

**Level 2**

# Anatomy and Physiology for Exercise



## Introduction

This workbook has been designed to help you learn the contents of the Level 2 Anatomy and Physiology unit. Completing the learning activities can help you to prepare for your assessment.

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The following colours are used in this workbook:

**Key**

- Learning activities
- Need to know
- Definition



## Section 5: The muscular system

### What you will cover

By the end of this section you will:

- know the structural characteristics and functions of the three types of muscle tissue
- know the structure of skeletal muscle fibres
- know the names and locations of the major anterior and posterior muscle groups
- know the structure and function of the pelvic floor muscles
- understand the types of muscle contraction
- understand the relationship between muscle contractions and movement of the major joints
- know the characteristics of different muscle fibre types and how this relates to function, and
- be able to recognise changes in muscle tissue with ageing.

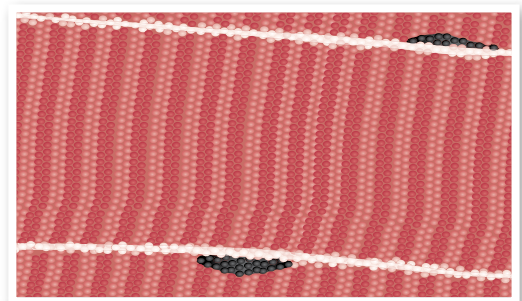
### Types of muscle

#### Skeletal muscle

Skeletal muscle has the following properties:

- it is also known as striated muscle due to its striped appearance. This effect results from the structure of sarcomeres, the segments of muscle fibres that divide the muscles along their length
- it only shortens in one direction
- it is sometimes called voluntary muscle because it is used to move the body to perform conscious actions, such as walking and picking things up, and
- it can work both aerobically and anaerobically.

Figure 5.1 Skeletal muscle

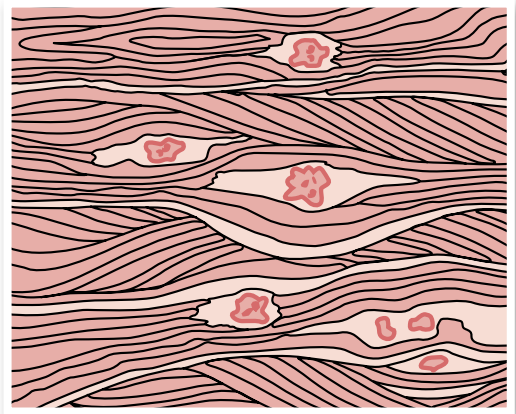


## Cardiac muscle

Cardiac muscle has the following properties:

- it is found only in the heart
- it is striated (striped) in appearance but unlike skeletal muscle its fibres branch off and connect to one another
- it operates using only the aerobic energy system. The reliance on this energy system means it is heavily dependent on oxygen and is extremely efficient at extracting it from blood
- it is involuntary as it contracts without conscious thought, and
- it is intrinsically activated by electrical impulses generated inside the heart. This electrical impulse is passed from one cardiac muscle cell to the others, resulting in the coordinated contractions of the heart.

Figure 5.2 Cardiac muscle

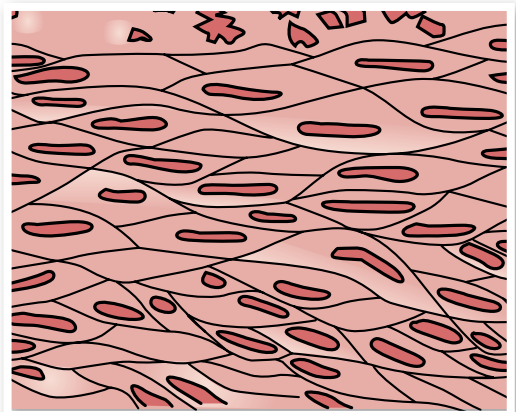


## Smooth muscle

Smooth muscle has the following properties:

- it is found in various places of the body, such as the blood vessels, digestive tract, airways and lungs
- it is not striated and contracts in all directions to cause constriction (narrowing) of the blood vessel/organ. Conversely, when smooth muscle relaxes the blood vessel /organ dilates (widens)
- it is activated involuntarily, meaning it requires no conscious thought, and
- it works anaerobically (without oxygen).

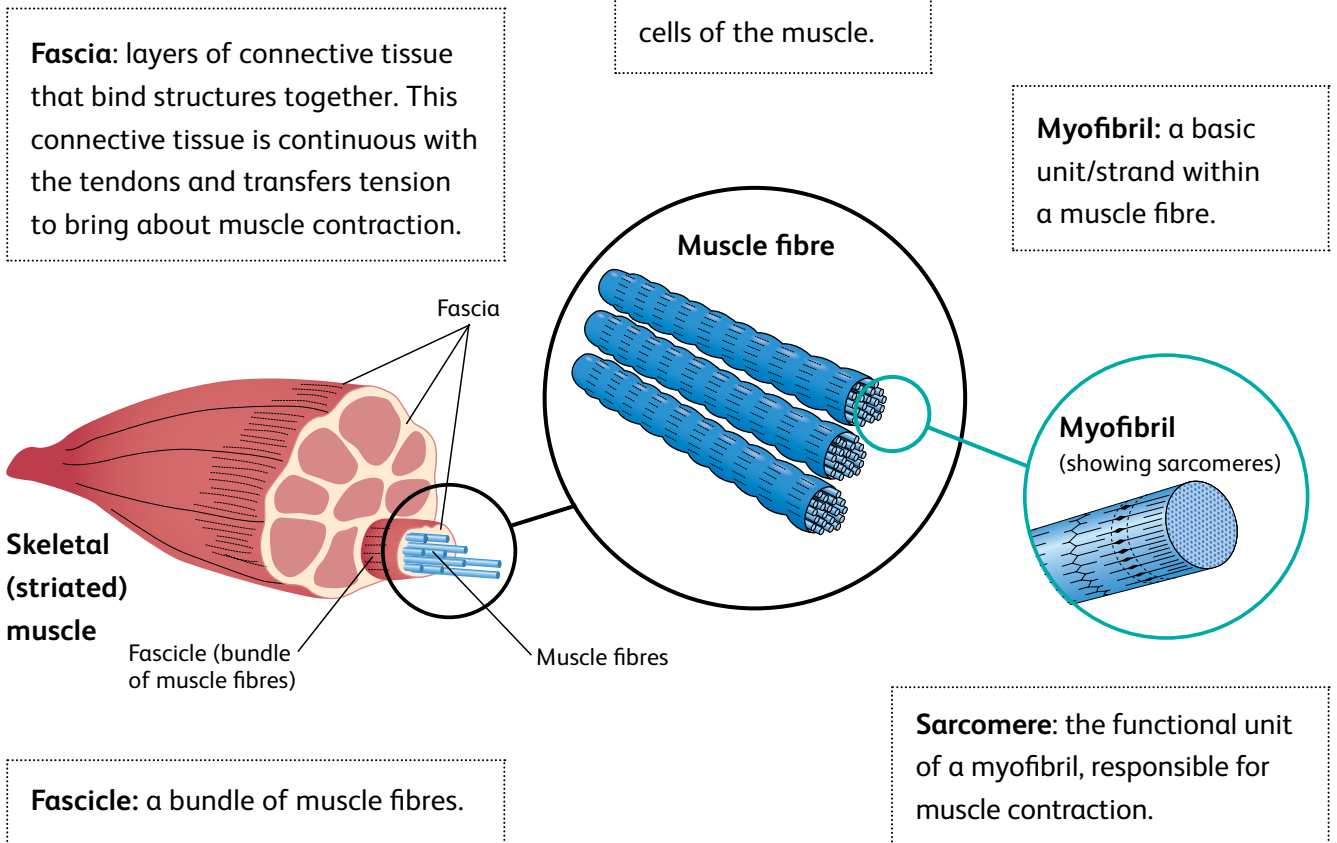
Figure 5.3 Smooth muscle



## Muscle anatomy

### Skeletal muscle structure

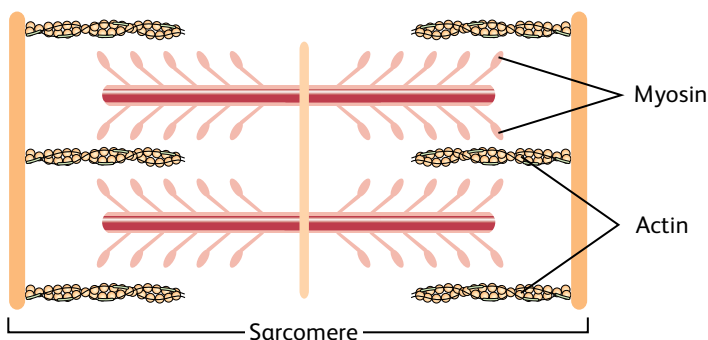
Figure 5.4 Muscle structure



### Muscle fibre structure

Muscle fibres are the cells of muscles, but they are not the smallest functional units within a muscle. Inside muscle fibres are myofilaments that run the length of the fibre. Each myofilament is divided along its length into functional units called sarcomeres. Each sarcomere contains the mechanism of muscle contraction, the 'sliding filaments' – actin and myosin.

Figure 5.5 The structure of a sarcomere



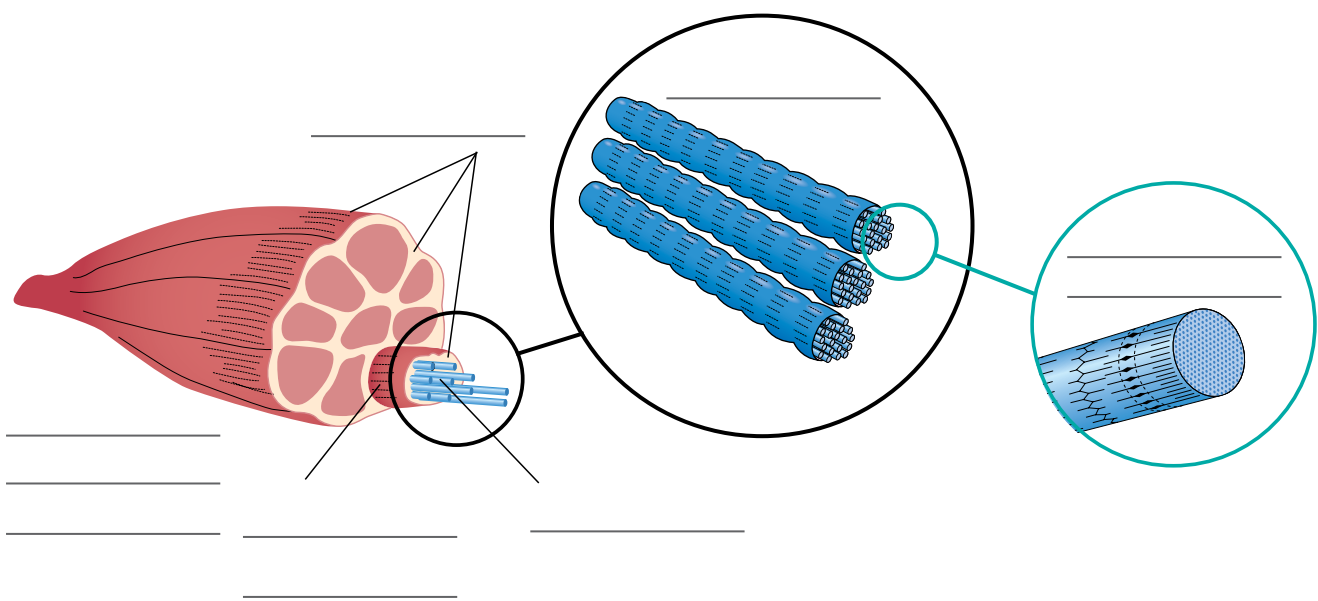
### Learning activity 5.1

Summarise the characteristics of the three different types of muscle found in the human body in the table below.

Muscle type	Appearance	Energy system	Location
Cardiac			
Smooth			
Skeletal			

### Learning activity 5.2

Study the labelled figure of muscle structure on the previous page and then attempt to label the figure below without referring back.





## Sliding filaments

The sliding filament theory is the method by which muscles are thought to contract. The two key components of this mechanism are proteins that cause the contraction: actin and myosin.

For the sliding filament theory to work and cause muscles to contract, energy is required. When skeletal muscle produces energy aerobically the mitochondria within the muscle are responsible for converting oxygen into usable energy in the form of adenosine triphosphate (ATP).

### *Sliding filament theory*

When a skeletal (voluntary) muscle is about to contract the following things will happen:

- 1 calcium is released and frees up the binding sites on the actin filaments
- 2 the arms (cross bridges) of the myosin filament bind to the actin
- 3 the myosin filaments pull on the actin, shortening the sarcomere and making the muscle contract, and
- 4 when the muscle lengthens they return to their original position ready to contract again.

### Actin and myosin

#### **Actin:**

- is the thin filament and looks like a strand of twisted beads, and
- each actin filament is anchored to one end of the sarcomere.

#### **Myosin:**

- is the thick filament that appears to have arms (known as cross bridges), and
- bundles of myosin filaments are located in the middle of the sarcomere.

### Mitochondria

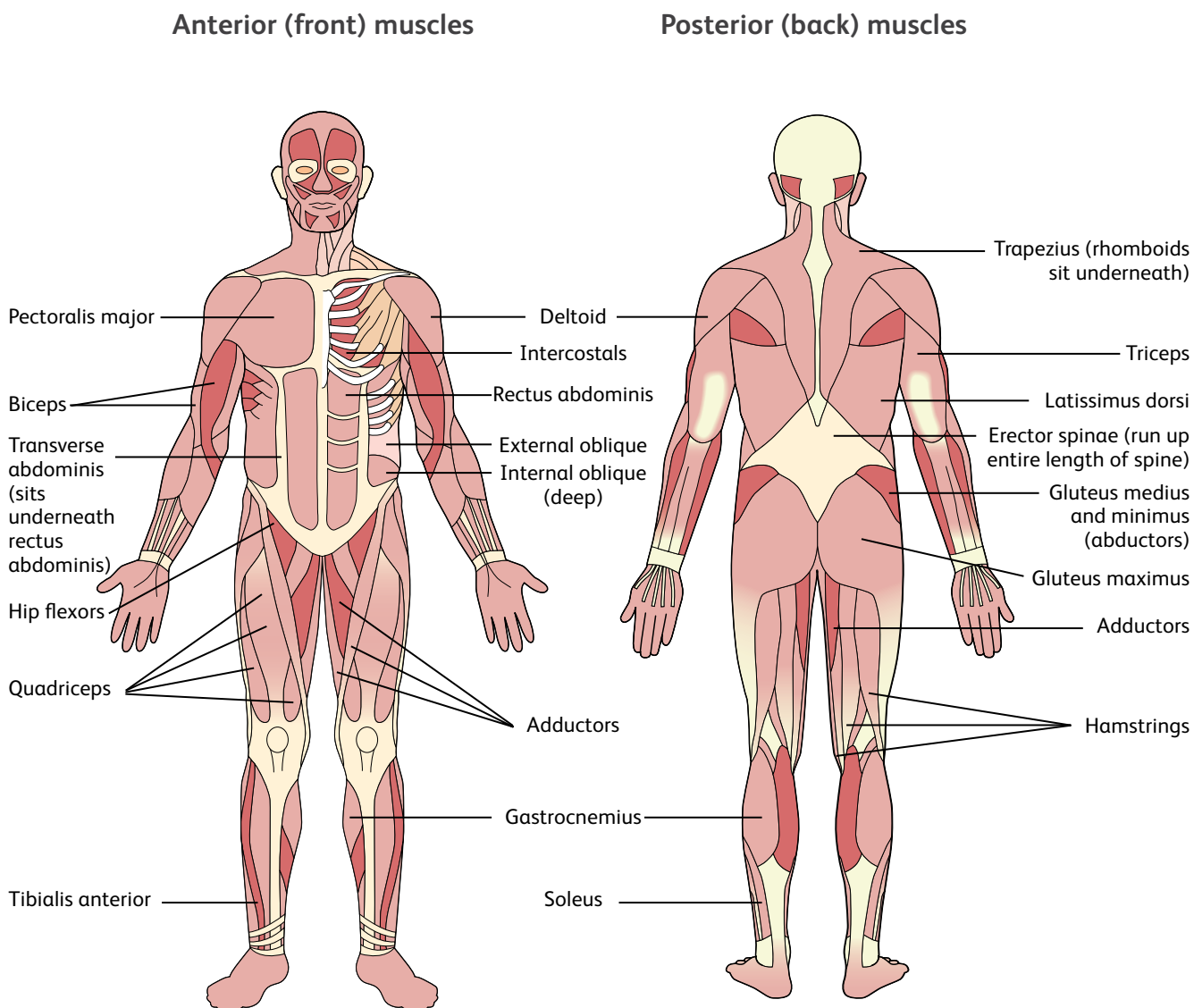
Mitochondria can be thought of as the powerhouse of the muscle cell. This is where aerobic energy production takes place within a muscle as oxygen is converted into ATP.



## Muscles of the body

There are over 600 muscles within the human body. Many of these are not necessary to know to be an effective fitness instructor. It is important, however, to know the locations and functions of the major muscles of the body involved in movement.

Figure 5.6 Major anterior and posterior muscles of the body





Core and pelvic floor muscles

**The core**

The core is traditionally thought of as the area between the pelvis and the rib cage, in particular it refers to the muscles that support, stabilise and move the lumbar region of the spine.

Some core muscles cannot be seen, sitting underneath other muscles meaning their functioning is invisible to the eye. The muscles here are particularly important to the correct functioning of the body. The core of the body relies heavily on muscular control to stabilise it as well as control movement.

The muscles of the core can be thought of as a cylinder, with the pelvic floor muscles forming the base of the cylinder and the diaphragm the top. The anterior of the cylinder is made up of the rectus abdominis (the 'six pack' muscle) and at the sides are layers of muscles, starting with the deep transversus abdominis, then internal obliques and on top, the external obliques. The posterior of the cylinder comprises a large sheet of connective tissue along with the erector spinae muscles and other deep lower back muscles.

When the muscles of the cylinder contract the pressure in the abdomen is increased and this helps to stabilise the area, maintaining neutral spine.

Figure 5.7 Anterior core muscles

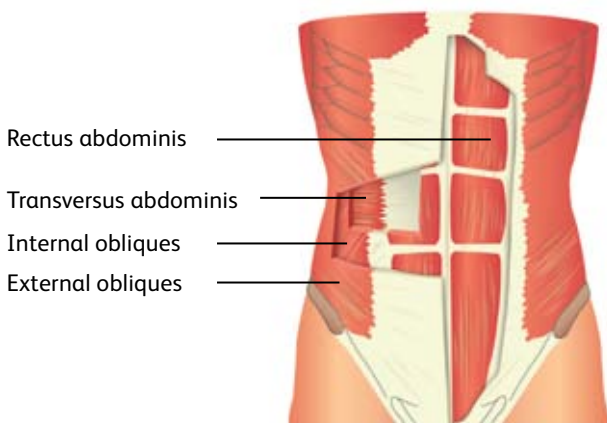
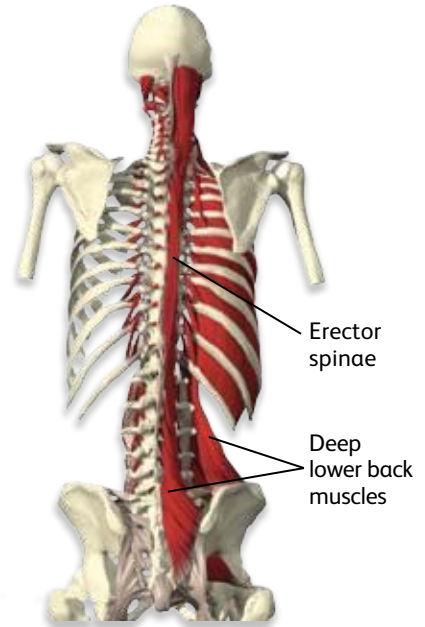


Figure 5.8 Posterior core muscles



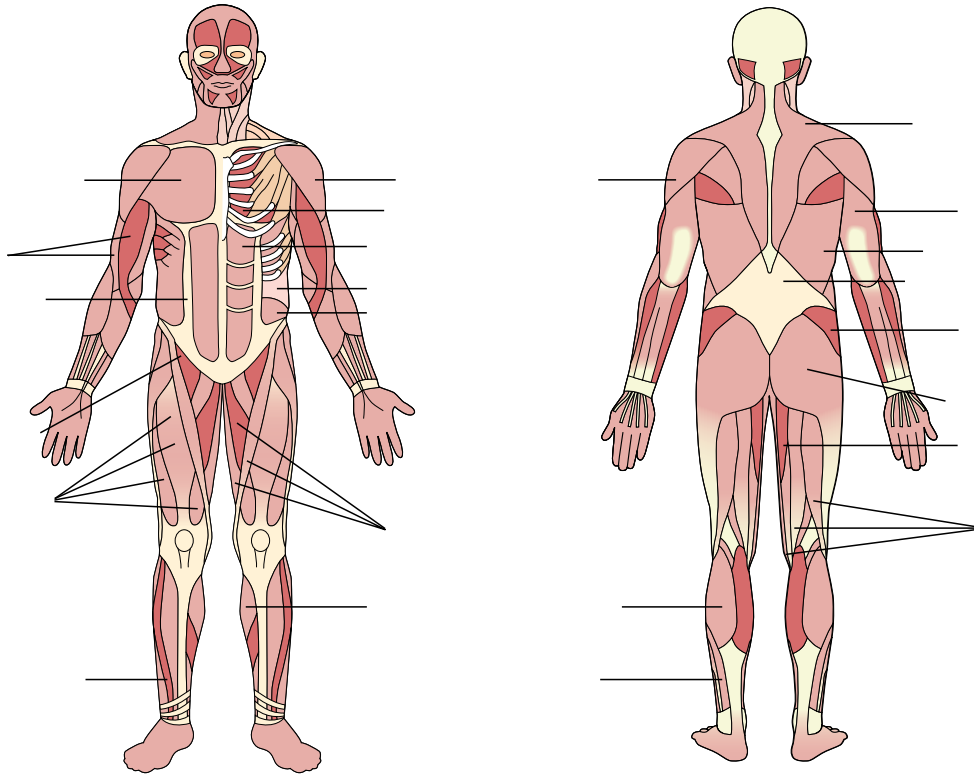
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**The pelvic floor**

The muscles at the base of the abdomen attached to the pelvis. They form a 'figure of eight' shape and play an essential role in core stability as well as controlling bladder and bowel continence.

### Learning activity 5.3

Fill in the labels on the diagram below.



## Muscle contractions

Skeletal muscles can contract in various ways depending on the role they have been asked to perform at the time.

### Isotonic contractions

Isotonic contractions are ones where movement occurs – such as lifting and lowering a weight. There are two phases to an isotonic contraction:

- **the concentric phase:** this is the lifting phase, where a muscle shortens to work against a load, and
- **the eccentric phase:** this is the lowering phase, where a muscle lengthens under tension to control a weight.

It is important to remember that this applies to the load (or weight) being lifted, so in an exercise such as a lat pull down, even though an exerciser is pulling the bar downwards, the weight is lifting upwards, making it the concentric phase.

### Delayed onset muscle soreness (DOMS)

Eccentric muscle contractions are responsible for the muscle pain and soreness that people experience in the one to two days following strenuous exercise. This is commonly known as DOMS and is a natural process that occurs as the muscles repair and adapt.

### Concentric (clouds)

A concentric contraction is where the muscle is shortening against a load or gravity. Remember this by visualising 'C' for clouds – during concentric contractions the weight is lifted upwards, towards the clouds.

### Eccentric (earth)

An eccentric contraction is where the muscle is lengthening under tension, with gravity. Remember this by visualising 'E' for earth – during eccentric contractions the weight is lowered down, towards the earth.

## Isometric contractions

Isometric contractions are where a muscle contracts and tension is created but the muscle length remains the same. Increases in blood pressure are associated with this type of contraction, so it is not advised for some people, for example those with high blood pressure.

## Muscles and movement

Muscle contractions only produce movement because muscles are attached at each end via tendons to bones across joints. A muscle can only act across a joint to produce movement by contracting to move one end of the muscle towards the other. In this way the human body is a little like a puppet: instead of pulling on different strings in a specific order to produce movements, the brain uses nerves to activate different muscles in a coordinated pattern to create the desired action. For this reason, a muscle can only 'pull' to create movement across one side of a joint.

During exercise muscles can play various roles depending on the movement being performed. These roles are:

- agonist
- antagonist
- synergist, and
- fixator.

### Isometric

- **Iso** means equal.
- **Metric** means length.

Examples of isometric exercises include plank and static wall squats.

### Roles of a muscle

- **Agonist** (prime mover): the major muscle working during an exercise to bring about movement.
- **Antagonist**: the opposing muscle to the agonist. This relaxes to allow movement to occur.
- **Synergist**: smaller helper muscles that aid the agonist to assist with movement.
- **Fixators**: act as stabilisers by contracting isometrically to prevent unwanted movement in other muscles, making movements more efficient.

## Agonists and antagonists

Muscles always work in the same agonist and antagonist pairs. For example, when the biceps are working (the agonist), the triceps are always the antagonist. This works the opposite way around, so when the triceps are the agonist, the biceps are the antagonist. This is true of all exercises involving these muscles.

Every muscle has an antagonistic partner. The common agonist/antagonist pairs are listed in table 5.1.

### Examples

#### *Biceps curl*

When performing a biceps curl, the agonist is the biceps muscle. The other major muscle crossing the elbow, is the triceps. It is located on the posterior of the upper arm opposite to the biceps. In order for the biceps to flex the elbow, the antagonist – the triceps – must be relaxed. Smaller muscles in the upper arm act as synergists to help the biceps with the exercise. To keep the upper arm stable, many other muscles act on the shoulder joint and shoulder girdle, including pectoralis major, deltoid, latissimus dorsi, trapezius and the rhomboids. These all play the role of fixators.

#### Remember!

It is important to be aware that even as the weight is lowering (elbow extension), the biceps are contracting not the triceps. Gravity will lower the arm to a fully extended position with no assistance from the triceps muscle.

The biceps have to contract **concentrically** (towards the clouds) to lift the weight, and **eccentrically** (towards the earth) to control the weight back to its start position.

Throughout this the triceps remain relaxed in their role of antagonist and merely lengthen and shorten under no tension to allow the biceps to work.

Table 5.1 Muscle pairs

Agonist*	Antagonist*
Deltoids	Latissimus dorsi
Pectoralis major	Trapezius and rhomboids
Biceps	Triceps
Rectus abdominis	Erector spinae
Hip flexors	Gluteus maximus
Hip adductors	Hip abductors
Quadriceps	Hamstrings
Tibialis anterior	Gastrocnemius and soleus

\* When the muscles in the right-hand column are working they become the agonist, and the opposing muscle in the pair becomes the antagonist.



Table 5.2 Biceps curl muscle roles

Role of muscle	Muscle/s
Agonist	Biceps
Antagonist	Triceps
Synergist	Smaller muscles in upper arm
Fixator	Core muscles/shoulder stabilisers

**Shoulder press**

Table 5.3 Shoulder press muscle roles

Role of muscle	Muscle/s
Agonist	Deltoids
Antagonist	Latissimus dorsi
Synergist	Triceps
Fixator	Core muscles/shoulder stabilisers

**Seated row**

Table 5.4 Seated row muscle roles

Role of muscle	Muscle/s
Agonist	Trapezius and rhomboids
Antagonist	Pectoralis major
Synergist	Biceps
Fixator	Core muscles/shoulder stabilisers

**Synergists**

One simple rule for remembering synergists in upper body exercises is:

- if it is a **pull** exercise such as a lat pull down or a seated row, the **biceps** are always a synergist, and
- if it is a **push** exercise such as a chest press or press-up, then the **triceps** are always a synergist.

**Learning activity 5.4**

In your own words define the following types of muscle contraction.

Concentric:  
 .....  
 .....  
 .....

Eccentric:  
 .....  
 .....  
 .....

Isometric:  
 .....  
 .....  
 .....

Now look at the following examples of exercises and state whether a concentric, eccentric or isometric contraction is taking place.

1. Lowering towards the floor when performing a squat.

2. Holding dumbbells up in front of you in a fixed position as in a front raise exercise.

3. Pushing the weight overhead when doing a shoulder press.



### Learning activity 5.5

List the antagonist for each of the following.

Agonist	Antagonist
Deltoids	
Pectoralis major	
Biceps	
Rectus abdominis	
Hip flexors	
Hip adductors	
Quadriceps	
Tibialis anterior	

### Linking muscle action to joint action

Knowing the location of a muscle and being aware of the joints it crosses are essential in understanding what movement will occur when that muscle contracts. Doing resistance training exercises is a great way to feel the relationship between a particular movement or joint action and the muscles that cause it.

### Learning activity 5.6

Do each of the following exercises until you can feel a muscle working. Identify the joint action you are performing and the muscle that you can feel getting fatigued.

#### Seated leg extension

Sitting on a chair, hold your thigh still and slowly straighten your leg from the knee until the leg is horizontal. Pause briefly then slowly lower it back down. Repeat until you can feel a muscle working.

- What joint action were you performing as you lifted the leg?

- 
- What joint action were you performing as you lowered the leg?

- 
- What muscle could you feel working?

#### Lateral raise

Hold a heavy book or full water bottle in one hand. Keeping your body still, slowly lift your arm straight out to the side until it is horizontal. Pause briefly then lower it slowly back to your side. Repeat this until you feel a muscle working.

- What joint action were you performing?

- 
- What muscle could you feel working?
-



## Muscle action matrix

The following table links together the knowledge you have covered in sections 3 and 4. It shows the joint actions possible at each joint and which muscles work to produce these actions.

Table 5.5 Muscle action matrix

Joint crossed by muscle	Muscle contracting (agonist)	Joint action (during concentric phase)	Joint action (during eccentric phase)
Shoulder	Latissimus dorsi	Adduction	Abduction
	Deltoid	Abduction	Adduction
	Latissimus dorsi	Extension	Flexion
	Deltoid	Flexion	Extension
	Pectoralis major	Horizontal flexion	Horizontal extension
	Trapezius and rhomboids	Horizontal extension	Horizontal flexion
Elbow	Biceps	Flexion	Extension
	Triceps	Extension	Flexion
Hip	Hip flexors	Flexion	Extension
	Gluteus maximus	Extension	Flexion
	Abductors	Abduction	Adduction
	Adductors	Adduction	Abduction
Knee	Quadriceps	Extension	Flexion
	Hamstrings	Flexion	Extension
Ankle	Gastrocnemius and soleus	Plantar flexion	Dorsi flexion
	Tibialis anterior	Dorsi flexion	Plantar flexion
Spine	Rectus abdominis	Flexion	Extension
	Erector spinae	Extension	Flexion
	Obliques	Lateral flexion	Lateral flexion
	Obliques	Rotation	Rotation

### Things to remember

As you can see from the table above, some muscles can contract to perform more than one joint action, such as the deltoids that can bring about shoulder abduction or shoulder flexion.

You will see that when the obliques contract concentrically they bring about either lateral flexion or rotation. In the eccentric phase, the same joint actions occur but in the opposite direction to bring the body back to its original position.

## Muscle physiology

Not all muscle fibres are the same: even within a single muscle there is a variety of types. The different types have their own characteristics and come into play at different intensities of activity. Muscles vary in the proportions of different fibre types they contain according to their location and function in the body. The proportions of different fibre types in a muscle group also vary between one person and another. This is one of the factors that make some people good at explosive power sports and others better at endurance activities.

### Muscle fibre type characteristics

There are two main muscle fibre types.

**Type 1 fibres**, also known as **slow twitch** fibres.

- These fibres are **red** in colour because they contain a large amount of myoglobin (a substance similar to haemoglobin that can bind oxygen in muscles).
- They also contain large numbers of mitochondria (the aerobic energy power stations of cells).
- They have many capillaries (tiny blood vessels) surrounding them.
- They are slow to contract and slow to fatigue.
- They are recruited for lower intensity, longer duration types of activity, meaning they are best for endurance or aerobic work.
- Elite marathon runners will have a high percentage of type 1 fibres in their muscles.

**Type 2 fibres**, also known as **fast twitch** fibres.

- These fibres are white in colour as they do not require oxygen for the work that they do.
- These fibres can contract rapidly and with high force but they fatigue quickly.
- They are recruited during high intensity activity, which tends to be short in duration.
- They contain relatively few mitochondria and have fewer capillaries surrounding them.
- Elite sprinters will have a high percentage of type 2 fibres in their muscles.

### Myoglobin

Myoglobin is a substance that binds to oxygen allowing muscles to produce aerobic energy more effectively. Myoglobin, much like haemoglobin, contains iron and this is what gives type 1 muscle fibres their bright red appearance.

As type 2 muscle fibres produce energy anaerobically they have lower levels of myoglobin and are therefore white in colour.

Table 5.6 Characteristics of muscle fibre types

Characteristic	Type 1	Type 2
Colour	Red	White
Contraction time	Slow	Fast
Time to fatigue	Long	Short
Energy system (see section 6, page 84)	Aerobic	Anaerobic lactic acid and creatine phosphate (CP)
Cross-sectional diameter	Small	Large
Amount of force generated	Low	High

### Muscle and ageing

As people age muscle tissue atrophies (wastes away) leading to reduced strength and endurance. This happens in everyone eventually but can be significantly slowed down with regular exercise.

## The muscular system summary

You should now be able to:

### 5.1 Identify the three types of muscle tissues:

- skeletal, cardiac and smooth

### 5.8 Identify different muscle fibre types and their characteristics:

- type 1 are red, use oxygen and are dominant in endurance sports
- type 2 are white, use very little oxygen and are dominant in strength and power activities

### 5.7 Identify the joint actions brought about by muscles:

- the different roles muscles play during movement: agonist, antagonist, synergist and fixator
- recognise the joint actions that take place when muscles contract concentrically and eccentrically

### 5.6 Identify different types of muscle action:

- isotonic (concentric and eccentric)
- isometric

### 5.2 Identify the characteristics and functions of the muscle tissues:

- skeletal is striated, voluntary and brings about movement
- cardiac is striated, involuntary and found only in the heart
- smooth is not striated, involuntary and found in blood vessels, the airways and the digestive tract

### 5.3 Describe the basic structure of a skeletal muscle:

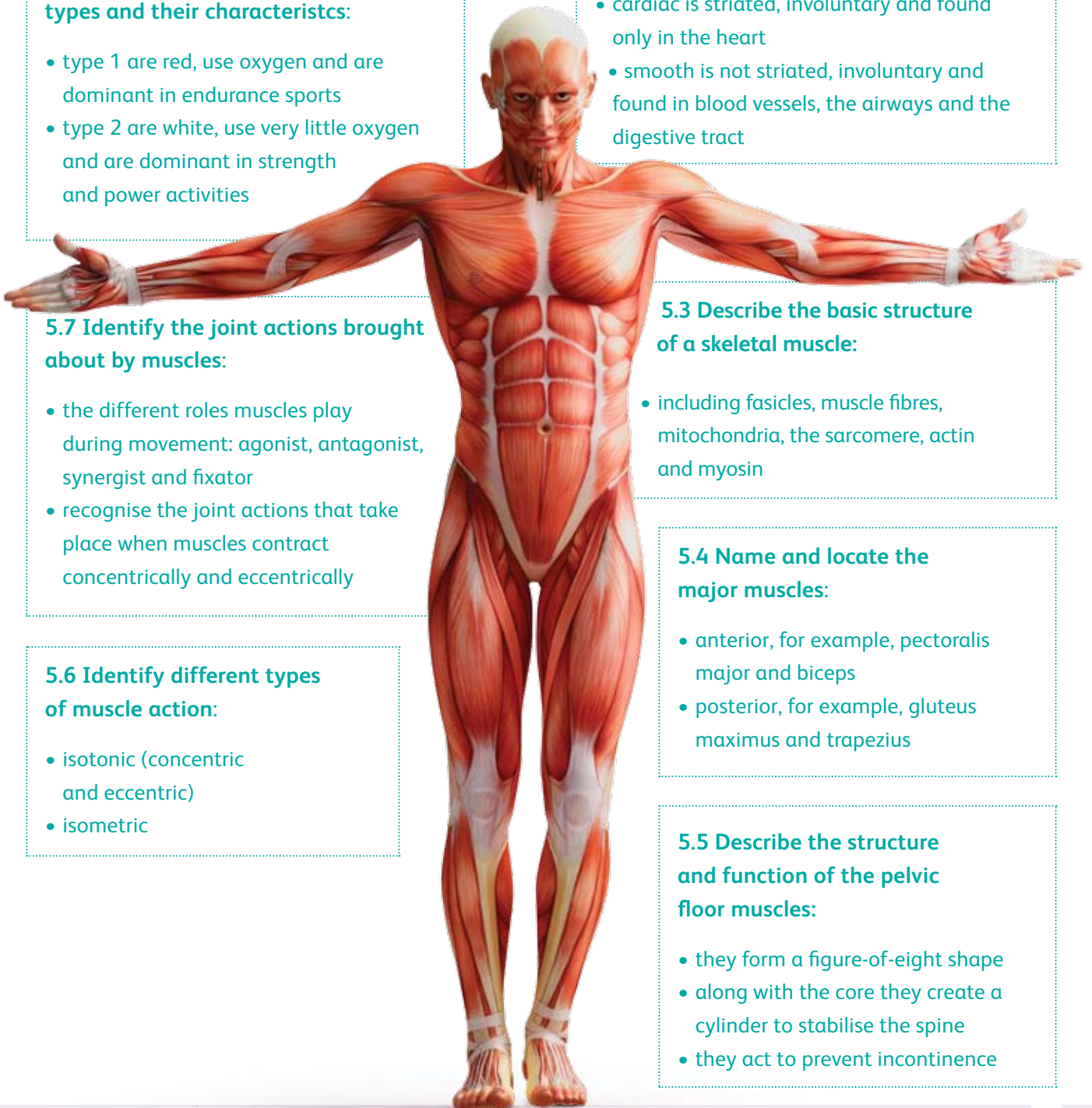
- including fascicles, muscle fibres, mitochondria, the sarcomere, actin and myosin

### 5.4 Name and locate the major muscles:

- anterior, for example, pectoralis major and biceps
- posterior, for example, gluteus maximus and trapezius

### 5.5 Describe the structure and function of the pelvic floor muscles:

- they form a figure-of-eight shape
- along with the core they create a cylinder to stabilise the spine
- they act to prevent incontinence



## Section 6: The energy systems

### What you will cover

By the end of this section you will:

- know how carbohydrates, fats and proteins are metabolised to re-synthesise adenosine triphosphate (ATP), and
- understand the roles of the three energy systems during activity and exercise of different intensities.

### ATP and energy

#### Adenosine triphosphate (ATP)

Energy is required for many of the processes that keep the human body functioning, including growth, development, repair of tissues and muscular contraction. ATP is the 'energy currency' used within the human body. An ATP molecule consists of one adenosine molecule and three phosphates, which are joined by high-energy bonds as shown in figure 6.1.

Energy is produced from the food that we eat; it cannot be created or destroyed but simply converted from one form to another. Carbohydrates are the preferred fuel and provide the most rapid source of energy. Once consumed, all food is broken down to its constituent molecules (carbon, hydrogen, oxygen and nitrogen) but, in order for these to be used as energy, they need to be stored as ATP.

ATP molecules store energy which is released where and when it is needed in the body through a simple chemical reaction which converts ATP to adenosine diphosphate (ADP). This reaction is the energy source for all energy-requiring functions in the human body.

Figure 6.1 An ATP molecule



#### Energy production

ATP is the only direct source of energy that can be used by the body.

**Adenosine triphosphate** molecules have three phosphates.

**Tri = three.**

**Adenosine diphosphate** molecules have two phosphates.

**Di = two.**

The breakdown of ATP into ADP is the source for **ALL** muscular contractions and other energy-requiring functions in the human body.

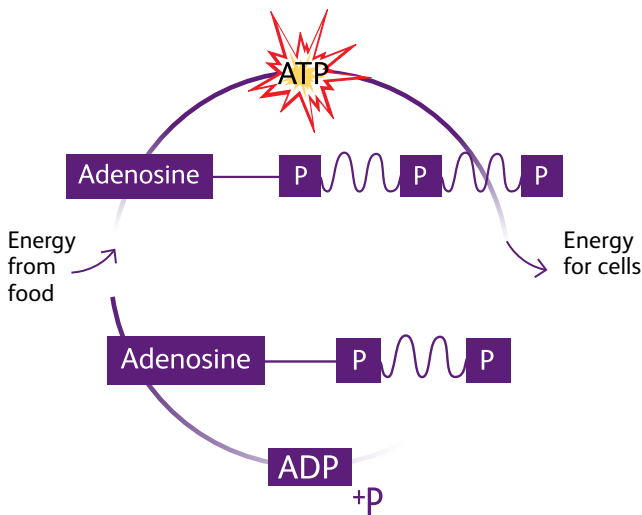
### Energy release and re-synthesis

When energy is needed, ATP molecules are broken down into ADP molecules and energy is released. The energy is created by breaking one of the high-energy phosphate bonds. In order for this reaction to happen, an enzyme is needed. Figure 6.2 represents this energy release.

Once energy is released from the ATP molecule, an ADP molecule and a free-phosphate remain. However, the body only stores a limited amount of ATP. So, in order for energy to be constantly available, ATP needs to be continuously produced. To do this, the ADP molecule and free-phosphate need to be 're-joined'. For this re-synthesis of ATP to occur, energy is required as shown in figure 6.3. The energy required for this reaction comes from food.

The breakdown and re-synthesis of ATP provides the energy source for the body, but it is only successful because less energy is required to re-synthesise ATP than is produced when it is broken down. Figure 6.4 shows the cycle of ATP breakdown and re-synthesis.

Figure 6.4 ATP cycle



### Enzymes

These substances are responsible for bringing about chemical reactions in the body.

Figure 6.2 Energy release

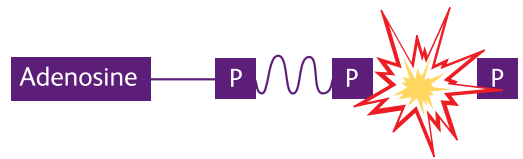


Figure 6.3 Re-synthesis of ATP



### Energy resynthesis

It is important to remember that the body only stores a limited amount of ATP. For energy to be constantly available, the body must remake ATP and this requires energy from the body's stores or from food.

## Learning activity 6.1

Answer the following questions.

1. What substance is broken down to create energy for all of the body's muscular contractions and energy-requiring functions?

2. Once your answer to question 1 has been broken down, what is it converted into?

3. What is needed to re-synthesise ATP?

## Nutrients

All of the macro-nutrients (carbohydrate, fat and protein) can be used as fuel within the human body:

- **carbohydrates**, in the form of glucose, are the body's preferred fuels and provide a rapid energy source
- **fats**, in the form of fatty acids (also known as triglycerides), are an efficient, energy-dense fuel source – they contain twice as much energy per gram as carbohydrate or protein, and
- **proteins**, in the form of amino acids, are very rarely used as an energy source. In order for them to be used, they must be processed in the liver to change their structure. They can then be used in the body for energy in the same way as glucose.

### A rechargeable battery

ATP can be thought of as a rechargeable battery. When fully charged, ATP can provide energy. Once this energy is used, it requires recharging in order to be able to provide more energy.

The body can use carbohydrates, fats and proteins to do this, but its preferred fuel is carbohydrate.

### Carbohydrates

- Provide 4Kcal of energy per gram.
- This is stored as glycogen in the body.

### Fats

- Provide 9Kcal of energy per gram.
- This is stored as triglycerides in the body.

### Protein

- Provide 4Kcal of energy per gram.
- This is stored as amino acids in the body.



## The three energy systems

When ATP is re-synthesised, it can occur in one of two ways:

- in the **presence** of oxygen – when it is called **aerobic**, and
- in the **absence** of oxygen – when it is called **anaerobic**.

Therefore, the energy systems in the human body can be split into aerobic and anaerobic energy systems. The anaerobic system can be further divided into the anaerobic lactic acid and the creatine phosphate (CP) systems.

### The aerobic energy system

At rest, and during low- to moderate-intensity activities, the aerobic energy system will provide the majority of the energy required by the body. The aerobic energy system can utilise carbohydrates, fats and proteins to re-synthesise ATP. The by-products of this energy system are water, carbon dioxide and heat. The average person has sufficient stored carbohydrate to fuel low- to moderate-intensity exercise for **around 80 minutes**.

Work in the aerobic energy system can continue indefinitely as long as oxygen is available and carbohydrate stores are topped up.

#### Aerobic energy sources

To produce energy aerobically the body will primarily use carbohydrates and fat in the form of glycogen (stored carbohydrates) and fatty acids.

When stores run low the body can use protein from the muscles as a back-up store if required. This is not ideal as it leads to loss of muscle.

### The lactic acid system

At higher exercise intensities insufficient oxygen is available for the aerobic system to re-synthesise all of the ATP required by the working muscles. Therefore, anaerobic energy systems are recruited to provide a higher proportion of energy than during lower-intensity activity. The anaerobic lactic acid system uses glycogen (the stored form of carbohydrate) to re-synthesise ATP quickly.

#### The energy systems

There are three energy systems which the human body uses to re-synthesise ATP, these are known as:

- the aerobic energy system
- the anaerobic lactic acid system, and
- the creatine phosphate (CP) system.

As the name suggests, this energy system produces lactic acid as a waste-product which can cause fatigue if it is allowed to build up within the working muscles. The burning feeling that people often experience in their muscles at higher exercise intensities is a result of lactic acid accumulation. When used as the primary energy system at intensities above lactate threshold, fatigue typically occurs after **around 60–90 seconds**.

### The creatine phosphate system

The creatine phosphate (CP) system dominates during very high-intensity activity, when near maximal explosive efforts are required. The fuel for this system is CP, which is stored in muscles in limited amounts. It is believed that there is enough stored for just **6–10 seconds** of high-intensity exercise.

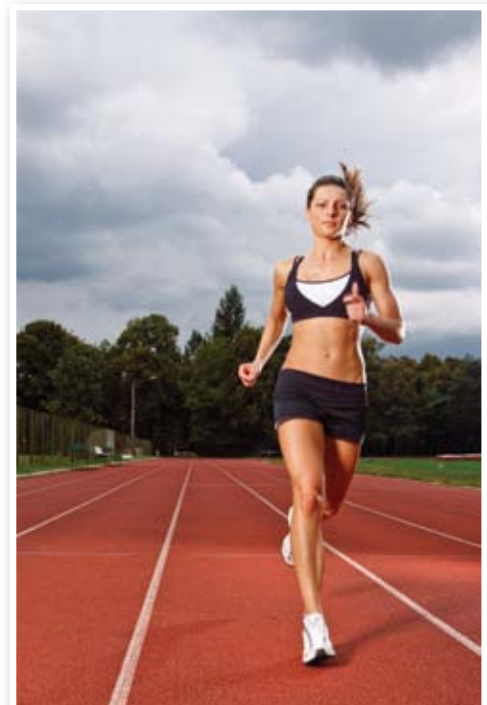
CP is a high-energy compound which, when broken down, releases its energy. This energy can be immediately used to re-synthesise ATP from ADP and a free-phosphate. The CP system is capable of re-synthesising large amounts of ATP very quickly, but the body’s store of CP limits the duration which this energy system can operate for.

Table 6.1 Summary of the differences between the energy systems

	Aerobic energy system	Lactic acid system	CP system
Exercise intensity	Low to moderate	High	Near maximal
Fuel	Carbohydrates, fats and proteins	Glycogen	Creatine phosphate (CP)
By-products	Water, carbon dioxide and heat	Lactic acid	None
Limiting factors	Exercise intensity and fuel availability	Lactic acid build-up	CP availability
Duration	Indefinite	Up to 90 seconds	6–10 seconds
Example activities	Marathon running, high repetition endurance resistance training	400m running	100m sprint, low repetition strength resistance training

### Creatine supplements

Some athletes take creatine supplements to increase the availability of CP. This allows the CP system to operate for a longer period of time, enabling an athlete to maintain speed or stay strong for one or two seconds longer in training and events.



### Learning activity 6.2

Name the three energy systems and, in your own words, describe how they re-synthesise ATP.

1.   
.....  
.....
2.   
.....  
.....
3.   
.....  
.....

### Learning activity 6.3

Fill in the gaps in the table below.

Parameter	Aerobic energy system	Lactic acid system	CP system
Exercise intensity	Low to moderate	High	
Fuel	Carbohydrates, fats and proteins		Creatine phosphate
By-products			None
Limiting factors		Lactic acid build-up	
Duration		Up to 90 seconds	
Example activities	Marathon running		

## Energy systems and exercise

The energy system that is predominantly used during exercise will depend upon the following:

- the intensity of the exercise
- the duration of the exercise, and
- the type of exercise.

It is important to note, however, that all three energy systems work all of the time. The energy systems are not switched on and off according to the type of activity being carried out. What changes is the relative contribution of each energy system to total ATP re-synthesis.

For example, in a 400 metre race the lactic acid system predominates. In the first few seconds, however, the CP system will assist to create energy as the runner begins to sprint and towards the end of the race as the athlete tires, the aerobic system will contribute more.

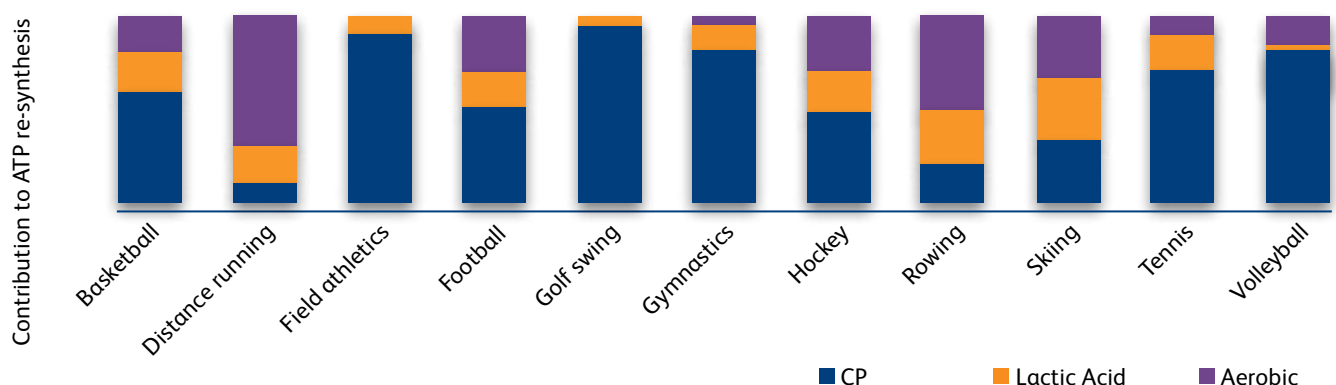
In team sports such as football, hockey, rugby and netball, the energy system that predominates will depend on what the competitor is doing at the time. For example, if they are not involved in play and are walking, the aerobic system will predominate, but if they are sprinting to get to the ball, then the CP system will take over as the dominate one.

Some types of exercise are more endurance-based and therefore use the aerobic system predominantly, whereas others are more power-based and therefore use the CP system more.

### Energy systems and exercise

Whether it's a very short-duration, high-intensity exercise or a very low-intensity, long-duration exercise, all three energy systems will be making a contribution to ATP re-synthesis. However, one or two of the energy systems will normally predominate.

Figure 6.5 Relative contribution of the three energy systems to selected sports (Foss ML & Keteyian S (1998), *The Physiological Basis of Exercise and Sport*, 6th edition).



### Learning activity 6.4

Think about three activities that you enjoy, for example, football, tennis and marathon running. Using the information shown in the graph in figure 6.5, estimate how much each energy system contributes to ATP re-synthesis during each of these activities. An example is given below.

Activity	Aerobic system	Lactic acid system	CP system
Skiing	33%	33%	33%

#### What happens with the onset of aerobic exercise?

When a person begins aerobic exercise – long-distance running for example – the first few minutes will be fuelled by anaerobic metabolism. This is because there is a delay in the body’s response to the commencement of activity, leading to a short period of time when insufficient oxygen is present even at low exercise intensities.

Once sufficient oxygen is present, the predominant energy system will be the aerobic system at low to moderate exercise intensities. This type of exercise will, therefore, be fuelled by carbohydrate and fat. As long as the exercise intensity does not increase dramatically, the aerobic energy system will continue to adequately fuel the exercise.

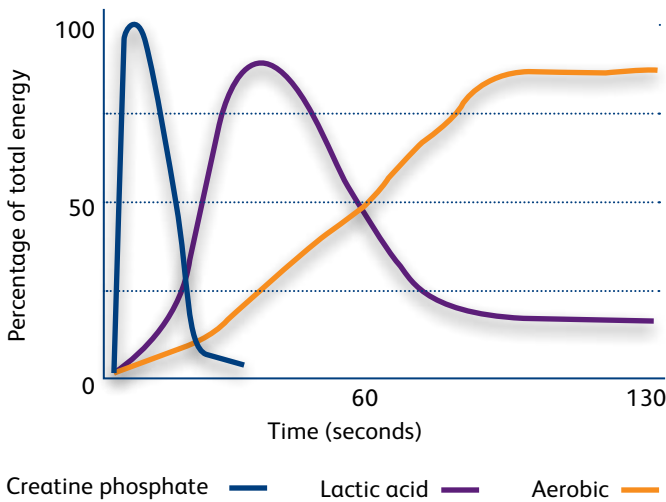


**What happens with the onset of anaerobic exercise?**

At the onset of anaerobic-type exercise – a 100 metre sprint for example – the body has to quickly re-synthesise a large amount of ATP in order to perform this high-intensity activity. Initially, stored ATP is used which will provide energy for around two to three seconds. Following this, the CP system becomes dominant until CP stores are depleted (up to 10 seconds).

If the demand for ATP re-synthesis continues once the CP stores have been depleted, the lactic acid system must take over as the dominant energy system. Whilst this energy system is dominating, high-intensity exercise can continue until lactic acid builds up within the working muscles.

Figure 6.6 The relative contribution of energy systems over time



**Learning activity 6.5**

In the table below, identify which energy system predominates for each activity. An example is given.

Activity	Predominant energy system
Marathon running	Aerobic
100m sprint	
Long-distance swimming	
Olympic weight lifting	
Tennis	
Rowing	
50m front crawl	
800m sprint	

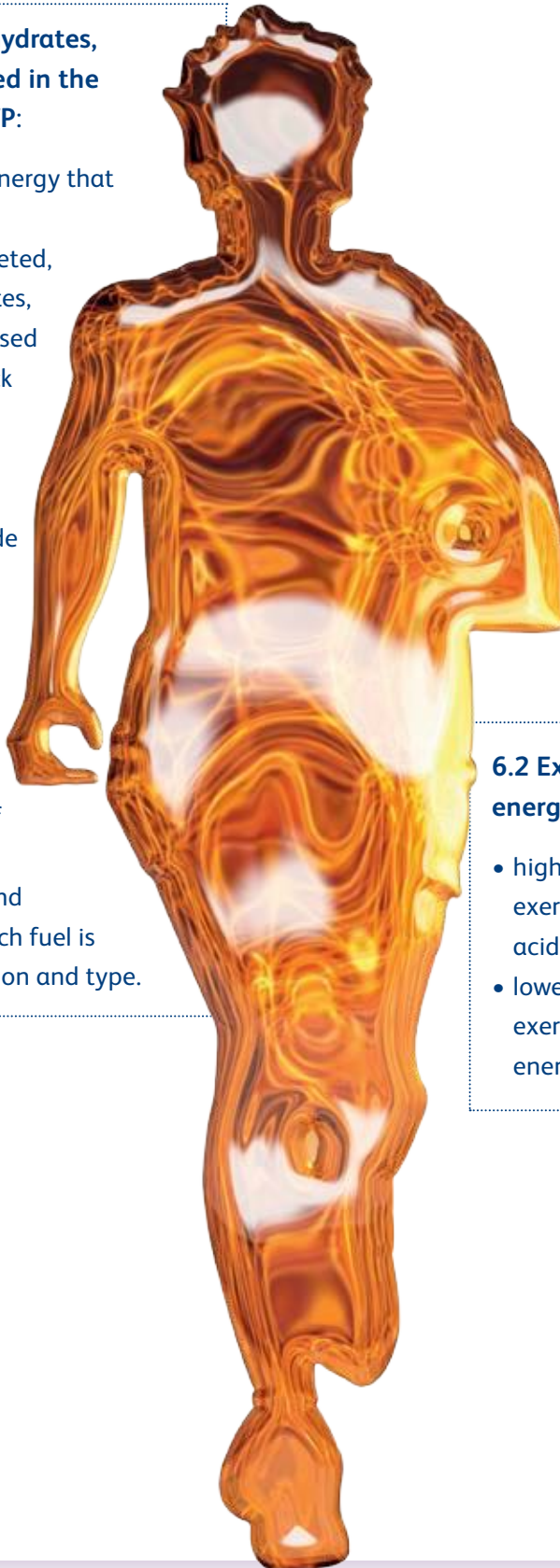


## The energy systems summary

You should now know how to:

### 6.1 Describe how carbohydrates, fats and proteins are used in the production of energy/ATP:

- ATP is the only form of energy that can be used by the body
- once ATP stores are depleted, energy from carbohydrates, fats or protein must be used to re-synthesize ADP back into ATP
- carbohydrates are the preferred energy source for the body. They provide 4Kcal of energy per gram and are stored as glycogen
- fats provide 9Kcal of energy per gram and are stored as triglycerides
- protein provides 4Kcal of energy per gram and are stored as amino acids, and
- the factors effecting which fuel is used are intensity, duration and type.



### 6.2 Explain the use of the three energy systems during exercise:

- higher-intensity, shorter-duration exercise uses the CP and lactic acid (anaerobic) systems, and
- lower intensity, longer duration exercise uses the aerobic energy system.

## Section 7: The nervous system

### What you will cover

By the end of this section you will:

- know the role and functions of the nervous system
- understand the process of muscle contraction
- understand the 'all or none' principle of motor unit recruitment, and
- know the role of exercise in improving motor skills through enhancing neuromuscular connections.

### Nervous system anatomy

The nervous system can be thought of as a person's control centre responsible for co-ordinating all biological processes, muscle contractions and movement. It is made up of the brain, spinal cord and nerves, and can be divided into the **central nervous system (CNS)** and the **peripheral nervous system (PNS)**.

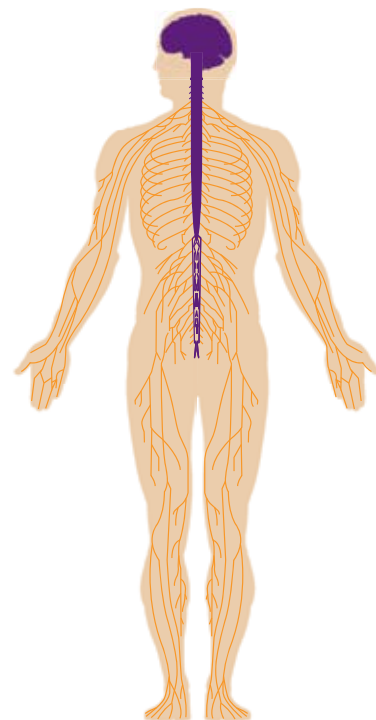
#### Central nervous system

In essence, it is the information processing centre. The CNS receives information from the peripheral nervous system, interprets it and then sends out signals which determine how the body reacts. The signals that are sent out can be conscious or unconscious.

#### Central nervous system (CNS)

The central nervous system is made up of the brain and spinal cord.

Figure 7.1 CNS and PNS



- Peripheral nervous system
- Central nervous system

## Peripheral nervous system

The PNS is made up of all of the nerves outside of the CNS. This part of the nervous system is responsible for relaying information to and from the CNS.

## Exercise and the nervous system

During exercise the nervous system is responsible for bringing about a number of important changes in the body. These are initiated by the ‘**fight or flight**’ response as adrenaline levels rise.

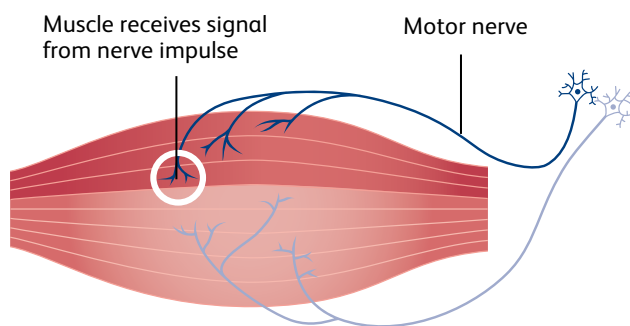
### The fight or flight response to exercise:

- increased heart rate
- increased breathing rate
- increased blood pressure
- diversion of blood from the digestive tract to the working muscles, and
- increased circulating levels of fats and carbohydrates.

## Movement

Movement of the human body is controlled by specialised nerves called motor nerves. In order for a muscle to contract, it must receive a signal from a nerve impulse, telling it to do so.

Figure 7.2 A neuromuscular junction



### Peripheral nervous system (PNS)

The peripheral nervous system is made up of nerves sending messages into and out of the CNS to the body.

### Motor neurons

Movement of the human body is controlled by specialised motor nerves.

## Nervous system physiology

### Neuromuscular connections

The nervous system is an intricate network of nerves that link the brain to every part of the body. For muscular actions to occur, a nervous impulse must follow a specific pathway in order to direct the muscle to move.

Muscle is composed of a large number of muscle fibres which are arranged in groups. Each group of muscle fibres is under the control of a single motor neuron. The motor neuron and all the muscle fibres it connects to (innervates), is called a motor unit. Figure 7.3 shows a motor unit.

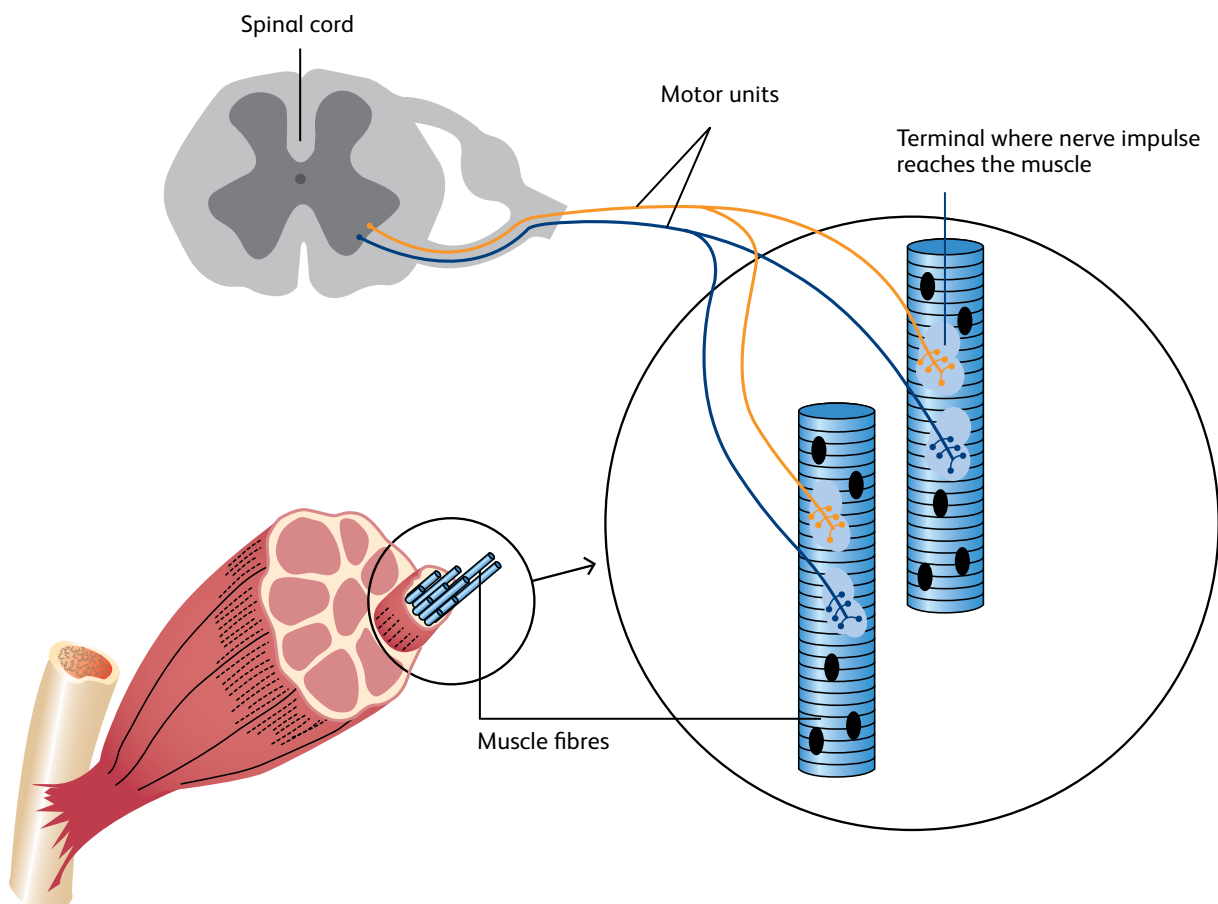
When an impulse travels down a motor neuron, all of the muscle fibres that it innervates will contract.

#### Motor unit

**A motor unit consists of a motor nerve and all the muscle fibres that it connects to.**

Motor units can contain anywhere from tens to thousands of muscle fibres. Those with larger numbers will produce powerful movements. Those that contain fewer fibres will produce smaller, more intricate movements.

Figure 7.3 A motor unit



## The ‘all or none’ law

Motor units fire on an ‘all or none’ basis. This means that, when the nervous impulse reaches the muscle fibres, they will either contract or not contract – there is no partial contraction. The factor that dictates whether a muscle fibre contracts or not is the strength of the nervous impulse – the impulse must reach a threshold level before the muscle fibres will contract. The strength of the contraction will be determined by:

- the number of muscle fibres recruited, and
- the frequency of the nerve impulse.

## Motor skill training

Motor skills are learnt sequences of movements that produce smooth, efficient actions which are required to perform specific tasks. The fact that these are learnt skills suggests that training can improve the performance of these movements.

### Neural pathways – practice makes permanent

As motor skills are learnt behaviours, the way that they are acquired will impact upon their future performance. If a skill is practised imperfectly time and time again, that imperfect technique will be imbedded and will become extremely difficult to change. Therefore, it is important to ensure that people use correct technique from the outset.

In addition, it must also be remembered that exercise produces a training effect relevant to the type of activity performed. This is why training should be specific to a person’s goals. For example, a person aiming to run a marathon will not benefit from developing neuromuscular pathways related to cycling.

### Exercise can enhance neuromuscular connections and improve motor fitness by:

- reinforcement and embedding of neural pathways
- improved co-ordination and synchronisation of motor unit recruitment
- increased motor unit recruitment
- increased firing frequency of motor units, and
- increased strength and power.

### Neural pathways

Motor skills can be improved through exercise with good technique.

#### Remember:

- practice does **not** make perfect
- **practice** makes **permanent**, and
- only **perfect** practice makes **perfect!**

Specific training is also important when considering motor unit recruitment:

- long-distance endurance training at low intensities improves the connections between the brain and muscles, increasing the recruitment efficiency of the smaller motor units containing type 1 fibres. It also enables the body to rotate between the use of the different smaller motor units, delaying fatigue.
- strength training will improve neuromuscular connections between the worked muscles and the CNS for anyone who participates, some may learn faster than others depending on age, skill and so on, and
- explosive heavy lifting improves the ability of the nervous system to co-ordinate the firing of large numbers of motor units together – to produce explosive co-ordinated movements more efficiently.

**Learning activity 7.1**

Imagine you are describing the nervous system to a friend who has no knowledge of anatomy and physiology. Record below how you would describe each of the following components.

Central nervous system (CNS):

.....

.....

.....

Peripheral nervous system (PNS):

.....

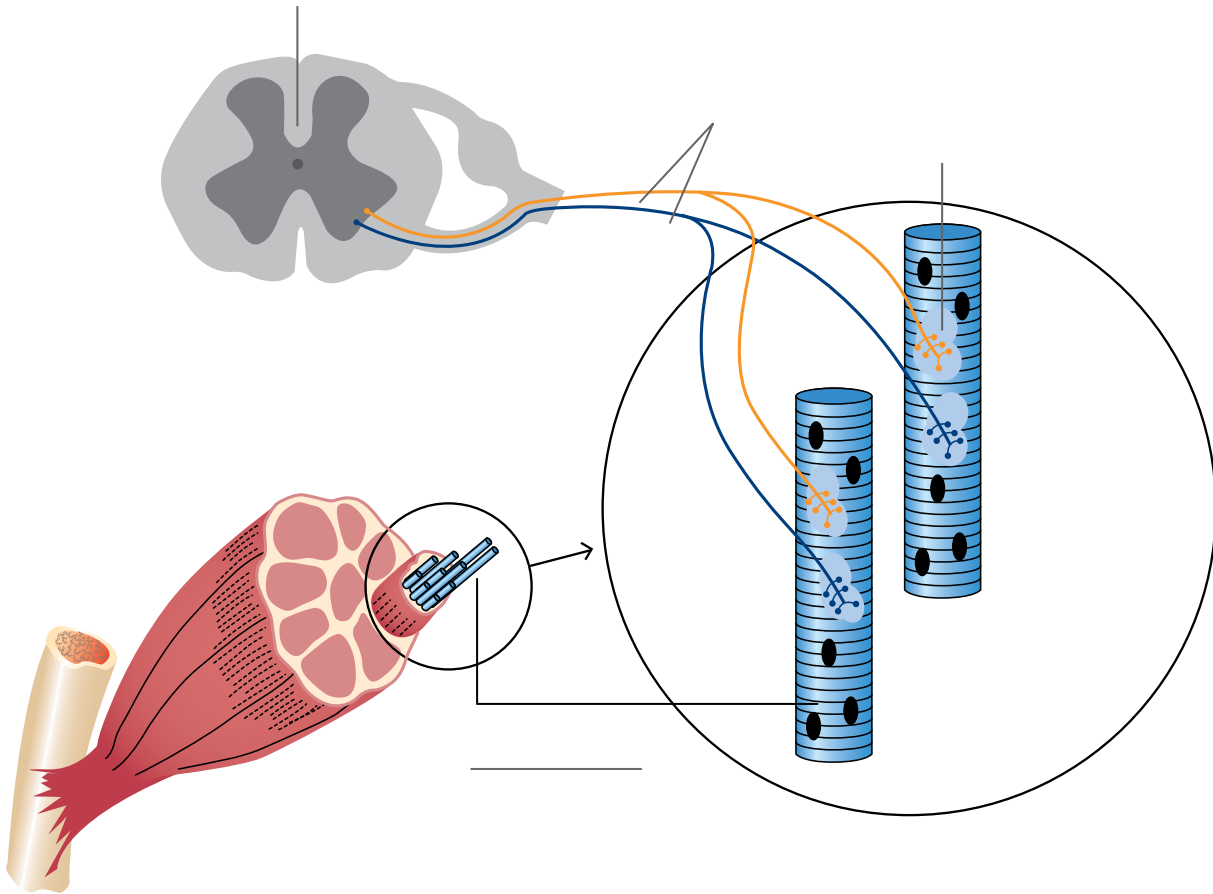
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.....



### Learning activity 7.2

Label the following figure of a motor unit.



### Learning activity 7.3

Briefly describe the following principle using your own words.

The 'all or none' principle:

.....

.....

.....

.....

.....

.....

.....

.....

## The nervous system summary

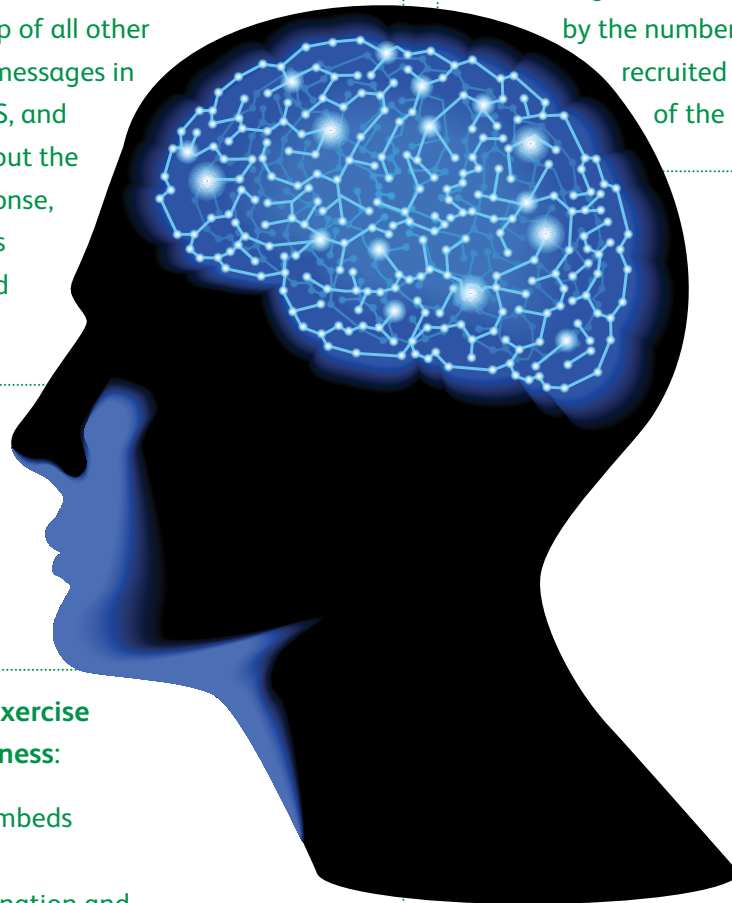
You should now be able to:

### 7.1 Describe the role and functions of the nervous system:

- it is the control centre responsible for all biological processes, muscle contractions and movement
- it is comprised of the central and peripheral nervous systems (CNS and PNS)
- the CNS includes the brain and spinal cord and processes information
- the PNS is made up of all other nerves and sends messages in and out of the CNS, and
- exercise brings about the fight or flight response, leading to changes including increased heart rate.

### 7.2 Describe the 'all or none' law of motor unit recruitment:

- a motor unit consists of a motor nerve and all the muscle fibres it connects to
- when nerve impulses reach muscle fibres there is no partial contraction, they either contract or do not contract, and
- the strength of contraction is determined by the number of muscle fibres recruited and the frequency of the nerve impulse.



### 7.3 Describe how exercise improves motor fitness:

- it reinforces and embeds neural pathways
- it improves co-ordination and synchronisation of motor unit recruitment
- it increases motor unit recruitment
- it increases firing frequency, and
- it increases strength and power.

# Section 8: Learning activity answers

## Section 5: The muscular system

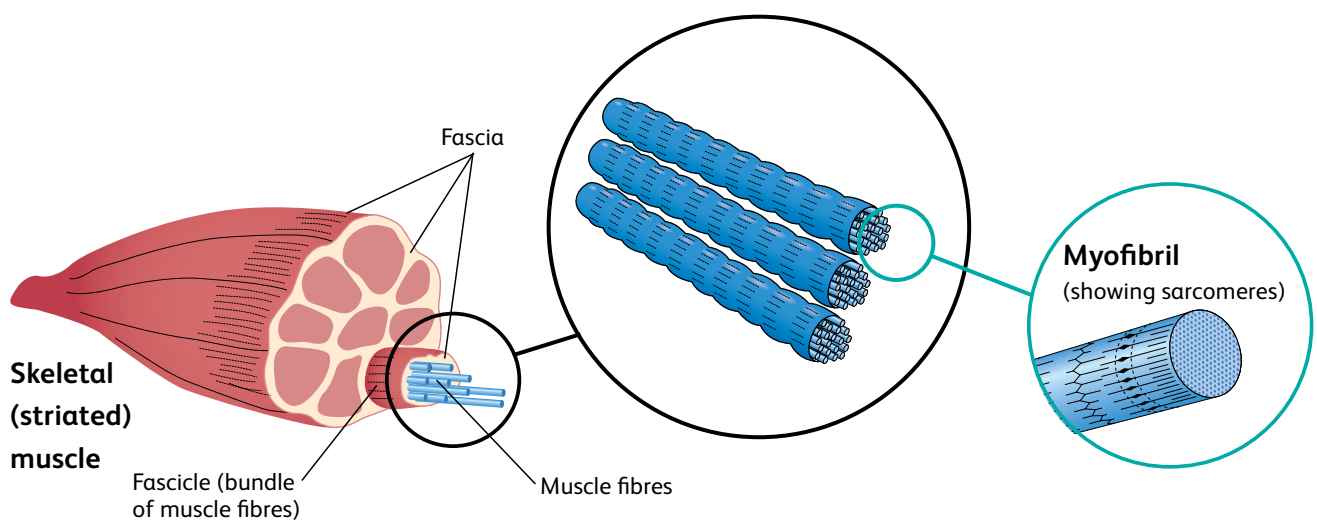
### Learning activity 5.1

Summarise the characteristics of the three different types of muscle found in the human body in the table below.

Muscle type	Appearance	Energy system	Location
Cardiac	Striated with fibres that branch off and connect to one another	Aerobic energy system	Heart
Smooth	Not striated (smooth) with fibres going in all directions	Anaerobic energy system	Tubes of the body, for example blood vessels, digestive tract, lungs
Skeletal	Striated with fibres that shorten in one direction only	Aerobic energy system and anaerobic energy system	Muscles

### Learning activity 5.2

Study the labelled figure of muscle structure and label the diagram.

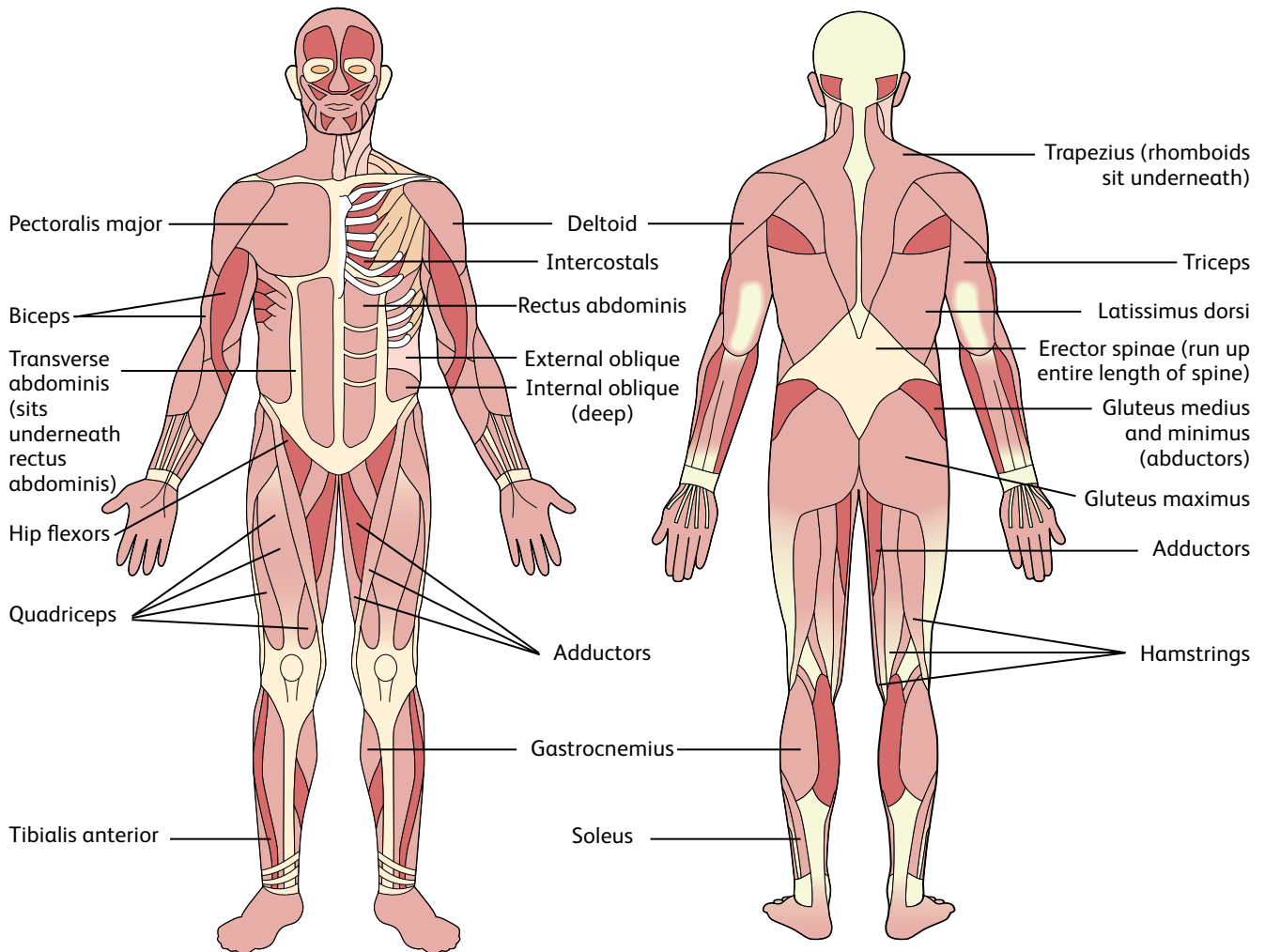


### Learning activity 5.3

Fill in the labels on the diagram below.

**Anterior (front) muscles**

**Posterior (back) muscles**



### Learning activity 5.4

In your own words define the following types of contraction.

**Concentric:**

The muscle shortens against resistance as the weight is lifted upwards towards the 'clouds'.

**Eccentric**

The muscle lengthens against resistance as the weight is lowered down towards the 'earth'.

**Isometric**

The muscle increases in tension but no movement occurs; it is a static contraction.

Now look at the examples of exercises and state whether a concentric, eccentric or isometric contraction is taking place:

1. Lowering towards the floor when performing a squat

**Eccentric**

2. Pushing the weight overhead when doing a shoulder press

**Concentric**

3. Holding dumbbells up in front of you in a fixed position as in a front raise exercise

**Isometric**

### Learning activity 5.5

List the antagonist for each of the following:

Agonist	Antagonist
Deltoids	Latissimus dorsi
Pectoralis major	Rhomboids and trapezius
Biceps	Triceps
Rectus abdominis	Erector spinae
Hip flexors	Gluteus maximus
Hip adductors	Hip abductors
Quadriceps	Hamstrings
Tibialis anterior	Gastrocnemius and soleus

### Learning activity 5.6

Do each of the following exercises until you can feel a muscle working. Identify the joint action you are performing and the muscle that you can feel getting fatigued.

#### *Seated leg extension*

Sitting on a chair, hold your thigh still and slowly straighten your leg from the knee until the leg is horizontal. Pause briefly then slowly lower it back down. Repeat until you can feel a muscle working.

- What joint action were you performing?  
**Knee extension.**
- What muscle could you feel working?  
**Quadriceps.**

#### *Lateral raise*

Hold a heavy book or full water bottle in one hand. Keeping your body still, slowly lift your arm straight out to the side until it is horizontal. Pause briefly then lower it slowly back to your side. Repeat this until you feel a muscle working.

- What joint action were you performing?  
**Abduction.**
- What muscle could you feel working? **Deltoid.**

## Section 6: The energy systems

### Learning activity 6.1

Answer the following questions.

1. What substance is broken down to create energy for all of the body's muscular contractions and energy requiring functions?  
**ATP**
2. Once your answer to question 1 has been broken down, what is it converted into? **ADP**
3. What is needed to re-synthesise ATP?  
**Energy from food or the body's energy stores.**

### Learning activity 6.2

Name the three energy systems and, in your own words, describe how they re-synthesise ATP.

4. Aerobic energy system – uses carbohydrates, fats and proteins to re-synthesise ATP and creates water, carbon dioxide and heat as by-products
5. The anaerobic lactic acid system – uses glycogen to re-synthesise ATP and produces lactic acid as a waste-product. Lactic acid can cause fatigue if it is allowed to build up within the working muscles
6. The creatine phosphate system – this system is fuelled by creatine phosphate (CP), which is stored in limited amounts in the muscles. When CP is broken down energy is released which is used to re-synthesise ATP from ADP and a free-phosphate.



### Learning activity 6.3

Fill in the gaps in the table below.

Parameter	Aerobic energy system	Lactic acid system	CP system
Exercise intensity	Low to moderate	High	Near maximal
Fuel	Carbohydrates, fats and proteins	Glycogen	Creatine phosphate
By-products	Water, carbon dioxide and heat	Lactic acid	None
Limiting factors	Exercise intensity & fuel availability	Lactic acid build-up	CP availability
Duration	Indefinite	Up to 90 seconds	6–10 seconds
Example activities	Marathon running	400m	sprinting

### Learning activity 6.4

Think about three activities that you enjoy. Using the information shown in the graph in figure 5.5, estimate how much each energy system contributes to ATP synthesis during each of these activities.

Activity	Aerobic system	Lactic acid system	CP System
Skiing	33 %	33 %	33 %
Football	30 %	20 %	50 %
Tennis	10 %	20 %	70 %
Marathon running	70 %	20 %	10 %

### Learning activity 6.5

In the table below, identify which energy system predominates for each activity.

Activity	Predominant energy system
Marathon running	Aerobic
100m sprint	CP
Long-distance swimming	Aerobic
Olympic weight lifting	CP
Tennis	CP
Rowing	Aerobic
50m front crawl	CP
800m sprint	Lactic acid

## Section 7: The nervous system

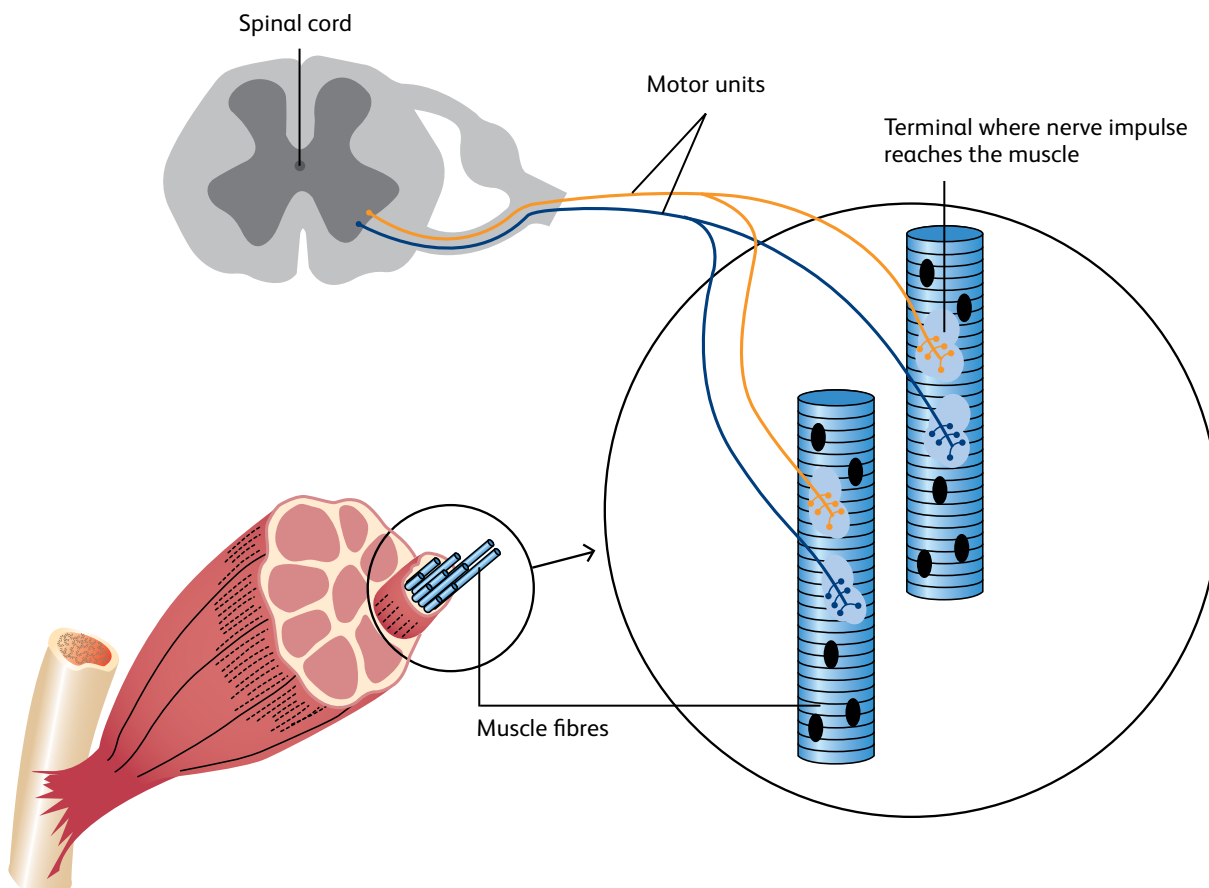
### Learning activity 7.1

Imagine you are describing the nervous system to a friend who has no knowledge of anatomy and physiology.

- **Central nervous system (CNS):** This is made up of the brain and spinal cord and is the information processing centre of the nervous system. It receives information from the peripheral nervous system, interprets it and sends out appropriate signals to the body.
- **Peripheral nervous system (PNS):** This is made up of all of the nerves outside of the CNS and is responsible for relaying information to and from the brain and spinal cord. The PNS is made up of cranial nerves and spinal nerves.

### Learning activity 7.2

Label the following of a motor unit



### Learning activity 7.3

Briefly describe the following principles using your own words.

- The 'all or none' principle – Motor units fire on an 'all or none' basis. When a nervous impulse reaches the muscle fibres, they either contract or not contract: there is no partial contraction. The thing that decides whether a muscle fibre contracts is the strength of the nervous impulse. The nervous impulse must reach a threshold level before the muscle fibres will contract'.

## Section 9: References and recommended reading

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