower velocities off this type of surface.

Figure 2.45: *An example of how the two impacting surfaces compress and how momentum transfers from one to the other*

Nature of the striking implement

In sports such as tennis, cricket, baseball, softball and golf the nature of the striking implements also affects the coefficient of restitution of the ball. Tennis racquets that are tightly strung have a greater degree of elasticity than those racquets that are strung with lower tensions. Consequently, the tennis ball rebounds more rapidly from highly strung racquets, whereas racquets with lower string tensions produce less power but greater control.

Velocity of impact

There is an optimum impact speed in any hitting sport. The harder the hit, the greater the compression of the ball. Balls must have some elasticity or they will shatter on impact. Golf balls generally have a coefficient of restitution of 0.7. How does this compare to the balls you used in activity 17? The more quickly a ball returns to its normal shape after impact, the more likely it is to have a high coefficient of restitution.

Friction

Friction is the force that arises whenever one body moves or tends to move across the surface of another; friction always opposes motion. There are two types of friction: sliding friction and rolling friction.

Sliding friction occurs when two objects slide or tend to slide on or over one another. A box lying on the floor (figure 2.46), for example, has two forces acting on it. With just these two forces acting, the box has no tendency to slide and therefore no friction is acting. However, the box will tend to slide if someone pushes the box (force 3 in figure 2.46). Only then will friction oppose this tendency (force 4 in figure 2.46).

An important characteristic of friction is that the frictional force is exactly equal to the force causing the box to slide, until sliding begins. Once the friction has reached its upper limit in magnitude (limiting friction), sliding is about to commence.

There are two ways of modifying friction between two bodies.
1. Alter the nature of the two surfaces, for example, oil or wax them, thus decreasing or increasing frictional force.
2. Change the forces that hold the surfaces together, for example, to get a book on a table to slide, simply lift the table at one end.

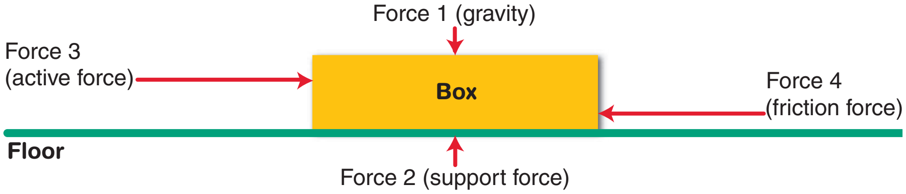


Figure 2.46: *Force 1 — gravity pulling the box downward; force 2 — the floor exerting upward support of the box; force 3 — the active force to create movement; force 4 — friction resisting motion*

Remember, it is easier to keep a body sliding than to start the slide.

Rolling friction occurs because the ball and the surface on which it is rolling are slightly deformed in the process. This type of friction is far less than sliding friction.

Coefficients of limiting friction and sliding friction range from 0.1 to 1.0. Rolling friction is of a coefficient of .001, therefore 100–1000 times less. The magnitude of rolling friction depends on:
- the nature of the ball and surface (soft, hard, wet, dry, over-inflated, under-inflated)
- normal reaction (the weight of ball)
- the diameter of the ball.

Friction is increased by the use of magnesium powder for grips by gymnasts, weightlifters and baseballers. Waxed skis reduce friction; leather soles on wooden floors reduce friction for ballroom dancers; and lycra body suits on cyclists and skiers reduce surface friction between the athlete and the oncoming air.

Balance and stability

In all sporting activities, whether stationary or moving, **balance** and stability plays an important part. **Stability** is defined as an object's resistance to movement, either linear or angular, from a balanced position. There are two types of stability:
1. static stability — when an object is at rest and is not moving with linear or angular motion it is said to be in a state of static stability
2. dynamic stability — when an object is in motion and is moving with linear or angular motion.

The stability of an object depends on:
- the mass of the object (its weight)
- the area of the object's base of support
- the height of the centre of gravity of the object above the base of support
- the position of the line of gravity relative to the base of support.

The mass of the object

The greater the mass of an object, the greater its stability will be, given that all other factors are equal. Therefore a heavier person is more stable than a lighter one. This is one of the reasons why sports such as wrestling and boxing are divided into weight divisions.

The area of the object's base of support

The area of the supporting base of an object is directly related to its stability. The greater the area of support, the greater the degree of stability.

The height of the centre of gravity of the object above the base of support

Gravity is a force that acts upon the human body in a vertical direction, pulling downwards towards the centre of the earth. Gravity acts on all objects in the same way, at a constant force of 9.8 metres per second squared. The **line of gravity** or pull of gravity will always pass vertically through the centre of an object's mass. This point is referred to as the object's centre of gravity, and it is defined as 'the point through which its total weight will always act'.

Locating the centre of gravity

The centre of gravity for a regular body such as rectangular block or a cylinder lies at the geometric centre of the body. It is easily located but for irregular-shaped bodies this process is more difficult and the centre of gravity can only be found by experiment or calculation.

The human body is not only irregular but it also changes its shape. Generally, the following applies:

- adult male — the centre of gravity is approximately 2.5 centimetres below the navel, or 57 per cent of their height
- adult female — the centre of gravity is approximately 55 per cent of their height from the ground
- child — the centre of gravity is approximately 60 per cent of their height from the ground.

The position of the centre of gravity of the human body changes with movement; it tends to move in sympathy with the movement and can even lie outside the body.

The higher the centre of gravity above the base of support, the less stable the object is. Athletes often lower their centre of gravity by bending the knees in order to increase their stability.

The position of the line of gravity relative to the base of support

The line of gravity is an imaginary vertical line passing downwards through the centre of gravity. The closer the line of gravity is to the limits of the base of support, the less the degree of stability of the object.

Movement can only occur when the line of gravity falls outside the object's base of support. This creates a state of imbalance and the object will move in the direction of imbalance. Athletes deliberately position the line of gravity close to the limits of their base of support so that only a small force is required to get them moving in the required direction. Swimmers and runners on the blocks lean forward in the direction of intended movement, so that when the gun goes off, it only requires a small amount of force to have them begin moving in the required direction.

Equilibrium

There are three states of **equilibrium**:

1. *stable equilibrium*. An object that will return to its equilibrium position after being pushed, pulled or hit has a state of stable equilibrium, for example, a punching bag suspended from the roof by a rope or a base-weighted punching doll.
2. *unstable equilibrium*. A gymnast performing on the balance beam is in a state of equilibrium but a small displacement from the position will cause her to fall off the beam.
3. *neutral equilibrium*. A tennis ball on the ground has no tendency to fall over, return to its original position or move further away. Its response to a slight push is to roll, which is different from the response of the punching bag or gymnast on the balance beam.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Compare and contrast the impact of different techniques on performance.**

Activity 18 Written report

Balance and stability

Study the diagrams in figure 2.47, then answer the questions.

1. Which player has the most stable position in example 1? Why?
2. Rank the defensive sports positions in example 2 from the most to the least stable. Explain your rankings.
3. Rank the diagrams in example 3 from least stable to most stable. Explain your rankings.
4. From which position in example 1 would it be easiest to initiate forward movement such as running to apply a tackle? Explain why.

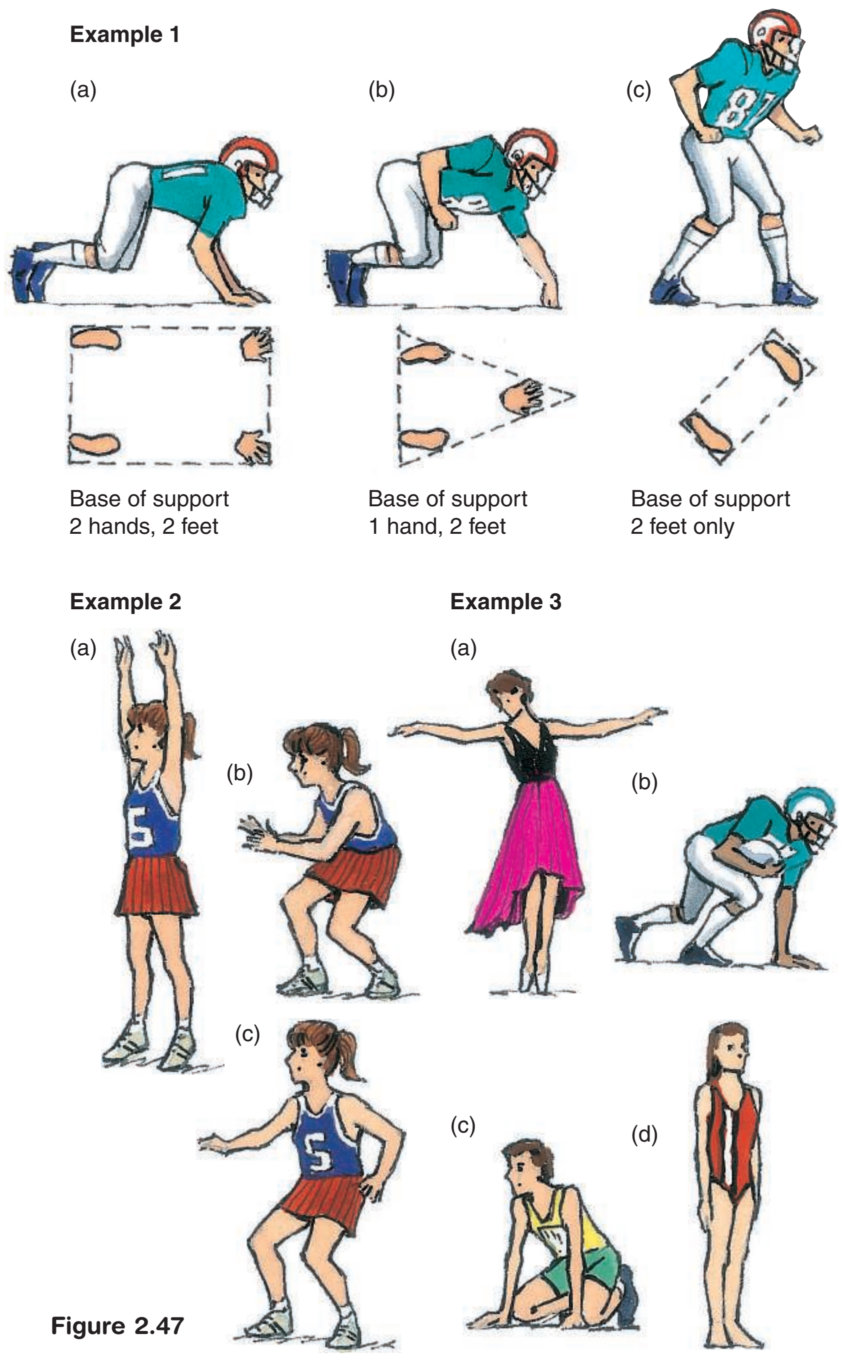


Figure 2.47

Figure 2.48: *Swimmers on the blocks lean forward so that their line of gravity falls close to the limits of their base of support. However, even the best sometimes lean too far.*

Application of biomechanical principles to basic movement patterns

Most sports and activities are made up of combinations of **basic or fundamental movement patterns**. These movement patterns include locomotion skills (running, stopping, jumping, hopping), balance and body management skills (balancing, evasion and landings) and object manipulation skills (throwing, catching, striking and kicking). They are the foundation or precursor movements to more specialised, complex skills used in sports, dance, gymnastics, outdoor education and physical recreation activities. The game of softball, for example, is comprised primarily of the basic movement patterns of throwing, catching, striking, running and stopping. The game of basketball is made up of throwing, catching, running, jumping, evading and stopping. Gymnastics activities consist of a running, balancing, jumping, hopping and landings.

All but a few physical activities are made up of combinations of these basic movement patterns. What changes from one activity to another is:

- *The way the movement patterns are used or performed*.
  For example, throwing and striking may be performed using different body actions, while in different body positions, while at a low/medium/high level, using a large/small action, rapidly/slowly, standing near to/far away from a partner or team mates, and using different implements (bats, racquets, sticks).
- *The context in which the movement pattern is used or performed*.
  For example, jumping may be performed within the context of a soccer game or in a gymnastics setting.
- *The environment in which the movement pattern is used or performed*.
  For example, throwing may be learned and performed in an aquatic environment, an out-of-door environment, a gymnasium environment, or a home environment.

The throwing movement pattern (overarm action) that is used to throw a ball is essentially the same movement pattern used to throw a ball with a lacrosse stick, to serve a ball with a tennis racquet, to serve or spike a volleyball, and to throw the ball when playing water polo. It is the ways, the contexts, and the environments in which the movement pattern is used that change from one activity to another.

The movement skills that evolve from a basic movement pattern are biomechanically similar in that they all share the same biomechanical goal and principles. For example, all the movement skills associated with the basic movement pattern of throwing, share the same common goal of imparting force to an object. Similarly, all landings, whether it is a landing on the feet, on the hands, or performed while rotating, share the same biomechanical goal of absorbing the force gradually over an optimum amount of time and distance.

The expectation is that after having learned the concept of throwing, for example, individuals will be able to transfer what they have learned to other skills and contexts where this movement pattern is used (e.g. the badminton and tennis overhead smash, the volleyball serve and spike, the javelin throw). Individuals who understand how to absorb force when landing on their feet should then be able to use that knowledge in other situations requiring the absorption of force.

The biomechanical principles and concepts that have been outlined in this chapter all influence the performance of these basic movement patterns. Coaches and teachers equipped with this biomechanical knowledge and understanding can assist learners to develop and refine these movement patterns more efficiently and effectively. For example, the development of an effective throwing action requires the application of the biomechanical concepts of force production including sequential summation of force, impulse and accuracy (flattening the arc) and leverage, angular motion including the moment of inertia, and projectile motion including the angle of release.

Qualitative analysis of human movement

One process or method for observing, analysing and improving the quality of human movement performance is commonly referred to as **qualitative analysis**. Duane Knudsen and Craig Morrison, in the second edition of *Qualitative Analysis of Human Movement* (Human Kinetics 2002), say that qualitative analysis 'involves the non-numerical analysis of movement information or a judgement on the quality of an aspect of movement'.

Coaches use qualitative analysis to observe and analyse performance to provide the most appropriate interventions to improve the performance. From a biomechanical perspective, coaches need to be able to observe and analyse movement patterns and skills related to the underlying biomechanical principles that help to determine the performance and execution of these skills. Through their knowledge of these principles they are able to provide the appropriate interventions and corrections that will improve performance.

A simple model of the process of qualitative analysis developed by Knudsen and Morrison (2002) involves four key tasks:

1. Preparation
2. Observation
3. Evaluation/diagnosis
4. Intervention.

Preparation

In the first task of qualitative analysis the coach is concerned with the process of developing a prerequisite knowledge base. The coach gathers information from scientific research, expert opinion and experience and considers carefully the key performance features of a movement or skill, as well as the common errors that performers exhibit. From a biomechanical perspective, this includes knowledge of the relevant biomechanical principles that are important in the proper and efficient execution of the movement or skill, and the typical errors associated with the application of these principles.

Observation

The second task, observation, involves systematically gathering appropriate information about the performance of the movement or skill. There are a number of different strategies for systematic observation of human movement, but perhaps the most common strategy involves observation by **phases of movement**. Put simply, this involves dividing the movement or skill into a number of phases or parts. Knudsen and Morrison (2002) suggest that most movements can be divided into three phases — the preparation phase, the execution phase, and the follow-through phase. Gerry Carr, in his book *Sports Mechanics for Coaches* (Human Kinetics 2004), states that many skills can be broken down into the following four phases: preparatory movements (set-up); windup or backswing; force-producing movements; and the follow-through (recovery). According to Carr, 'a phase is a connected group of movements that appear to stand on their own and that the athlete joins together in the performance of the total skill'. He then goes on to suggest that the next step is to divide each phase into its **key elements**. Key elements are distinct actions that join to make up a phase. For example, in the force-producing phase of a golf drive, the key elements are the weight shift, hip rotation, head position and arm and club extension.

Evaluation/diagnosis

The third aspect of qualitative analysis involves the identification of the desirable (strengths) and undesirable (weaknesses) aspects of the movement or skill performance, as well as the identification of possible ways of improving the performance (interventions).

Most of the literature about qualitative analysis suggests there are two primary ways in which coaches can evaluate movement performance. The first method involves the coach comparing a mental image of the desirable actions of a movement performance with the actual observed performances of the athlete. Coaches have frequently employed this process of focusing on the differences between a model of correct form and the actual movement. The second method of evaluation involves a determination by the coach of the extent to which biomechanical factors that affect the performance of the movement or skill were applied or achieved. A knowledge of biomechanical principles like those outlined earlier in this chapter can be used to evaluate a wide variety of movement patterns and motor skills, and these principles are directly related to interventions and corrections that can improve performance.

Intervention

The final task in qualitative analysis is intervention. This involves providing feedback and correction, usually under practice conditions, that will lead to improved performance.

The process of qualitative analysis can be used by coaches and teachers to assist athletes and students in developing and refining the basic movement patterns of throwing, striking, running, stopping, kicking and catching as well as a range of motor skills that emanate from these fundamental movement patterns.

Two excellent sources of information about the process of qualitative analysis of human movement, and more specifically the process of applying biomechanical principles to movement patterns and motor skills, are *Qualitative Analysis of Human Movement* (second edition) by Duane V. Knudsen and Craig S. Morrison (Human Kinetics 2002) and *Sport Mechanics for Coaches* (second edition) by Gerry Carr (Human Kinetics 2004).

Case study analysis: Biomechanics of throwing

Table 2.5 provides a basic case study analysis of some of the key biomechanical principles associated with the performance of the fundamental movement pattern of throwing (standing overarm throw).

Table 2.5 *Biomechanics and the overarm throw (observation by phase of movement)*

Movement phase	Technique — key elements	Biomechanical principles
1. Preparatory phase	• Body weight — leaning backwards, weight over leg • Body position — non-throwing side to target • Head position — facing target • Leg action — apart, weight on back leg • Arm action — throwing arm extended back with elbow bent	• The side-on position of the body, the backward rotation of the shoulder girdle and the extension of the throwing arm back behind the body prepare the thrower for the application of force over the largest possible distance and time frame. The backward body lean makes this distance and time frame even greater (impulse). • The bent elbow of the throwing arm results in a decrease in the moment of inertia of the arm as it is rotated forward in the next phase of the movement.
2. Execution phase	• Body weight — shift forward to target • Body position — rotate open to target • Head position — eyes on target • Leg action — step forward to target with closest leg (opposite leg to throwing arm) • Arm action — shoulder girdle and throwing arm rotated forward; extension of the arm at the elbow during latter part of the forward movement • Wrist action — snap wrist	• Stepping forward with the opposing leg establishes a large base of support for the application of force (balance, summation of force, transfer of momentum). • It also allows the thrower's hips, body and shoulder to be rotated forward toward the direction of throw (transfer of momentum, summation of force). • More massive, slower moving parts of the body (e.g. hips, trunk) begin the movement sequence while lighter body segments (e.g. throwing arm) trail behind (summation of force). • Each of the thrower's body segments, from the legs through to the shoulder and throwing arm, sequentially accelerate (summation of force). • This ends in the tremendous velocity of the throwing arm, which is further increased by the straightening of the arm at the elbow prior to release (levers, angular velocity).
3. Follow-through phase	• Body weight — on front foot closest to target • Body position — follow arm to target • Head position — eyes on target • Leg action — bring back leg up to front leg • Arm action — throwing arm across body	• The actions of the body, the back leg and the throwing arm moving across the body ensure that force is applied for as long as possible (impulse). • They also allow for the safe dissipation of momentum from the thrower's body after the release of the ball. • The flight path of the ball once it leaves the thrower's hand is affected by the velocity of the release; the angle of release; height of release; and air resistance (projectile motion).

A similar analysis to this can be easily performed for other fundamental movement patterns such as running, striking, kicking and the like.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Evaluate the efficiency of movement techniques using biomechanical principles.**

Activity 19 Multimedia presentation

Basic movement patterns

1. Work with a partner to select a basic movement pattern such as throwing, striking, running, stopping, kicking or catching.
2. Describe the fundamentals of how this movement pattern should be performed, making specific reference to and explanation of the application of relevant biomechanical principles and concepts.
3. Include diagrams and illustrations to aid your explanations. You could take digital photographs or even make an instructional video if you have access to a digital camera or video camera. (*Note:* make sure you obtain parental permission to take photographs or video footage of any subjects you use — discuss this with your class teacher.)
4. Present your information in the form of a PowerPoint presentation.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics and skill learning.**
- **Evaluate the efficiency of movement techniques using biomechanical principles.**

Activity 20 Laboratory report

Teaching basic movement patterns

In this laboratory activity, you will work with your partner from activity 19 to teach your selected movement pattern to a group of younger children. Your teacher will have arranged for your class to work with a group of local primary school children, preferably from grade 2 or 3.

Method

- Based upon the knowledge you and your partner gained in activity 19, you are to teach your selected movement pattern to a small group of children over a period of two or three 30-minute sessions.
- You will need to determine the appropriate instructional demonstrations, teaching and coaching points and practice activities.

Results

- You need to provide an outline (lesson plan) of the instructional demonstrations, teaching and coaching points and practice activities you utilised in each of your sessions. Include diagrams and illustrations to aid your explanations.
- You should take digital photographs or even video footage if you have access to a digital camera or video camera to show the students engaged in your lesson. Photograph or video the children performing the skill both before and after your lesson. This will enable you to evaluate whether or not there was any change in performance as a result of your instruction. (Note: make sure you obtain parental permission to take photographs or video footage of the children — discuss this with your class teacher.)

Questions

1. Evaluate and comment on whether or not there was any improvement or change in performance of the students as a result of your instruction. Utilise the photos or video you took to support your comments.
2. Report on any problems, difficulties or skill errors encountered by the children in acquiring and developing the movement pattern.

Biomechanics and skill technique

The knowledge and application of biomechanical principles and research by athletes and coaches have also been largely responsible for the development of new, revised and improved skill techniques in a wide range of sports and physical activities. Table 2.6 provides an outline of a select few of these sporting technique changes that can be traced back to the application of biomechanical principles and concepts.

The article in figure 2.49 illustrates how biomechanical research is being utilised to improve skill performance, in this instance the drop punt kick in Australian Football.

Table 2.6

Changes in technique due to the influence of biomechanics

Sport or activity	Technique change or development	Biomechanical principles or concepts
Shot put	Standing throw O'Brien technique Baryshnikov rotational technique	Summation of force Impulse
High jump	Scissors technique Eastern cut-off technique Western roll technique Straddle technique Fosbury flop technique	Centre of gravity Action and reaction Transfer of momentum
Sprinting	Standing start Crouch start	Force production Impulse
Swimming: ***Freestyle***	Flutter kick Bent arm recovery 'S' pull underwater	Water resistance Moment of inertia Force production
Breaststroke	Modified arm pull Whip kick instead of frog kick	Force production Water resistance

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Compare and contrast the impact of different techniques on performance.**
- **Evaluate the efficiency of movement techniques using biomechanical principles.**

Activity 21 Oral presentation

Technique changes

1. Select one of the sports or activities and associated technique changes from table 2.6 and research the nature of the changes that have occurred in technique.
2. Present your findings as an oral presentation to the rest of the class.
3. Make sure you outline the biomechanical principles and concepts underlying the technique developments that have taken place.
4. You might wish to supplement your oral presentation with diagrams and pictures to show the nature of the changes in technique that have taken place.

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Compare and contrast the impact of different techniques on performance.**
- **Evaluate the efficiency of movement techniques using biomechanical principles.**

Activity 22 Written report

Why the search is on for the perfect punt

Read the article entitled 'Why the search is on for the perfect punt' (figure 2.49) and complete the following tasks:

1. What type of technology is being utilised in the research project outlined in the article?
2. How do you think clubs, players and football in general might benefit from the outcomes of the research project?
3. Research what information you can find on what constitutes the correct technique for the drop punt kick in Australian Football.
4. Obtain some photographs or video footage of AFL players that you consider display good technique and those who appear to display questionable technique. Briefly justify your selections.

Why the search is on for the perfect punt

by Larry Schwatrz

The angle of the ankle, the height of the heel, the feat of the feet — all are under the microscope in a new study at La Trobe University.

It has the power to make or break. AFL players from Bill Brownless to Gary Buckenara have used it to snatch victory from certain defeat. The greatest of all kickers, Tony Lockett, relied on it.

Now science is being harnessed to develop the most popular of kicks in contemporary football.

In a Melbourne laboratory, scientists are helping an AFL club develop a secret weapon — the perfect drop punt. Fifteen players have taken part in preliminary stages of a study at a new musculoskeletal research centre at La Trobe University. Ten more are expected to be involved.

'The drop punt study is specifically looking at accuracy' says Julian Feller, associate professor of health services.

'Essentially, what we're trying to do is get a model for what constitutes a good kick?'

A founding director of the centre, he says the club, which had asked not to be identified, had approached the university in the hope of being involved.

Researchers use eight high-speed cameras to track reflective markers attached to legs, feet and footballs, in 'a project that came out of mutual discussions between representatives of the university and the club'.

The human movement, 'gait laboratory', with computerised walkway three-dimensional motion analysis and platform for detailed measurement of gait and movement, is said to be the best of its kind in Australia.

The facility on the Bundoora campus allows for measurement of a maximum 20-metre kick, and might have been inappropriate for kicks such as a long-distance, torpedo punt.

'It was never any question as to the sort of kick we examined.' Dr Feller says of the drop punt. 'It just seemed the obvious choice. It's the standard kick. Most of the other kicks have disappeared.'

A leading orthopaedic surgeon who has reconstructed some AFL players' knees, Dr Feller says it is too early to know to what extent the club might benefit from its involvement in research.

'Assuming we can identify the factors that make you kick accurately,' Dr Feller says, 'the next step is to demonstrate those factors to the players … to see whether they can go and reproduce more accurately a better kick.'

Already some players involved have indicated that they have new insights on the trajectory of their kicking foot and stability of the other leg. But it is not yet known if research will support the impressions.

Computer reconstruction of drop punts by the 15 players can be viewed from all angles in a manner Dr Feller likens to software programs that enable prospective buyers to examine house interiors.

The extent to which an ankle or knee is bent at different stages of the kicking can be calculated. 'So it's quite a technical exercise in terms of the interpretation of the data,' says Dr Feller.

The research project is just one of several at the new centre, opened late last year by federal Health Minister Kay Patterson. Others include a study related to osteoarthritis, a debilitating condition affecting one in four women over 50.

The technique used in the drop punt research was developed to analyse how we walk. The centre is also using it to help the recovery of patients who have undergone surgery on the anterior cruciate ligament, the most common knee reconstruction.

According to the great player and coach Ron Barassi, the La Trobe project reflects a change in approach to the game. 'I was amazed when I began coaching how little was thought of the basics of the kick,' he says.

He agrees that some supporters might fear a scientific approach will undermine the unpredictability and fun in the game.

'However, if you said to them would you rather a team go into a laboratory and win a premiership or not go into a laboratory and lose a premiership,' Barassi says, 'I mean, there'd only be one answer to that.'

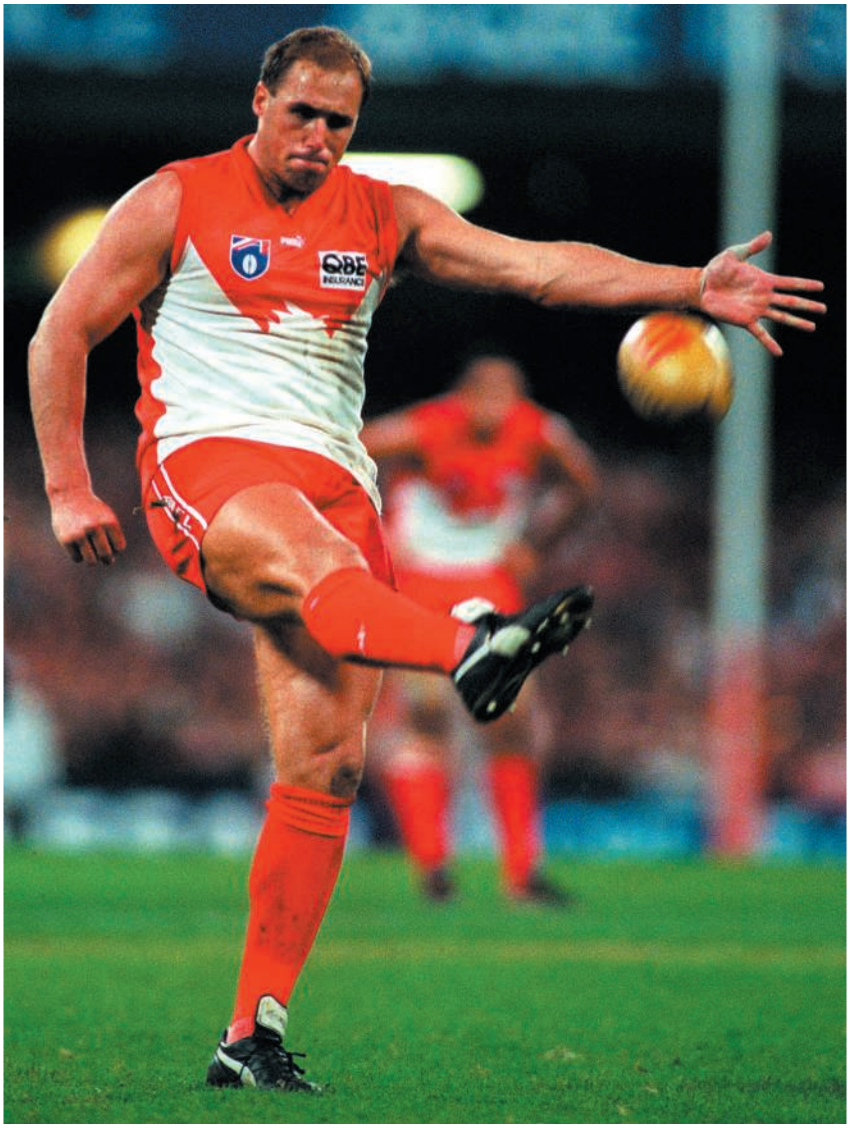
Once, players were at least as likely to resort to the stab kick, the flat punt or torpedo punt. Now the drop punt is Australian rules' kick of choice. Almost every coach, at any level of the game, insists on its use, to the exclusion of other kicks.

Fingers are spread evenly along each side of the ball, thumbs extended towards the lacing. The part of the boot strikes the bottom point of the ball. It spins backwards over and over.

'The reliability of it,' Ron Barassi says of the distinctive drop punt some say was developed by Jack Dyer in the 1930s, 'It's a proven thing. The drop kick is harder to do. And the torpedo kick has always been a chancy one …'

The drop punt is favoured for reasons of accuracy, if not distance. It has created some of the most dramatic moments in the game.

Kicking after the siren had sounded in the first qualifying final at the MCG in 1994, Bill Brownless wanted to be



sure it sailed between the posts. So instead of a spiralling torpedo kick, he chose a drop punt from 50 metres to give Geelong a five-point win over Footscray.

The siren had sounded too when Hawthorn's Gary Buckenara used a drop punt to snatch a spectacular two-point victory against Melbourne at Waverley Park and put his team into the 1987 Grand Final.

Scores were level in a 1996 preliminary final against Essendon when a mighty 60-metre drop punt by Tony Lockett, also after the siren, gave the Swans the point from a behind needed.

Lockett is widely regarded as having had the most perfect technique. He enjoyed a 70 per cent accuracy rate. But ironically, he executed one of his least impressive drop punts to score his record-breaking 1300th goal for the Swans in round 10 of the 1999 season against Collingwood at the Sydney Cricket Ground.

Figure 2.49:
Biomechanical research is being utilised to improve skill performance, in this instance the drop punt kick in Australian Football.

Source:
Schwartz, L. *The Sunday Age*, 20 January 2002.

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 23 Laboratory report

Biomechanics in the playground

Introduction

Playground equipment at the local park or primary school offers a great opportunity to experience many of the biomechanical principles covered in this chapter.

In this laboratory activity the following biomechanical principles will be experienced:

- force application
- force reception
- leverage
- impulse
- friction
- moment of force
- moment of inertia
- angular velocity
- conservation of angular momentum

utilising the following playground equipment:

- slide
- monkey bars
- horizontal bars
- swing
- see saw
- merry-go-round (wizzy dizzy).

Aim

The aim of this activity is to experience and revise a range of selected biomechanical principles in a playground environment.

Method

Undertake the following activities and then complete the associated questions. Note the activities do not need to be completed in sequential order.

The slide

- Climb to the top of the slide and then allow yourself to slide to the bottom.

1. When sitting at the top of the slide what must be applied to enable you to move?
2. What two factors determine how fast you will slide down?
3. How do they affect how you will travel?
4. What happens when you get to the bottom of the slide?
5. What is the design mechanism on the slide to help you achieve this?
6. Explain what happens in terms of force reception when your feet come into contact with the ground at the bottom of the slide?

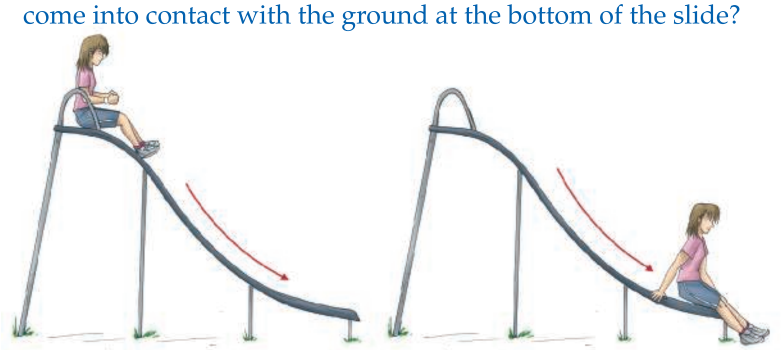


Figure 2.50

Key knowledge

- **Developing and refining basic movement patterns by applying a selection of biomechanical principles**

Key skills

- **Describe biomechanical principles using the correct terminology.**
- **Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.**
- **Compare and contrast the impact of different techniques on performance.**
- **Evaluate the efficiency of movement techniques using biomechanical principles.**

Activity 23 *continued*

The monkey bar or horizontal bar

- Grasp onto the bar as shown in figure 2.51.
- Initiate a swinging action.

1. What do you do to initiate this swinging action without someone pushing you (applying an external force)?
2. Assuming your hands on the bar are the axis of rotation, what are you trying to do with your body (mass) with regard to moment of inertia, moment of force and gravity?

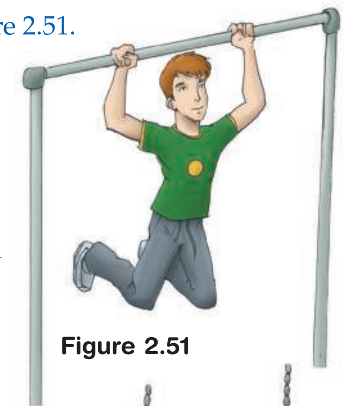


Figure 2.51

The swing

- Sit on the swing (figure 2.52) and initiate a swing without anyone pushing you.
- Once the swing is in motion, carefully stand up on the swing for a few goes back and forth. Sit back down carefully.
- Stop swinging and then get a partner to push you on the swing to get you moving back and forth.

1. How do you initiate a swing without somebody pushing you? Describe the body actions you perform and then explain these in biomechanical terms.
2. Do you go faster (increased angular velocity) when you stand up on the swing compared to sitting on the swing? Explain this in terms of mass and distance from the axis of rotation.
3. Is there a difference in air resistance between standing and sitting on the swing? Explain your answer biomechanically.
4. When your partner started pushing you on the swing, what two factors determined how much you increased your momentum?
5. When your partner was pushing you on the swing, was it harder for them to push you as you started to go faster and higher (i.e. with increased momentum)? Explain using the biomechanical principle of impulse why this was the case.

Figure 2.52

The see-saw

- Sit on the see-saw with a partner on the other end who weighs more or less than you do.
- Try to balance the see saw so that it remains horizontal (figure 2.53).

1. What did you and your partner do to get the see saw balanced?
2. Explain this in terms of mass and distance from the axis of rotation (moment of inertia).

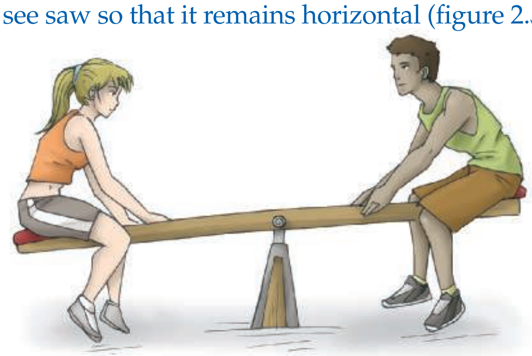


Figure 2.53

continued ➤

Key knowledge

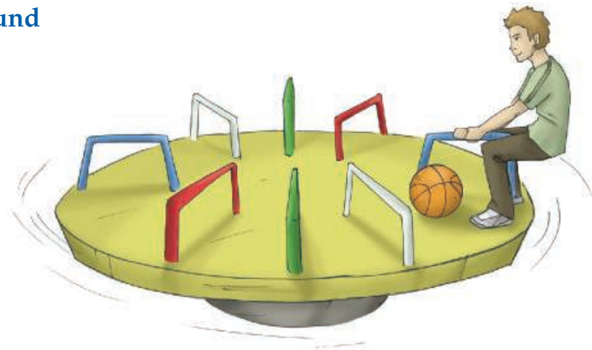
- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 23 *continued*

The merry-go-round (wizzy dizzy)



This piece of playground equipment can tell us a lot about the biomechanics of sport but they are increasingly difficult to find in playgrounds.

- Stand or sit on the merry-go-round with a basketball resting at your feet.
- Have some other students start spinning the merry-go-round. When it is rotating, release the basketball, and note the pathway it takes as it flies off the merry go around.

1. The pathway that the basketball should have taken as it flew off the merry-go-round is the same pathway that an implement such as a ball would theoretically take when it leaves our hand after a circular motion such as a cricket bowl or softball pitch. However, we employ certain actions to flatten the arc of this motion in order to ensure that the implement is released in the intended direction. Outline some of the actions that can be employed to flatten the arc in bowling or pitching.

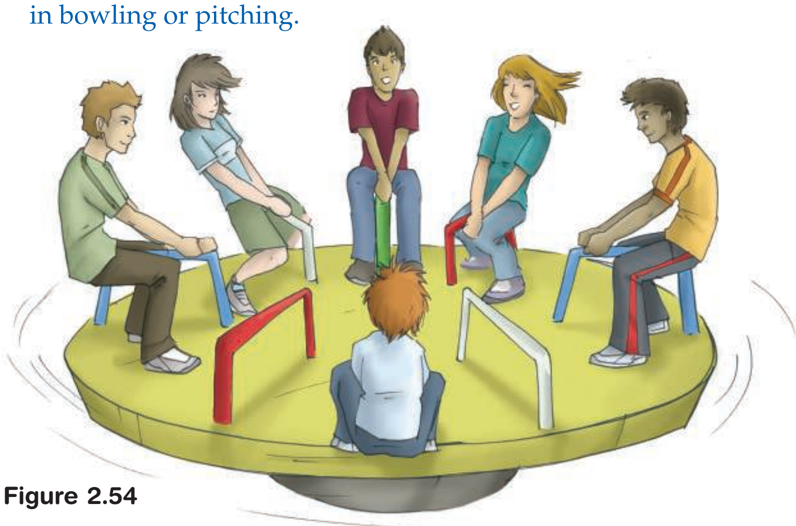


Figure 2.54

- Gather a group of six or so students and get them to sit on the merry-go-round. Get some other students to push the merry-go-round and get it spinning.
- As the merry-go-round is spinning have the students on it carefully alternate every 10 seconds or so from leaning inwards and outwards from the centre of the merry-go-round (see figure 2.54).

2. What happens to the velocity of the merry-go-round as the students alternate between leaning in and leaning out from the centre?

3. Explain using the biomechanical principles of moment of inertia and angular velocity why this happens.

4. What eventually slows the merry-go-round and causes it to stop?

Key knowledge

- Developing and refining basic movement patterns by applying a selection of biomechanical principles

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to biomechanics.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Activity 24 Case study analysis

Biomechanics of a selected sport

- Select two or three skills or movements from a sport or activity of your choice and analyse them biomechanically.
- For each selected skill provide a series of photographs or a video of the skill being performed.
- Analyse each skill in order to identify and explain any biomechanical principles or concepts that apply to the performance of the particular skills. For example, volleyball dig — summation of force, impulse, impact and momentum.
- Report your findings in the form of a written report or oral presentation to the rest of the class.

CHAPTER REVISION

Key knowledge

- Developing and refining basic movement patterns (for example, striking, throwing, running and stopping) by applying a selection of biomechanical principles such as force and momentum, impact, transfer of momentum, inertia, balance, action and reaction, pushing and pulling

Key skills

- Describe biomechanical principles using the correct terminology.
- Perform, observe, analyse and report on practical and laboratory exercises related to skill learning.
- Compare and contrast the impact of different techniques on performance.
- Evaluate the efficiency of movement techniques using biomechanical principles.

Chapter summary

- Biomechanics is the sport science that applies the laws of mechanics and physics to human performance.
- Some technologies and equipment used by biomechanists today include cinematography, computerised video analysis, 3-dimensional motion analysis, force platforms, electromyography, wind tunnels, and resistance pools.
- Forces are 'any pushing or pulling activity that tends to alter the state of motion of a body'. The forces applied to the body can be both external and internal. Forces can include isometric force (force without motion), isotonic force (force with motion), sub-maximal force and maximal force.
- Maximal force production is usually the result of the summation of a number of forces, which can occur either simultaneously or sequentially.
- Inertia, momentum, impulse, accuracy and force reception are all biomechanical concepts that operate in applying an effective force:
  - the greater an object's inertia, the greater the force required to alter its state of rest or motion.
  - momentum = mass × velocity. The greater the momentum of an object the further it will travel and the harder it will be to stop or slow the object.
  - impulse = force × time over which force is applied. The greater the force applied and the longer it can be applied, the greater the object's impulse.
  - accuracy when throwing or striking an object requires a flattening of the arc to allow a greater distance over which force can be applied in the desired direction of travel.
  - force reception involves the absorption of force over a distance or period of time.
- The principles of force production are summarised in Newton's three laws of motion:
  - the first law: the law of inertia
  - the second law: the law of acceleration and momentum
  - the third law: the law of action and reaction.
- The use of levers allows humans to apply increased force and to generate greater speed in executing sporting and everyday activities. Levers can be of three different classes, which provide different mechanical advantages:
  - first class levers: examples include a crowbar and a pair of scissors.
  - second class levers: examples include a wheelbarrow and a bottle opener.
  - third class levers: most levers within the body (the bones and associated joints) are of this type.
- There are three basic forms of motion — linear motion, angular (or rotary) motion and general motion.
- Forces that produce angular motion are called eccentric forces.
- Two extremely important concepts in angular motion are the concepts of moment of inertia and conservation of angular momentum:
  - moment of inertia is the product of the mass of the body and the distance that the mass is distributed away from the axis of rotation. The closer the mass is distributed to the axis of rotation, the easier it is to rotate.
  - angular momentum is the product of moment of inertia multiplied by angular velocity. If angular momentum remains constant, it follows

that if the moment of inertia of a body is decreased by bringing it closer to the axis of rotation, then the angular velocity must increase and vice versa.
  – angular momentum can also be transferred from one body part to another. The concept of sequential summation of force is based on the transfer and conservation of angular momentum from one body part to the next.

- Projectile motion is when any object travels through free air space. The factors affecting the flight of projectiles include the velocity of release, the angle of release, the height of release, gravity, air resistance and spin.
- The effect of air resistance on a projectile depends on a number of factors including the size or surface area of the projectile, the nature of the surface area, the shape of the projectile, the velocity of the projectile, the projectile's mass or weight, and any spin imparted to the projectile.
- The Magnus effect explains the change of flight paths of projectiles, particularly balls that have spin imparted to them.
- The coefficient of restitution of an object is a measure of its elasticity upon impacting with a given surface or other body. For example, the higher a ball rebounds after bouncing, the greater its coefficient of restitution and hence the greater its elasticity.
- Friction is the force that arises whenever one body moves or tends to move across the surface of another. There are two types of friction: sliding friction and rolling friction.
- Stability refers to an object's resistance to movement from a balanced position. There are two types of stability: static and dynamic.
- The stability of an object depends on the mass of the object; the area of the object's base of support; the height of the centre of gravity of the object above its base of support; and the position of the line of gravity relative to the base of support.
- The application of biomechanical concepts and principles can be used by coaches and teachers to assist learners to develop and refine basic movement patterns such as running, throwing, catching, striking and kicking.
- Biomechanics has also been largely responsible for the development of new and improved skill techniques in a wide variety of sports and activities.
- One process or method for observing, analysing and improving the quality of human movement performance is qualitative analysis. This process involves four key tasks — preparation, observation, evaluation, diagnosis and intervention.

Review questions

1. Define in your own words the key terms listed below, all of which appear in this chapter. When you have finished, check your definitions with those in the glossary on page 285.

air resistance	**basic (fundamental) movement patterns**
angle of incidence	**biomechanics**
angle of reflection	**centre of gravity**
angle of release	**coefficient of restitution**
angular momentum	**conservation of angular momentum**
angular (rotary) motion	**conservation of momentum**
angular velocity	**curvilinear motion**

deformation
drag force
eccentric force
elasticity
equilibrium — stable, unstable and neutral
flattening the arc
follow-through
force
force arm
force couple
force reception
force summation — simultaneous and sequential
friction
fulcrum or pivot
general motion
gravity
height of release
key elements
impulse
inertia
isometric contraction or force
isotonic force
lever
line of gravity
linear motion
Magnus effect
moment arm
moment of force
moment of inertia
momentum
performance analysis
phases of movement
projectile motion
qualitative analysis
resistance arm
rolling friction
sliding friction
spin — topspin, backspin, sidespin
stability
surface area
trajectory
transfer of angular momentum
transfer of momentum
velocity of release

2. What are some of the contributions that biomechanics can make to improve sports performance?
3. Outline the typical equipment and technology utilised by biomechanists today. Research one of these equipment items and provide a brief overview of what it is and what it does.
4. Describe the sequence of body parts and movements involved in the summation of forces required to perform an overarm serve in volleyball.
5. Outline each of Newton's three laws of motion.
6. What type of lever is represented in each of the following?
   (a) a wheelbarrow
   (b) a crowbar
   (c) a bottle opener
   (d) a hammer removing a nail from a piece of wood
   (e) a bicep curl exercise.
   Draw a simple diagram to represent each of the above examples of levers, clearly labelling the fulcrum, the force arm, the resistance arm, the point of force application and the resistance or load.
7. For each of the following, state what type of motion — linear, curvilinear or angular — the whole body experiences:
   (a) rounding the bend in a 400-metre sprint
   (b) running between second and third base in softball
   (c) the trajectory of a javelin
   (d) a one arm giant on the horizontal bar
   (e) the flight phase of a ski jumper.
8. What type of force is required to produce rotation of a body and where must this force be applied?
9. Why would you spin faster when seated on a swivel chair with your legs tucked in as compared with when your legs are extended? Explain your answer.

10. Explain the interplay of angular momentum, moment of inertia and angular velocity as a gymnast performs a front somersault during a floor routine.
11. Under what conditions would the optimal angle of release of a projectile be 45 degrees?
12. Explain three factors that affect the distance a projectile may travel.
13. What factors increase the amount of air resistance experienced by a projectile in flight?
14. For a sport of your choice, outline the measures employed to reduce the amount of air or water resistance experienced by the performer.
15. Explain how the Magnus effect influences the flight path of a ball imparted with spin. Include a diagram to aid your explanation.
16. What will happen to the flight path of a ball in tennis that is hit with topspin as compared to a ball that is hit with backspin? What will happen once the ball bounces on the court in both cases?
17. How can the elasticity of a ball be assessed? What is the term given to this measurement?
18. Indicate the likely changes in a squash ball's coefficient of restitution under the following conditions:
    – cooled in a freezer
    – after 20 minutes of play.
19. What effect does the court surface in tennis (such as grass, clay and plexipave) have on the behaviour of the ball once it bounces on the court surface?
20. What four factors influence the stability of an object?
21. What must happen in order for a body to lose balance?
22. A rugby league player is about to tackle an oncoming opponent. Outline three things the tackler could do to increase his stability just before impact?
23. Write out the mathematical formulas for the following biomechanical concepts:
    (a) momentum
    (b) impulse
    (c) moment of force
    (d) moment of inertia
    (e) angular momentum
    (f) coefficient of restitution.
24. Outline the key tasks involved in the process of qualitative analysis of human movement.
25. How would the process of qualitative analysis assist a coach in developing and refining basic movement patterns and motor skills?

Useful websites

Aerodynamics of cricket balls—
www.geocities.com/k_achutarao/MAGNUS/magnus_cricket.html

Australian Institute of Sport—
www.ais.org.au/biomechanics/index.asp

Coaches' Infoservice—
www.coachesinfo.com/

Health and Bioscience, University of East London—
www.uel.ac.uk/hab/sports/biomechanics_facilities.htm