INQUIRY QUESTION
How does the musculoskeletal system work together to produce movement such as in this chinup?
The skeletal and muscular systems work together to produce movement in physical activity, and one cannot function without the other. The different muscle fibre types, the range of muscle movements and how they are stimulated to move by the central nervous system are essential learning for the developing sportsperson.

**KEY KNOWLEDGE**
- The major muscles of the human body
- Characteristics and functions of muscle fibres including fibre arrangement and type (fast-twitch and slow-twitch)
- Types of muscular actions (isoinertial, isometric and isokinetic)
- Agonists, antagonists and stabilisers, and the concept of reciprocal inhibition
- Control of muscles including the recruitment (size principle) and activation (‘all or nothing’ principle) of motor units in relation to force production
- Interactions of muscles and bones to produce movement in physical activity, sport and exercise

**KEY SKILLS**
- Use and apply correct anatomical terminology to the working of the musculoskeletal system in producing human movement
- Perform, observe and analyse a variety of movements used in physical activity, sport and exercise to explain the interaction between bones, muscles, joints and joint actions responsible for movement
- Describe the role of agonists, antagonists and stabilisers in movement
- Describe the relationship between motor unit recruitment, activation and force production

**CHAPTER PREVIEW**

![Diagram showing the muscular system and its components]

- **Body movement**, **Bodily functions**, **Posture**
  - **Functions**
  - **Muscular system**
  - **Types of muscles**: Cardiac, Smooth, Skeletal
    - Major skeletal muscles, Muscles and actions produced, Muscle fibre arrangement, Features, Major fibre type, Structure of muscle, Muscular activity, action and control
      - Muscular contractions: Eccentric, Concentric, Isoinertial, Isometric, Isokinetic
Functions of the muscular system

The human body has over 600 muscles. These muscles function to allow a range of physical movements that we either consciously or subconsciously control. These movements range from fine motor skills such as blinking an eye or writing, to gross body movements such as running or throwing a ball.

Body movement

All muscles that we can consciously control (voluntary control) are attached to bones. Such muscles are also known as voluntary muscles. The central nervous system sends a message to the relevant muscle, and then the muscle pulls the bones to allow the desired movement.

Adequate posture

Muscles are continually in a state of tone that affects their ability to help our body to maintain an upright posture when awake and to function safely during sleep. People with poor muscle tone generally have poor posture and resultant aches and pains because gravity is defeating the muscles’ resistance. Muscles of the upper back — such as the trapezius, rhomboids and the latissimus dorsi — strongly influence posture maintenance. Regular exercise helps improve muscle tone, which allows resting muscles to resist being stretched and keeps them in constant readiness.

Essential bodily functions

Involuntary muscles are those over which we have little or no conscious control (involuntary control). They function continuously and preserve our ongoing body needs whether we are awake or not. The heart is a muscle over which we generally have little control, and muscular effort also controls our digestive and breathing demands.

Types of muscle

Muscles can be classified into three main groups:
- smooth
- cardiac
- skeletal.

Smooth muscle

Smooth muscle is found in hollow organs such as the walls of the digestive tract, the bladder and the blood vessels (figure 3.1). You have no conscious control over smooth muscle contractions (thus called ‘involuntary’), which are slow, sustained and rhythmic. The contractions of the smooth muscle in the intestinal walls and stomach, for example, move food through the digestive tract. Such muscles fatigue more slowly than skeletal muscle.
Cardiac muscle
Cardiac muscle is found only in the heart. The muscle fibres are intertwined, which helps the heart push blood into arteries going to the lungs and other body tissues (figure 3.2). The heart is an involuntary muscle (although some people claim that they can make their heart beat faster or slower at will) and it is difficult to fatigue. When a nerve impulse arrives at the heart, the message is relayed from cell to cell, causing rhythmic contractions and relaxations.

Skeletal muscle
Skeletal muscle attaches to and causes movement of the skeleton. It is striated, meaning that it has a striped appearance (figure 3.3). Skeletal muscle is under voluntary control because you are consciously aware of the muscles and can control their contractions. The muscles may also take part in reflex actions, such as a knee-jerk reaction. If you want to throw a netball or kick a soccer ball, your brain sends a message to the muscles concerned and the required physical action results. As skeletal muscle is responsible for human movement, this muscle type will be the focus of the next section.
3.1 The muscular system: functions, types and major muscle groups

**Major skeletal muscles**

To be able to study body movements, it is important to identify the positions and actions of the major muscle groups of the body (figure 3.4 and table 3.1). Muscles are usually named according to their characteristics or locations. For example: the triceps, which has three points of origin; the pectoralis major, which is a large (major) muscle of the chest or pectoral region; and the quadriceps femoris, which consists of four separate muscles anterior to the femur.

**Figure 3.4** Muscles of the human body: (a) anterior view and (b) posterior view
<table>
<thead>
<tr>
<th>Major muscle</th>
<th>Action</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shoulder/chest — anterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deltoid</td>
<td>Shoulder abduction</td>
<td>Bowling in cricket</td>
</tr>
<tr>
<td></td>
<td>Shoulder flexion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shoulder extension</td>
<td></td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>Shoulder flexion</td>
<td>Tennis forehand</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>Shoulder abduction</td>
<td>Boxing punch</td>
</tr>
<tr>
<td><strong>Shoulder/back — posterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trapezius</td>
<td>Scapula elevation</td>
<td>Shoulder shrug</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>Shoulder adduction</td>
<td>Butterfly stroke in swimming</td>
</tr>
<tr>
<td><strong>Arm — anterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>Elbow flexion</td>
<td>Pullup</td>
</tr>
<tr>
<td>Wrist flexors</td>
<td>Wrist flexion</td>
<td>Wrist curl</td>
</tr>
<tr>
<td><strong>Arm — posterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>Elbow extension</td>
<td>Throwing a javelin</td>
</tr>
<tr>
<td>Wrist extensors</td>
<td>Wrist extension</td>
<td>Squash backhand</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectus abdominis</td>
<td>Trunk flexion</td>
<td>Situp</td>
</tr>
<tr>
<td>Obliques</td>
<td>Trunk flexion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trunk rotation</td>
<td></td>
</tr>
<tr>
<td>Erector spinae</td>
<td>Trunk extension</td>
<td>Gymnastics backflip</td>
</tr>
<tr>
<td></td>
<td>Trunk rotation</td>
<td></td>
</tr>
<tr>
<td><strong>Pelvis — anterior/medial/posterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sartorius</td>
<td>Hip flexion</td>
<td>Breaststroke kick</td>
</tr>
<tr>
<td></td>
<td>Knee flexion</td>
<td></td>
</tr>
<tr>
<td>Adductors</td>
<td>Hip adduction</td>
<td>Riding a horse</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Hip extension</td>
<td>Running</td>
</tr>
<tr>
<td></td>
<td>Hip abduction</td>
<td></td>
</tr>
<tr>
<td><strong>Leg — anterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>Hip flexion</td>
<td>Kicking/cycling</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>Knee extension</td>
<td>Jumping</td>
</tr>
<tr>
<td>Vastus intermedius</td>
<td>Knee extension</td>
<td>Rock climbing</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>Knee extension</td>
<td></td>
</tr>
<tr>
<td>Tibialis anterior</td>
<td>Dorsi flexion</td>
<td>Freestyle kick</td>
</tr>
<tr>
<td><strong>Leg — posterior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamstrings</td>
<td>All three muscles —</td>
<td>Running</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>hip extension and knee flexion</td>
<td></td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>Gastrocnemius</td>
<td>Calf raises</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>Soleus</td>
<td>Ballet — toe point</td>
</tr>
</tbody>
</table>
The muscular system: functions, types and major muscle groups

TEST your understanding
1 Form a small group. Together, look closely at the image on page 32 at the start of this chapter and then:
   (a) make a list of the bones, muscles, joints and joint actions responsible for movement
   (b) explain how movement can occur using the musculoskeletal system.
2 Outline the three functions of the muscular system.
3 Name and describe the three types of muscle and identify if they are under voluntary or involuntary control.
4 Download the muscle chart from your eBookPLUS. Label the major muscles in the body.
5 List the major muscles of the following muscle groups:
   (a) hamstrings
   (b) quadriceps
   (c) abdominals.

APPLY your understanding
6 Practical activity: movements and muscles
   Complete the actions listed in the table below to determine the muscle responsible.

<table>
<thead>
<tr>
<th>Movement created</th>
<th>Muscle responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk flexion</td>
<td></td>
</tr>
<tr>
<td>Shoulder adduction</td>
<td></td>
</tr>
<tr>
<td>Elbow extension</td>
<td></td>
</tr>
<tr>
<td>Hip flexion</td>
<td></td>
</tr>
<tr>
<td>Shoulder elevation</td>
<td></td>
</tr>
<tr>
<td>Trunk extension</td>
<td></td>
</tr>
<tr>
<td>Ankle (dorsi) flexion</td>
<td></td>
</tr>
<tr>
<td>Knee flexion</td>
<td></td>
</tr>
<tr>
<td>Hip adduction</td>
<td></td>
</tr>
</tbody>
</table>

7 Practical activity: muscles creating movement
   With a partner, complete each movement/skill to determine the muscle involved.
   (a) wide-grip pushup (floor to straight arms)
   (b) situp
   (c) tennis serve
   (d) kicking a football
   (e) forward swing in baseball batting

8 Practical activity: investigating the action of major muscles
   With a partner complete the following activities and record your results.
   (a) Jump upwards with a 60-centimetre take-off. What action occurs at the ankle joint?
   (b) Perform abduction of your arm. What is the major muscle moving your arm?
   (c) Complete ten situps. What muscles work hard during this action?
   (d) Perform horizontal flexion of your arms. What happens to your scapula?
   (e) Bend your elbow. What is the major moving muscle?
   (f) Extend your elbow. What is the major moving muscle?
   (g) Kick a ball. What action is performed by the quadriceps?
3.2 The muscular system: features, arrangement and microscopic structure

**KEY CONCEPT** Skeletal muscles all have features that distinguish what they can do; in particular, movements that they make and force they can generate. It is important to understand the microscopic structure of skeletal muscle and how these structures assist with creating movement.

**Common features of muscles**

Most muscles have certain common features:
- Nervous control — nerve stimuli control muscle action.
- Contractility — muscles contract and become thicker.
- Extensibility — muscles have the capacity to stretch when a force is applied.
- Elasticity — muscles can return to their original size and shape once stretched.
- Atrophy — muscles can decrease in size (waste) as a result of injury, illness or lack of exercise.
- Hypertrophy — muscles can increase in size (growth) with an increase in activity.

**Muscle fibre arrangement**

Muscle fibres are organised in different ways according to the shape (or arrangement) and function of the muscles (figure 3.5). The main arrangements of major skeletal muscles used in physical activity include fusiform, pennate and radiate muscles.

**Figure 3.5** Skeletal muscle fibre arrangement
Fusiform muscles

Fusiform muscle fibres run the length of the muscle belly. They are designed for mobility because they produce contractions over a large range, yet they produce low force (e.g. sartorius and biceps).

Pennate muscles

Pennate muscle fibres run at angles to the tendons. These muscles do not provide as much mobility as do fusiform muscles because they are designed for strength and power. There are three categories of pennate muscles:

- unipennate muscles — fibres are only found on one side of a central tendon (e.g. the semimembranosus in the hamstrings and the tibialis anterior)
- bipennate muscles — fibres run off either side of a central tendon (e.g. the rectus femoris in the quadriceps)
- multipennate muscles — fibres branch out from several tendons (e.g. the deltoid). This arrangement enables the body to generate the greatest force.

Radiate muscles

Radiate muscle fibres radiate from the main tendon. These muscles are a compromise between fusiform and pennate muscles because they are capable of producing strength and power while retaining their mobility (e.g. the pectoralis major).

Structure of skeletal muscles

Skeletal muscle is covered with a layer of connective tissue called the epimysium. The epimysium thickens as it reaches the ends of the muscle to form tendons that usually attach to bone.

Skeletal muscle consists of thousands of muscle fibres that run the length of the muscle and are arranged in bundles called fasciculi. (A single bundle is called a fasciculus.) Each individual muscle fibre is surrounded by connective tissue called the endomysium, which binds the fibres together to form the bundles. The fasciculi are surrounded by a layer of connective tissue called the perimysium, which helps bind the fasciculi together (figure 3.6).

![Figure 3.6 The muscle belly in cross-section](image-url)
The muscle fibre
Each muscle fibre is surrounded by a cell membrane called the sarcolemma. Underlying the sarcolemma is a gel-like fluid called sarcoplasm. This fluid contains:
- mitochondria, which are the site of aerobic energy production
- myoglobin, which carries oxygen to the mitochondria
- fat, carbohydrate and protein (energy nutrients)
- adenosine triphosphate (an immediate energy source)
- enzymes, which are chemicals that speed up energy production
- actin and myosin myofilaments (contractile proteins).

Each muscle fibre is made up of long strands called myofibrils. Each myofibril consists of many individual units, called sarcomeres, which are responsible for contracting the muscle.

Sarcomeres
A sarcomere is a contractile unit, and each one is designated by a line at either end called a Z line. Each sarcomere consists of two protein myofilaments called actin and myosin. Actin is a thin filament that attaches to the Z line. Myosin is a thick filament situated between each of the actin filaments. Figure 3.7 illustrates the several bands and zones that help define the sarcomere:
- the I band, where only actin is found
- the A band, where both actin and myosin are found. It equates with the length of the myosin filaments.
- the H zone, where only myosin is found. It is the gap between the ends of the actin.

Cross bridges
The myosin filaments have cross bridges (oar-like structures) that are attracted to the actin filaments (figure 3.7).
- At rest, there is little contact between the actin and the myosin.
- When a nerve impulse arrives at the neuromuscular junction, calcium is released.
- In the presence of calcium, the myosin filaments can now attach to the actin.

**Figure 3.7** Arrangement of sarcomeres within the muscle fibre
The breakdown of ATP enables the cross bridges to attach to the actin filaments and pull them into the centre of the sarcomere in a ‘rowing’ action (figure 3.8) and the sarcomere contracts.

The cross bridges continue to detach and reattach themselves from the actin filaments, shortening the sarcomere.

The structural rearrangement of actin and myosin filaments change whereby Z lines move closer together, the I band reduces in width, the A band remains the same length and the H zone may disappear.

Every sarcomere along the muscle fibre shortens, leading the whole muscle to contract.

The muscle will relax when the actin and myosin filaments lose contact with each other — that is, when the cross bridges detach from the actin.

**FIGURE 3.8** Structural rearrangement of actin and myosin filaments at rest and during contraction


**Muscle tone**

Not all the myosin filaments detach themselves from the actin. Some may stay in contact, so the muscle is never completely relaxed — the muscle is then said to have ‘tone’. The advantage of muscle tone is that the actin and myosin are already partly connected, so they can be activated quickly when a muscle contraction is ready to occur. It also helps us to maintain good posture and look good!
**TEST your understanding**

1. Outline the main features of all muscles.
2. The deltoid is an example of a muscle that displays a multipennate fibre arrangement. Explain why multipennate muscles produce greater force than fusiform muscles.
3. Name the two protein myofilaments, and identify where they are found and which filament attaches to the cross bridges.
4. Explain muscle tone and the advantage of having it.
5. Explain what happens to the following structures in a sarcomere during a muscle contraction. Draw a picture to illustrate your explanation.
   - (a) Z lines
   - (b) A band
   - (c) I band
   - (d) H zone

**APPLY your understanding**

6. **Practical activity: participate in a weight-training session**
   For each exercise you complete in your weight-training session, identify:
   - the muscle being used
   - the muscle fibre arrangement of that muscle
   - the action performed by that muscle.
   Write your results in a table similar to the one shown below.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Muscle</th>
<th>Muscle fibre arrangement</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicep curl</td>
<td>Bicep</td>
<td>Fusiform</td>
<td>Flexion</td>
</tr>
</tbody>
</table>

---
3.3 The muscular system: initiation of muscular activity, action and control

**KEY CONCEPT** Muscles create movement by pulling on the bones to which they attach. In order to do this, messages are sent from the brain to the muscles to initiate movement. Muscles work in pairs to produce coordinated movements.

**Nervous control of muscles: initiation of muscular activity**
- To enable conscious control of muscles, the brain must send electrical nervous messages to the muscle.
- These messages or signals travel down the spinal cord to the motor nerves that branch from the spinal cord to the relevant muscles.
- Leaving the spinal cord, the motor nerve separates into smaller motor neurons that then divide a number of times to attach to individual muscle.
- Where the nerves meet the muscle fibres, there is a gap (called a neuromuscular junction or the synaptic cleft) across which the nerve impulse has to travel.
- A neurotransmitter, which is a chemical compound called acetylcholine, helps the nerve impulse make this jump.
- The muscle will continue to contract for as long as the brain sends messages and the relevant energy sources last (figure 3.9).

**Motor units**
The number of fibres within each motor unit varies according to the precision of the movement required. Generally, muscles (such as those in your hand) that perform precise, controlled movements such as writing, typing or throwing darts have small motor units, where one motor neuron may be responsible for stimulating only a few fibres. Muscles such as the quadriceps that perform gross movements such as running or kicking a ball have large motor units, where one motor neuron may stimulate thousands of fibres (figure 3.10).

**Stages of nervous control of muscle action**
1. Brain initiates message.
2. Nervous impulse branches from spinal cord to motor nerve.
4. Message branches off to arrive at all muscle fibres controlled by that nerve; travels across gap at neuromuscular junction (aided by acetylcholine) and all connected muscle fibres contract.

**FIGURE 3.9** Nervous control of muscular movement

A motor unit consists of one motor neuron and the muscle fibre it stimulates. (Each neuron may stimulate a number of muscle fibres.)

**FIGURE 3.10** Two motor units. Neuron A stimulates three muscle fibres, while neuron B stimulates only two.
**Henneman principle (size principle)**

The Henneman principle, which is also known as the size principle, states that the recruitment of motor units within a skeletal muscle commences with small motor units to large motor units. Small motor units are recruited first at low muscle forces, for example walking. An increase in muscle force, from walking to sprinting, leads to an increase of larger motor units.

**Characteristics of small motor units are:**
- slow contracting
- easily excitable and recruited
- fatigue resistant
- utilised for prolonged activities (walking, posture control).

**Characteristics of large motor units are:**
- fast contracting
- less easily excitable and recruited
- rapidly fatigable
- utilised for high force activities (sprinting, hitting, jumping).

**Motor unit activation and force production**

Each person’s muscle strength reflects their ability to produce force to overcome a load or to produce a movement. The development of muscle force is dependent on a number of factors:
- number and type of motor units activated
- size of the muscle
- initial length of muscle that is being activated
- angle of the joint
- the muscle’s speed of action.

More force can be generated with more motor units activated. Fast-twitch (FT) motor units produce more force due to each FT motor unit having a larger cell body and more axons and innervates from 300 to 800 muscle fibres. Conversely, a slow-twitch motor unit has a small cell body and innervates from 10 to 180 muscle fibres. Large muscles have more muscle fibres so can produce more force than smaller muscles.

**Strength of muscular contraction**

Skeletal muscles can generate a range of contractions varying from strong maximal contractions to complete relaxation. However, for a contraction to occur, there must be a strong enough nerve impulse to innervate (stimulate) the muscle fibres.

**The ‘all or nothing’ principle**

The ‘all or nothing’ principle states that the nerve impulse will not stimulate the muscle fibres until it reaches a certain threshold level. Once the nerve impulse reaches this threshold, all fibres of the motor unit will contract at the same time and maximally. If the impulse is too weak, no fibres will contract at all. However, the intensity of muscular contractions can vary in two ways.

- By varying the number of motor units stimulated. Not all the motor units within a muscle need to be recruited at one time for a muscle contraction. If you require a large degree of strength (e.g. lifting a heavy weight), then more nerve impulses are sent, activating more motor units and therefore contracting more muscle fibres. If you require a minimal degree of strength (e.g. putting a golf ball), then fewer impulses are sent, contracting fewer fibres.

- By varying the frequency at which the impulses arrive at the motor unit. The greater the frequency of nerve impulses, the greater the contractions in the muscle. If you require a large degree of strength (e.g. for performing a vertical jump), then impulses will be sent at a faster rate to the muscles involved.
**Skeletal muscle action and control**

**Muscle action**

Skeletal muscles create movement by pulling on the bones to which they are attached. They have a more rigid attachment to a bone at one end, and they are attached across a joint to another bone that is usually more moveable.

**Muscle origin**

○ The muscle's point of attachment to the more stationary bone is called the origin (or the fixed end) and tends to be closer (or more proximal) to the main mass of the body. The origin of a muscle is often quite widespread because it helps ‘anchor’ the muscle.

**Muscle insertion**

○ The muscle's more moveable point of attachment is called the insertion (the moving end) and tends to be located away (or more distal) from the mass of the body. It usually attaches to the bone near the joint that is to be moved by the muscle, and adheres in most cases by means of a strong non-elastic tendon (figure 3.11).

**Muscle contraction**

○ When a muscle contracts, the origin and insertion are drawn together, shortening the muscle. The bones attached to the muscle produce movement in a specific direction. This movement is called the muscle’s action. For example, the action of raising your arm by your side (abduction) is caused by the contraction of the deltoid muscle, where the insertion of the muscle at the humerus moves towards the muscle's origin at the scapula.

---

**The origin** is the fixed point of attachment that is closer (or proximal) to the body’s midline.

**The insertion** is usually attached to the bone that moves most when the muscle contracts. It is further (or distal) from the body’s midline.

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**Figure 3.11** Skeletal muscles — insertions and origins
Muscle control

Skeletal muscles work in pairs or groups to produce movement — that is, as a muscle contracts on the front side of the body (anterior), usually the muscles at the back (posterior) with the opposite action relax. For example, when the quadriceps muscle group (anterior) contracts to kick a football or to push from the ground when acceleration is required during a team game, the hamstrings muscle group (posterior) must relax or stretch.

During a particular movement, a muscle performs one of the following four roles:

- **Agonist** (or prime mover). This muscle causes the major action. There is usually more than one prime mover in a joint action, and there are prime mover muscles for all moveable joints.

- **Antagonist.** This muscle must relax and lengthen to allow a movement to occur. It causes an opposite action to that caused by the agonist. Generally, muscle flexors and extensors work in an agonist–antagonist relationship. For example, when a person bends their elbow, the flexor (biceps) is the agonist while the extensor (triceps) is the antagonist. These roles can be reversed. For example, when a person straightens their elbow (as when serving in tennis), the extensor (triceps) is the agonist while the flexor (biceps) is the antagonist. This pairing of actions can also be seen with other movements such as adduction and abduction.

- **Synergist** (or assistant). This muscle assists the agonist to produce the required movement to reduce any excessive or unnecessary movements. During elbow flexion, for example, the biceps is the agonist and it is assisted by the brachialis and brachioradialis.

- **Stabiliser** (or fixator). These muscles ensure that the joint remains stable while the agonist and antagonists are working. The muscle will shorten just slightly during contraction, causing only minimal movement to allow the action to be performed more effectively. When someone shoots a goal in netball, for example, the abdominals and the erector spinae muscles contract to stabilise the body and to enable the arms and shoulders to perform the skill.

Coordinated movement

The process of the agonist muscle contracting and its opposing muscle, the antagonist, relaxing is called **reciprocal inhibition** (figure 3.12). Efficient movement involves a process of give and take on each side of the joint. When you perform major movements such as kicking a soccer ball, a coordinated sequence of these muscle actions must occur. This depends on the nervous system, because the muscles need to be stimulated to contract in the proper sequence with exact timing and with the most appropriate degree of force to provide a smooth, controlled movement. This is why beginners at a task often appear jerky — for example, either overhitting or underhitting a ball.
3.3 The muscular system: initiation of muscular activity, action and control

**FIGURE 3.12** Reciprocal inhibition: when one muscle is contracting, the opposite muscle in the pair is relaxing.

**TEST your understanding**

1. Describe how a nervous impulse moves from the brain to a muscle site to initiate a movement.
2. Define the term motor unit. Discuss the differences in amount of fibres of each motor unit.
3. Describe the following principles:
   - (a) ‘all or nothing’ principle
   - (b) Henneman (size) principle.
4. Explain the difference between origin and insertion. Provide an example.
5. Define the following terms:
   - (a) agonist
   - (b) antagonist
   - (c) synergist
   - (d) stabiliser.
6. Explain the process of reciprocal inhibition. Provide an example of a muscle pair that clearly demonstrates this process.

**APPLY your understanding**

7. **Practical activity: reciprocal inhibition with movements**
   In pairs, conduct each movement and state the agonist and antagonist muscle in each exercise.
   - (a) a pushup
   - (b) a chinup with hands facing towards you
   - (c) a chinup with hands facing away from you
   - (d) a biceps curl in weight training
   - (e) a bench press in weight training
   - (f) a leg extension in weight training
   - (g) an upright row in weight training
   - (h) a half squat in weight training
   - (i) accelerating from the blocks in an athletic sprint
   - (j) the full rowing movement when rowing
   - (k) a forehand in tennis
   - (l) shooting for goal in netball
   - (m) a hockey penalty stroke
   - (n) moving from standing to sitting
   - (o) throwing a cricket ball from the boundary to the “keeper”.

8. **Practical activity: action muscles in sport**
   Participate in a sport or recreational activity of your choice.
   - (a) List four different body movements used in the activity.
   - (b) Sketch each movement. These may be your best artwork or simple but clear stick figures. Use one A4 page for each drawing.
   - (c) Identify the agonist muscles and the antagonist muscles for each movement.

9. **Practical activity: free weights**
   - (a) Working in pairs, select five exercises from the following list of free weight exercises: calf raise, leg curl, leg extension, squat, situp, lat pulldown, bench press, bicep curl, tricep extension.
   - (b) For each exercise you need to:
     - (i) identify one joint that is moving
     - (ii) identify the movement that is occurring at the joint in the first stage of the movement
     - (iii) identify the agonist muscle contracting
     - (iv) identify the antagonist muscle (opposing muscle that is relaxing).
Muscle fibre types

There are two distinct types of muscle fibres within the body's muscular system: fast-twitch fibres, and slow-twitch fibres. The relative proportions of these fibre types are genetically determined, but on average most muscles contain about 50 per cent of each fibre type (i.e. 50 per cent fast-twitch and 50 per cent slow-twitch). Each fibre is better suited to a different intensity of physical activity.

Fast-twitch fibres can be further categorised into two types on the basis of various structural and functional characteristics, so that skeletal muscle fibres can now be classified into three types (table 3.2):

- **Type 1 muscle fibres**: slow-twitch oxidative. These fibres contain large amounts of myoglobin, and large numbers of mitochondria and blood capillaries. They are red in colour and have a very high capacity for generating ATP by oxidative metabolic processes. They are suited to low-intensity, longer duration, aerobic work. Athletes who have a larger proportion of slow-twitch fibres are suited to events such as marathons, triathlons, long-distance cycling and cross-country skiing.

- **Type 2A muscle fibres**: fast-twitch oxidative. These fibres contain an large amount of myoglobin, and large numbers of mitochondria and blood capillaries. They are pinkish in colour and have a very high capacity for generating ATP by oxidative metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity, are relatively resistant to fatigue, and are classed as partially aerobic and are suited to events that require both aerobic and anaerobic elements. Athletes who have a larger portion of type 2A fast-twitch fibres are suited to events such as middle-distance running and swimming.

- **Type 2B muscle fibres**: fast-twitch glycolytic. These fibres contain a low myoglobin content, relatively few mitochondria and blood capillaries, and large amounts of glycogen. They are white and are geared to generate ATP by anaerobic metabolic processes.
The human body in motion

The muscular system: muscle fibre types and muscular contractions

- fatigue easily
- split ATP at a fast rate, and have a fast contraction velocity
- suited to high-intensity, short-duration, anaerobic work.

Athletes who have a larger proportion of type 2B fast-twitch fibres are suited to events that require explosiveness such as sprinting, throwing and weight-lifting.

### TABLE 3.2 Characteristics of fast- and slow-twitch muscle fibres

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Slow-twitch</th>
<th>Fast-twitch oxidative</th>
<th>Fast-twitch glycolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Also known as</td>
<td>Type 1</td>
<td>Type 2A</td>
<td>Type 2B</td>
</tr>
<tr>
<td>Colour</td>
<td>Red</td>
<td>Pinkish</td>
<td>White</td>
</tr>
<tr>
<td>Used for</td>
<td>Aerobic</td>
<td>Anaerobic (long-term)</td>
<td>Anaerobic (short-term)</td>
</tr>
<tr>
<td>Fibre size</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Motor neuron size</td>
<td>Small</td>
<td>Large</td>
<td>Very large</td>
</tr>
<tr>
<td>Resistance to fatigue</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Force production</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Speed of contraction</td>
<td>Slow</td>
<td>Fast</td>
<td>Very fast</td>
</tr>
<tr>
<td>Hypertrophy potential</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capillary density</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Myoglobin content</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Oxidative capacity</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Glycolytic capacity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Major fuel</td>
<td>Triglycerides</td>
<td>Creatine phosphate/glycogen</td>
<td>Creatine phosphate/glycogen</td>
</tr>
</tbody>
</table>

**FIGURE 3.14** Rohan Dennis, time trial winner of the 2015 Tour de France and hour-record holder at the Velodrome Suisse, has a high percentage of slow-twitch fibres in his leg muscles. These help him to excel in endurance events.
Types of muscular contraction

Muscle contractions are classified according to the movement they cause:
- **Dynamic** — mechanical work is performed and joint movement is produced
- **Static** — no mechanical work is performed and joint position is maintained.

There are five types of muscular contraction classified under the dynamic and static categories:
- **Dynamic** — concentric, eccentric, isoinertial, and isokinetic
- **Static** — isometric.

**Dynamic work**

**Concentric contraction** is when muscles develop sufficient tension to overcome the resistance of the body segment, the muscle length shortens and causes joint movement to create the contraction (concentric contraction) — for example, the biceps curl where the bicep muscle shortens to lift the dumbbell from the straight arm position.
**Eccentric contraction**

Eccentric contraction occurs when the muscle lengthens while the force is developed to decelerate the motion of a joint. This occurs in activities that resist gravity, and it will slow the limb or trunk movement to allow for controlled movement of the joint/s — for example, lowering the body during a situp, lowering the body during a squat or even gently setting down an object. The process is similar to a drawbridge, where the bridge must be lowered in control while working against the effect of gravity.

**Isokinetic contraction**

An isokinetic contraction allows the performer to work at a constant angular velocity against a weight or resistance that changes as the performer moves through the working muscle's possible range of movement (figure 3.17). Hence the velocity of the contracting muscle is constant so the muscle contracts concentrically and eccentrically with different directions of joint motion. These contractions are only possible with the use of expensive, specialised equipment. The amount of force applied by these machines always equals the amount of force applied by the muscle, so it is possible to develop strength through a muscle’s entire range of motion. Thus isokinetic contractions are considered to be the most effective way to develop strength and endurance.

**Isoinertial contraction**

An isoinertial contraction is a type of dynamic muscle work where the resistance against which the muscle must contract remains constant. For example, when lifting the weight in a bicep curl, at the start of the exercise, the weight of the dumbbell must be overcome. Initially the involved muscles contract isometrically in order to produce enough tension to begin to overcome the load of the dumbbell. As soon as the force produced by the muscle is greater than the resistance, then the muscle contracts concentrically, and causes acceleration of the bicep curl exercise.

**Static work**

**Isometric contraction**

An isometric contraction produces the most amount of force of any type of muscular contraction, and therefore causes the muscle to tire more quickly. The muscle generates a force, but the muscle length remains unchanged. Many sports rely on performers using isometric contractions (figure 3.16). Examples include the rugby scrum, rock climbing, amateur wrestling holds, the position out on the trapeze in sailing, and the grip on a playing stick or racquet.

**Figure 3.16** Isometric muscle contractions are important in many sports.
CHAPTER 3 • Structure and functions of the muscular system

TEST your understanding

1. Outline the differences between the three types of muscle fibres.
2. Download and view the table of muscle fibre types in your eBookPLUS. Complete this table.
3. Name and describe the five types of muscle contraction. Provide an example of each.
4. Consider the following sports and decide, giving reasons, whether fast-twitch fibres, slow-twitch fibres or a combination of both would be more important in them:
   - weight-lifting
   - athletics, a long jumper
   - Tour de France
   - athletics, a decathlete
   - soccer, a goal-keeper
   - tennis
   - hockey, inside right
   - sprint cycling
   - netball, wing attack
   - basketball, centre
   - AFL, centre half forward
   - water polo.

APPLY your understanding

5. Practical activity: muscle movements
   Work in a group of three to undertake the following tasks. Demonstrate the movements to the class.
   - Demonstrate three examples of how concentric and eccentric movements are used in sport. Outline the major muscle group(s) performing the contraction in each example, and nominate whether the contraction is eccentric or concentric.
   - Demonstrate three examples of how isometric movements are used in sport. Outline the major muscle group(s) performing the contraction in each example.

6. Practical activity: muscle contractions in volleyball
   Play a game of volleyball. Identify two activities in the game that involve performing the following contractions:
   - isometric contractions
   - concentric contractions
   - eccentric contractions
   - isoinertial contractions.
KEY SKILLS

- Use and apply correct anatomical terminology to the working of the musculoskeletal system in producing human movement
- Perform, observe and analyse a variety of movements used in physical activity, sport and exercise to explain the interaction between bones, muscles, joints and joint actions responsible for movement
- Describe the role of agonists, antagonists and stabilisers in movement
- Describe the relationship between motor unit recruitment, activation and force production

UNDERSTANDING THE KEY SKILLS

To address these key skills, it is important to remember the following:
- correct anatomical names for the major muscles and muscle fibres in the body
- understand how muscle contraction works and the link with motor unit recruitment
- understand and identify the various types of muscle contractions and the roles of agonists, antagonists and stabilisers.

PRACTICE QUESTION

The above picture depicts a physiotherapist measuring the angle of movement during flexion of the left leg at the knee joint.

a. **State** what type of muscle contraction is occurring in the hamstring muscle group during flexion of the knee. (1 mark)

b. **State** the agonist muscle group which is mainly responsible for extending the knee. (1 mark)

c. **Describe** the role of the agonist and antagonist during flexion of the knee. Your response must refer to the muscle groups. (3 marks)

Sample response

a. **Concentric** muscle contraction

b. **Quadriceps** muscle group is the **agonist** muscle responsible for **extending** the knee.

c. During **flexion** of the knee, the **hamstrings** are the **agonist** muscle group that contract and enable **flexion** of the knee joint. The **quadriceps** act as the antagonist muscle group by relaxing and lengthening to allow **flexion** of the knee joint.

PRACTISE THE KEY SKILLS

1. Discuss the differences between the characteristics of slow-twitch and fast-twitch muscle fibres.
2. Explain how skeletal muscles must work in pairs to produce movement.
3. State the muscles and anatomical movement to produce the body movement of jumping.
CHAPTER REVIEW

CHAPTER SUMMARY

Muscular system

- The muscular system has three main functions:
  - to allow movement
  - to maintain adequate posture
  - to maintain essential bodily functions.
- The three types of muscle are smooth (involuntary), cardiac (involuntary) and skeletal (voluntary).
- Muscles are usually named from their various characteristics or locations.
- Muscle fibres are organised in different ways according to the shape (or arrangement) and function of the muscles. The main arrangements of major skeletal muscles used in physical activity are fusiform, pennate and radiate muscles.
- Skeletal muscle consists of thousands of muscle fibres that run the length of the muscle. Each muscle fibre is made up of myofibrils. Each myofibril consists of many individual units, called sarcomeres, which contain actin and myosin and are responsible for contracting the muscle.
- Messages are sent from the brain to the muscles to initiate movement. A motor unit consists of the motor neuron plus the muscle fibres it stimulates.

KEY SKILLS EXAM PRACTICE

1. (© ACHPER 2015, from the written exam paper, 2015, Q15)

Changes to elements of a sarcomere during contraction

```
<table>
<thead>
<tr>
<th>Element width (μm)</th>
<th>H-zone</th>
<th>I-band</th>
<th>A-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Source: Ballarat and Clarendon College.

a. In terms of muscular contraction, describe what is happening during Phase B. 4 marks

b. i. Describe the advantage of a pennate muscle arrangement compared to a fusiform muscle arrangement. 1 mark

ii. Provide an example of a multipennate muscle. 1 mark

c. Explain why muscle fibres don't simply contract at 50 per cent of their maximum in order to alter the strength of a contraction. 3 marks
Skeletal muscles create movement by pulling on the bones to which they are attached. During a particular movement, a muscle performs one of four roles: agonist (prime mover), antagonist (relaxing muscle), synergist or stabiliser.

The process of the agonist muscle contracting and its opposing muscle, the antagonist, relaxing is called reciprocal inhibition.

There are two different categories of muscle fibre:

- fast-twitch fibres
- slow-twitch fibres.

Muscle contractions are classified according to the movement they cause, dynamic or static. The five types are concentric, eccentric, isoinertial, isokinetic and isometric.

**MULTIPLE CHOICE QUESTIONS**

1. Muscles move bones by
   (A) lengthening.
   (B) pulling.
   (C) pushing.
   (D) shortening.

2. Each myofibril is made up of tiny units called
   (A) myofilaments.
   (B) myosin.
   (C) actin.
   (D) sarcomeres.

3. The muscles mainly responsible for making movements are known as
   (A) agonists.
   (B) stabilisers.
   (C) antagonists.
   (D) fixators.

4. The paired movement of a muscle is called
   (A) agonist.
   (B) reciprocal inhibition.
   (C) antagonist.
   (D) all or nothing.

5. The muscle fibres responsible for explosive movements are called
   (A) explosive twitch.
   (B) fast-twitch oxidative.
   (C) slow-twitch.
   (D) fast-twitch glycolytic.

6. Pushing against an immovable wall is an example of what type of muscular contraction?
   (A) Concentric
   (B) Isometric
   (C) Eccentric
   (D) Isoinertial

7. Muscles can be classified into three main groups:
   (A) voluntary, involuntary and smooth.
   (B) cardiac, voluntary and rough.
   (C) skeletal, involuntary and smooth.
   (D) smooth, cardiac and skeletal.

8. Muscle fibres that run at angles to the tendons are classified as
   (A) radiate muscles.
   (B) fusiform muscles.
   (C) pennate muscles.
   (D) elasticity muscles.

9. The major muscle involved in shoulder flexion is
   (A) sartorius.
   (B) serratus anterior.
   (C) pectoralis major.
   (D) soleus.

10. The cross bridges during muscle contractions continue to detach and reattach themselves from the
    (A) myosin filaments.
    (B) sarcomere filaments.
    (C) actin filaments.
    (D) muscle fibre filaments.
EXAM QUESTIONS

Question 1

a. Which agonist muscle group is mainly responsible for raising the athlete up from the floor to the position shown in the picture?  
1 mark

b. Describe the type of muscle contraction required to hold the position shown.  
1 mark

Question 2

Describe the differences between fast-twitch and slow-twitch muscles when considering the amount of triglycerides they store.  
2 marks

Question 3

a. Describe the action of the elbow joint when the biceps contracts eccentrically.  
1 mark

b. Describe the process of reciprocal inhibition referring to the bicep curl as an example.  
2 marks

Question 4

The ‘all or nothing’ principle states that when a muscle develops tension, its fibres will either fully contract or will not contract at all. Explain two ways in which the amount of tension developed in the muscle can be altered.  
2 marks

Question 5 (adapted from ACHPER Trial Exam 2015, question 4)

a. Discuss a similarity and difference within the agonist muscle during the concentric and eccentric phase of the bicep curl.  
2 marks

b. With reference to a chosen joint action, explain the concept of reciprocal inhibition.  
3 marks