

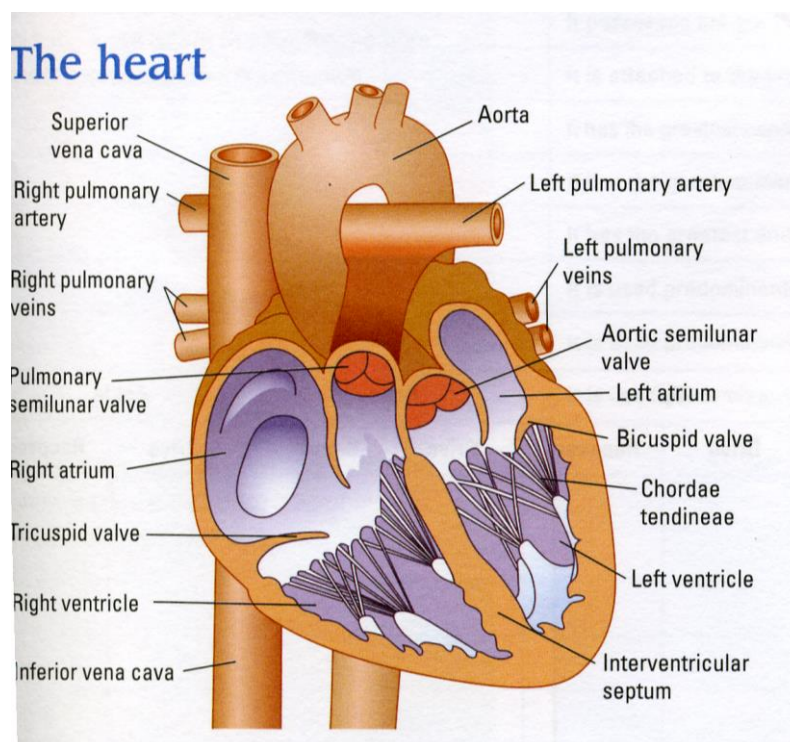
Cardiovascular System Year 12 Summer Preparation

What You Need To Know:

- Describe the stages of the cardiac cycle and understand how it is linked to the conduction system
- Give definitions of cardiac output, stroke volume and heart rate and explain the relationship between them
- Understand Starling's law of the heart
- Explain heart rate range in response to exercise and describe the hormonal and nervous effects on heart rate
- Explain the role of blood carbon dioxide in changing heart rate
- Explain cardio-vascular drift.
- Describe the concept of cardiac hypertrophy and how it leads to bradycardia/athlete's heart

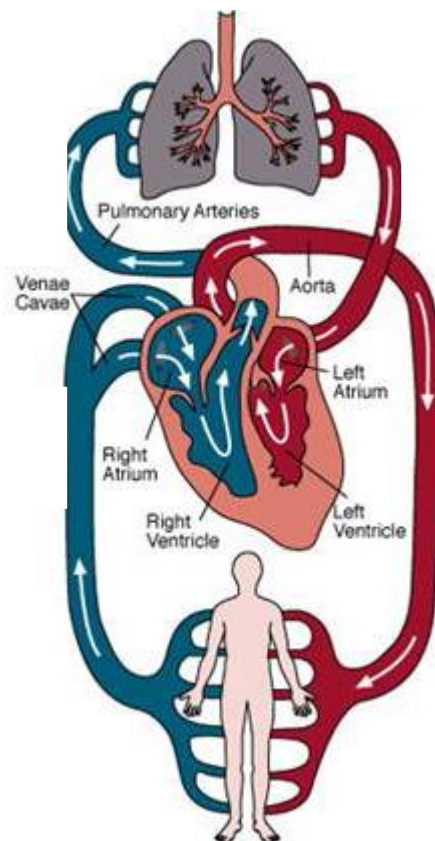
Chambers of the heart

The heart is divided into two parts by a muscular wall called the septum and each part contains an atrium and a ventricle. The atria are smaller than the ventricles as all they do is push the blood down into the ventricles. This does not require much force so they have thinner muscular walls. The ventricles have much thicker muscular walls as they need to contract with greater force in order to push blood out of the heart. The left side of the heart is larger as it needs to pump blood all round the body whereas the right side pumps deoxygenated blood to the lungs which are in close proximity to the heart.



Blood Vessels of the heart

Several blood vessels are attached to the heart. The vena cava brings deoxygenated blood back to the right atrium and the pulmonary vein delivers oxygenated blood to the left atrium. The pulmonary artery leaves the right ventricle with deoxygenated blood to go to the lungs and the aorta leaves the left ventricle with oxygenated blood leading to the body. This can be highlighted in the simplified diagram below.



In order for the heart to work effectively, it requires a good blood supply and this is provided by the coronary artery which carries oxygenated blood. Deoxygenated blood is removed by the veins of the heart into the right atrium through the coronary sinus.

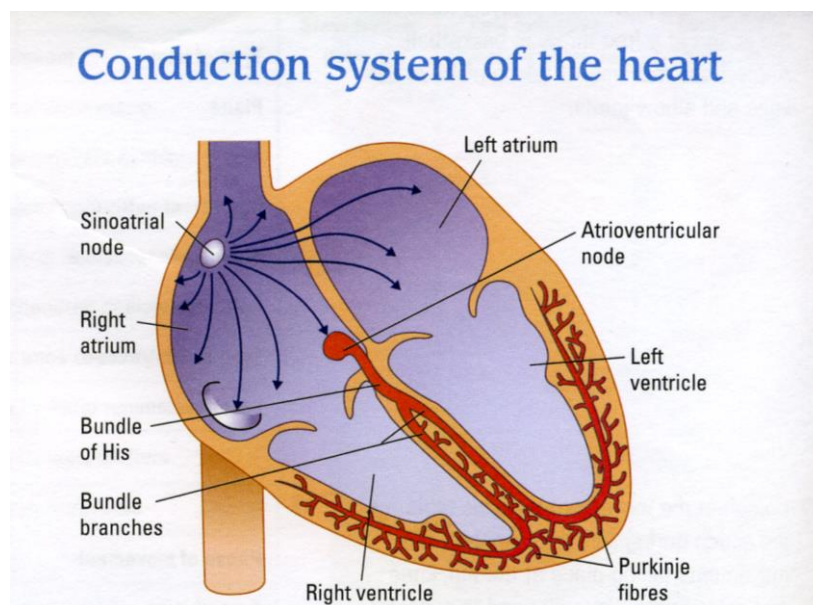
Valves of the Heart

There are four main valves in the heart that regulate blood flow by ensuring it moves in only one direction. They open to allow blood to pass through and then close to prevent back flow. The tricuspid valve is located between the right atrium and right ventricle and the bicuspid valve between the left atrium and left ventricle. The semi-lunar valves can be found between the right and left ventricles and the pulmonary artery and aorta.

The Conduction System

When the heart beats the blood needs to flow through it in a controlled manner, in through the atria and out through the ventricles. Heart muscle is described as being **myogenic** as the beat starts in the heart muscle itself with an electrical signal in the sinoatrial node (pacemaker). This electrical signal then spreads through the heart in what is often described as a wave of excitation (similar to a Mexican wave).

From the SA node the electrical signal spreads through the walls of the atria causing them to contract and forcing blood into the ventricles. The signal then passes through the atrioventricular node (AV) found in the atrioventricular septum. The AV node delays the transmission of the cardiac impulse for approximately 0.1 seconds to enable the atria to fully contract before ventricular contraction begins. The electrical signal then passes down through some specialised fibres which form the bundle of His. This is located in the septum separating the two ventricles. The bundle of His branches out into two bundle branches and then moves into smaller bundles called purkinje fibres which spread throughout the ventricles causing them to contract.



The Cardiac Cycle

This describes the emptying and filling of the heart and involves a number of stages. The diastole phase is when the chambers are relaxing and filling with blood and the systole phase is when the heart contracts and forces blood either round the heart or out of the heart to the lungs and the body. Each complete cardiac cycle takes approximately 0.8 seconds. The diastole phase lasts 0.5 seconds and the systole phase lasts for 0.3 seconds. It can be summarised in the tables below:

Stage	Action of atria	Result
Atrial systole	Walls contract	Blood forced through the bicuspid and tricuspid valves into the ventricles
Atrial Diastole	Walls relax	Blood enters right atrium via the vena cava and the left atrium via the pulmonary vein but cannot pass into the ventricles as tricuspid and bicuspid valves are closed.

Stage	Action of Ventricles	Result
Ventricular systole	Walls contract	Pressure of blood opens the semi-lunar valves and blood is ejected into the pulmonary artery to the lungs and aorta to the body. Tricuspid and bicuspid valves shut.
Ventricular diastole	Walls relax	Blood enters from atria 'passive ventricular filling' - not due to atrial contraction. The semi-lunar valves are closed.

Key term:

Systole: the contraction phase of the heart

Diastole: the relaxation phase of the heart

The link between the cardiac cycle and the conduction system

Quite simply the cardiac cycle describes the flow of blood through the heart during one heart beat. As the heart can generate its own electrical impulse it controls this flow of blood via the conduction system.

Cardiac Dynamics

Stroke volume

The amount of blood pumped out by the heart ventricles in each contraction. On average the resting stroke volume is approximately 70ml.

Stroke volume can be determined by the following:

- Venous return-this is volume of blood returning back to the heart via the veins. If venous return increases then stroke volume will also increase (ie. If more blood enters the heart then more blood goes out!!)
- The elasticity of cardiac fibres-this is concerned with the degree of stretch of cardiac tissue during the diastole phase of the cardiac cycle. The more the cardiac fibres can stretch the greater the force of contraction will be. A greater force of contraction can increase stroke volume. This is also called **Starlings Law**.
- The contractility of cardiac tissue (myocardium)-the greater the contractility of cardiac tissue, the greater the force of contraction. This results in an increase in stroke volume. It is also highlighted by an increase in the ejection fraction. This refers to the percentage of blood pumped out by the left ventricle per beat. An average value is 60% but it can increase by up to 85% following a period of training.

$$\text{Ejection fraction} = \frac{\text{stroke volume}}{\text{end diastolic volume}}$$

Heart rate

The number of times the heart beats per minute. On average the resting heart rate is approximately 72 beats per minute. The fitter an individual is the lower the heart rate. For example, Miguel Indurain, an elite cyclist, had a resting heart rate of only 28 beats per minute.

Cardiac output

The amount of blood pumped out by the heart ventricles per minute. It is equal to stroke volume multiplied by heart rate.

$$\text{Cardiac Output (Q)} = \text{Stroke Volume (S.V.)} \times \text{Heart Rate (H.R.)}$$

$$Q = 70 \times 72$$

$$Q = 5040 \text{ ml (5.04litres)}$$

It can be seen from this calculation that if heart rate or stroke volume increase, then cardiac output will also increase.

Heart rate range in response to exercise

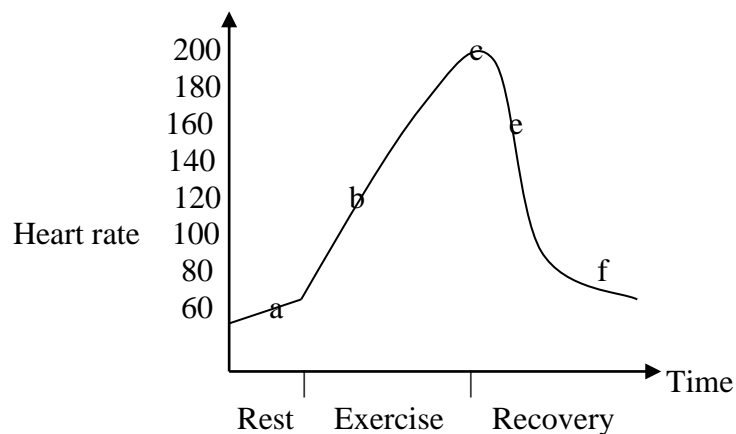
Heart rate increases with exercise but how much it increases is dependent on the intensity of the exercise. Heart rate will increase in direct proportion to exercise

intensity. The higher the intensity the higher the heart rate. Heart rate does eventually reach a maximum. Maximum heart rate can be calculated by subtracting your age from 220. A 17 year old will have a maximum heart rate of 203 beats per minute

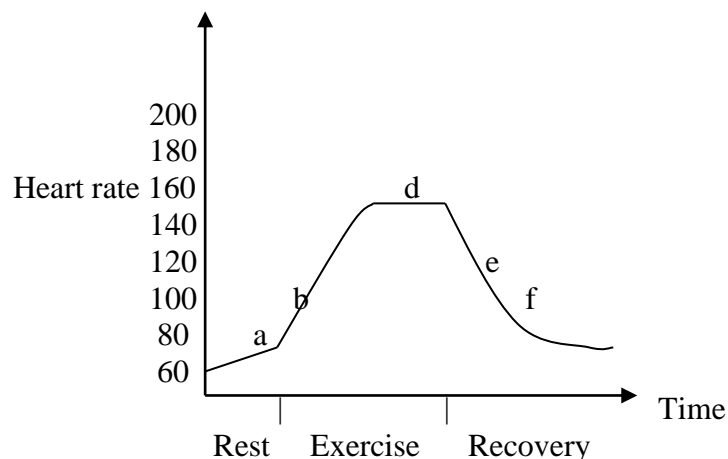
$$220 - 17 = 203$$

The graphs below illustrate what happens to heart rate during maximal exercise such as sprinting and sub-maximal exercise such as jogging.

Maximal exercise



Submaximal exercise



a = *Anticipatory rise* due to hormonal action of adrenalin which causes the SA node to increase heart rate

b = *Sharp rise* in heart rate due mainly to anaerobic work

c = Heart rate continues to rise due to maximal workloads stressing the anaerobic systems.

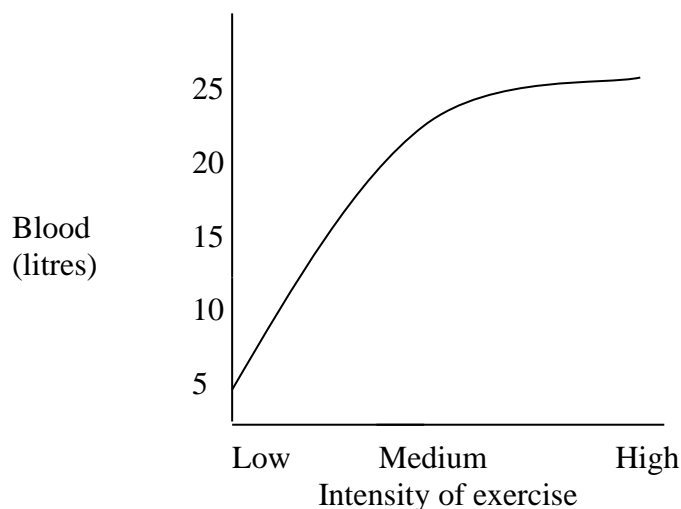
d = *Steady state* as the athlete is able to meet the oxygen demand with the oxygen supply

e = *Rapid decline* in heart rate as soon as the exercise stops

f = *Slower recovery* as body systems return to resting levels. Heart rate needs to remain elevated to rid the body of waste products, for example, lactic acid.

Regular aerobic training will result in hypertrophy of the cardiac muscle i.e. the heart physically gets bigger. This will have an important effect on stroke volume, heart rate and therefore cardiac output. A bigger heart will enable more blood to be pumped out per beat (i.e. stroke volume). In more complex language the end diastolic volume of the ventricle increases. If the ventricle can contract with more force and thus push out more blood the heart as a result does not have to beat as often so the resting heart rate will decrease. This is known as bradycardia. This increase in stroke volume and decrease in resting heart rate will mean that cardiac output at rest will remain unchanged. This is not, however, the case during exercise as an increase in heart rate, coupled with an increase in stroke volume will result in an increase in cardiac output. Cardiac output will increase as the intensity of exercise increases until maximum exercise capacity is reached and then it plateaus.

Key term: bradycardia is a decrease in resting heart rate to below 60 beats per minute



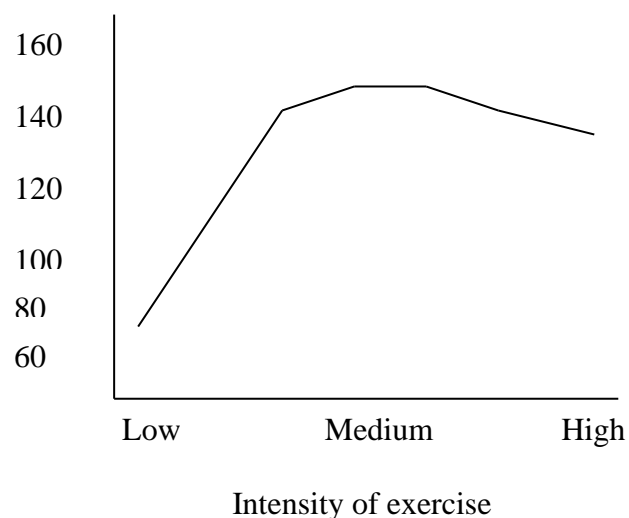
The following table shows the differences in cardiac output (to the nearest litre) in a trained and untrained individual both at rest and during exercise. The individual in this example is aged 18 so their maximum heart rate will be 202 beats per minute. (Maximum heart rate is calculated as 220- your age).

	SV	x	HR	=	Q
Rest Untrained	70	x	72	=	5 litres
Exercise Untrained	120	x	202	=	24 litres
Rest Trained	85	x	60	=	5 litres
Exercise Trained	170	x	202	=	34 litres

As can be seen from the table this increase in cardiac output will have huge benefits for the trained person as they will be able to transport more blood to the working muscles and therefore more oxygen. In addition when the body starts to exercise the distribution of blood flow changes. This means that a much higher proportion of blood passes to the working muscles and less passes to organs such as the intestine. The amount of blood passing to the kidneys and brain remains unaltered.

Stroke Volume in response to exercise

Stroke volume increases as exercise intensity increases. However this is only the case up to 40-60% of maximum effort. Once a performer reaches this point then stroke volume plateaus. One explanation for this is that the increased heart rate near maximum effort results in a shorter diastolic phase. Quite simply, the ventricles do not have as much time to fill up with blood so cannot pump as much out!



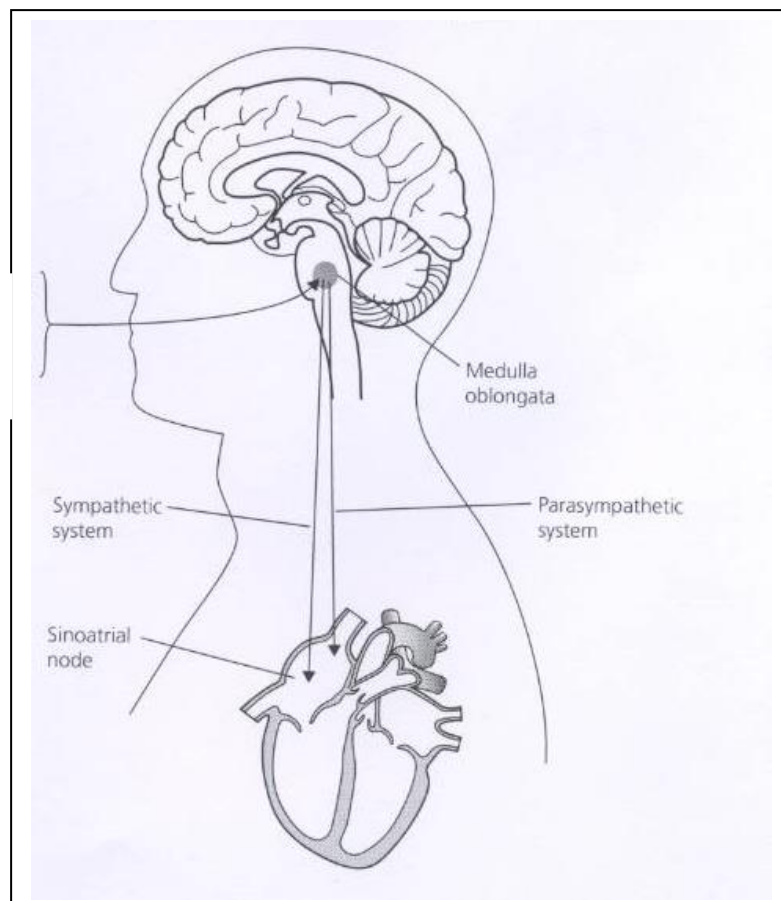
Control of Heart rate

Heart rate needs to increase during exercise to ensure the working muscles receive more oxygen. As discussed earlier the heart generates its own impulses from the sinoatrial node but the rate at which these cardiac impulses are fired can be controlled by two main mechanisms:

Neural control mechanism.

This involves the autonomic nervous system which consists of the sympathetic system which stimulates the heart to beat faster and the parasympathetic system which returns the heart to its resting level. These two systems are co-ordinated by the cardiac control centre located in the medulla oblongata of the brain. The cardiac control centre is stimulated by chemoreceptors, baroreceptors and proprioceptors. During exercise, chemoreceptors detect an increase in carbon dioxide, lactic acid and a decrease in oxygen. The role of blood carbon dioxide is important in controlling heart rate. An increased concentration of carbon dioxide in the blood will have the effect of stimulating the sympathetic nervous system. Baroreceptors detect an increase in blood pressure and proprioceptors detect an increase in muscle movement. These receptors then send an impulse to the cardiac control centre which then sends an impulse through the sympathetic nervous system or cardiac accelerator nerve to the sinoatrial node to increase heart rate. When the parasympathetic system or para vagus nerve stimulates the sinoatrial node, heart rate decreases. This process can be summarised in the diagram below:

Chemoreceptors
Baroreceptors
Proprioceptors



Top Tip: Don't be vague, tell the examiner what the receptors detect, for example chemoreceptors detect an increase in carbon dioxide, don't just say chemical changes!

2. *Hormonal Control Mechanism*

Adrenalin and noradrenalin are stress hormones that are released by the adrenal glands. Exercise causes a stress induced adrenalin response which results in the following:

- Stimulation of the SA node (pacemaker) which results in an increase in both the speed and force of contraction.
- An increase in blood pressure due to the constricting of blood vessels.
- An increase in blood glucose levels which is used by the muscles for energy.

What is Cardiovascular Drift?

We used to think that while exercising at a steady level, the body reached a steady state where the heart rate remained the same. However, new research has shown that if you monitor heart rate more closely it does not remain the same but instead slowly climbs. This is cardiovascular drift. In more detail cardiovascular drift is characterised by a progressive decrease in stroke volume and arterial blood pressure, together with a progressive rise in heart rate. It occurs during prolonged exercise in a warm environment despite the intensity of the exercise remaining the same. Suggestions as to why this occurs are that when we sweat a portion of this lost fluid volume comes from the plasma volume. This decrease in plasma volume will reduce venous return and stroke volume. Heart rate again increases to compensate and maintain constant cardiac output. To minimise this cardiovascular drift it is important to maintain high fluid consumption before and during exercise.

Effects of Training on the Heart

If you perform continuous, fartlek or aerobic interval training over a period of time, physiological adaptations take place that would make the initial training sessions appear very easy. This is because your $\text{VO}_2(\text{max})$ has improved due to the changes your body has made. Some of these changes or adaptations effect the heart. It becomes much more efficient. The table below identifies the changes that have taken place in the heart.

Key term: $\text{VO}_2(\text{max})$ is the maximum amount of oxygen that can be taken in and used by the body in one minute

<p><i>Athletes heart.</i></p> <p>This is a common term for an enlarged heart caused by repeated strenuous exercise. Due to the increased demands of exercise the chambers of the heart will enlarge as will muscle mass. This results in an increase in the volume of blood that can be pumped out per beat. Consequently the heart has to contract less frequently</p>	<p><i>Hypertrophy</i> of the myocardium (heart gets bigger and stronger). This means that an increase in the size of the ventricles allows them to fill with more blood during the diastolic phase of the cardiac cycle and will result in <i>bradycardia</i> (a decrease in resting heart rate) and an <i>increase in stroke volume.</i></p> <p><i>Maximum cardiac output</i> will also increase but will remain the same at rest and sub-maximal level of exercise</p>	<p><i>Increased capillarisation</i> of the heart muscle which increases the efficiency of diffusion of oxygen into the myocardium</p>	<p><i>Increased contractility.</i></p> <p>Resistance/strength training causes an increase in the force of heart contractions due to a thickening of the ventricular myocardium. This will <i>increase stroke volume</i> and will also <i>increase the ejection fraction</i> as a higher percentage of blood is pumped</p>
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Practice makes perfect

1. During exercise heart rate will increase to meet the extra oxygen demand required by the muscles. Explain how the increasing level of carbon dioxide in the blood raises heart rate. [3]
2. What effect would a 6 month period of aerobic training have on the heart of a soccer player [3]
3. Just before the start of an 800m race the athlete will experience a change in heart rate. What change occurs in the athletes heart rate and why does this happen [2]
4. Explain the terms bradycardia and ‘athletes heart’ [2]
5. Define the terms cardiac output and stroke volume and explain the relationship between them [3]
6. What are the effects of a period of training on ***resting*** stroke volume and cardiac output [2]