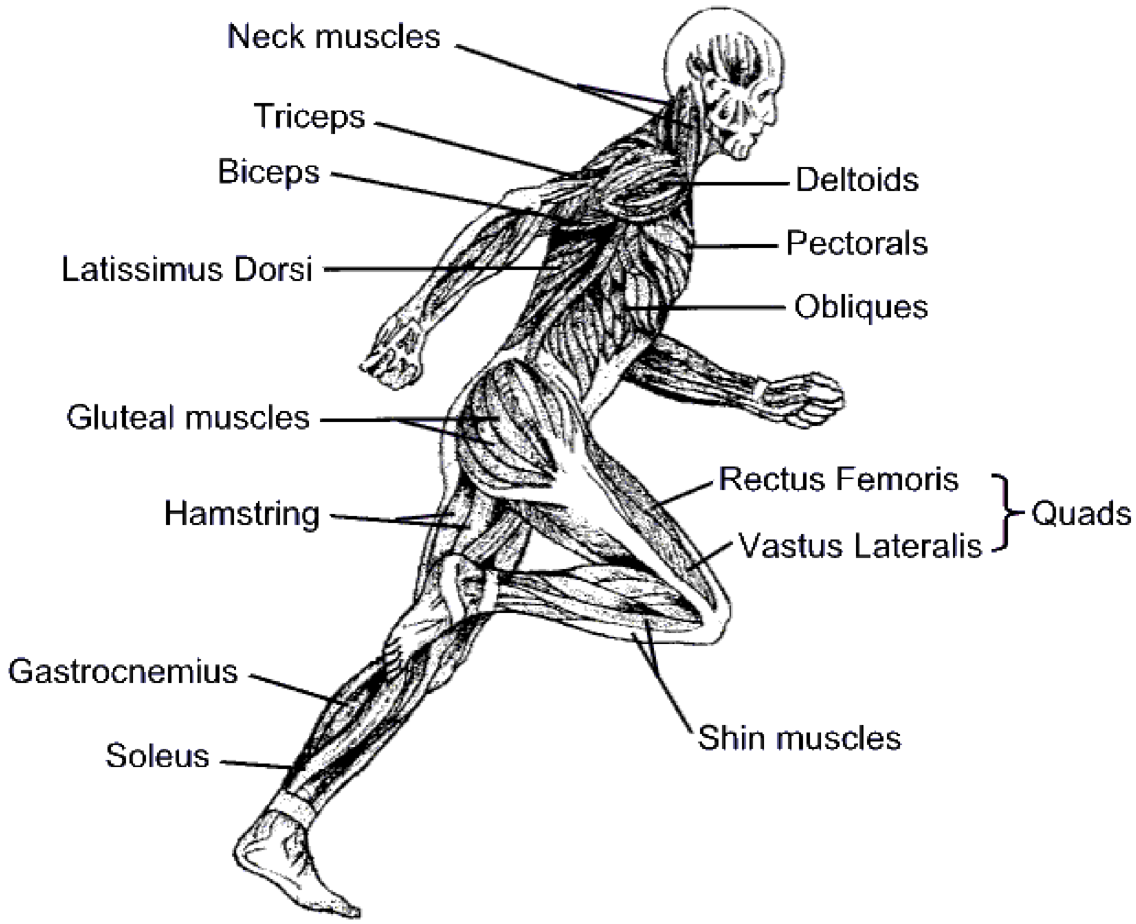
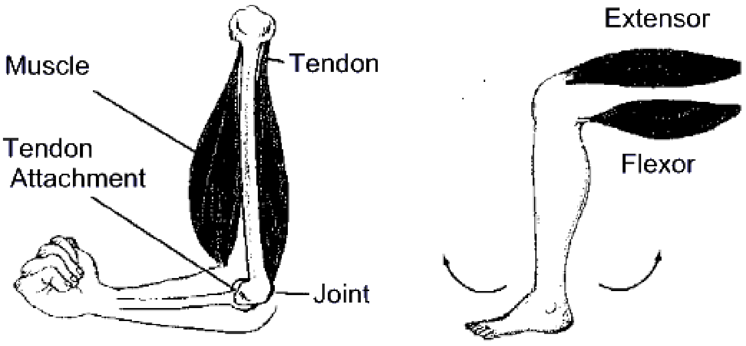
Human Physiology



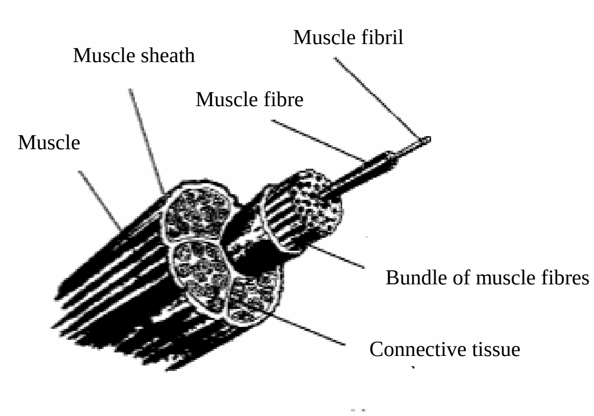
The muscles

Our muscles make up about 40 percent of our bodyweight. For a man of average build this could be 30-35 kg and 20-25 kg for a woman. There are over 300 muscles in the body with different sizes and functions (see diagram). The smallest muscles in our fingers only weigh a couple of grams while the largest muscles in our thighs can weigh several kilos.

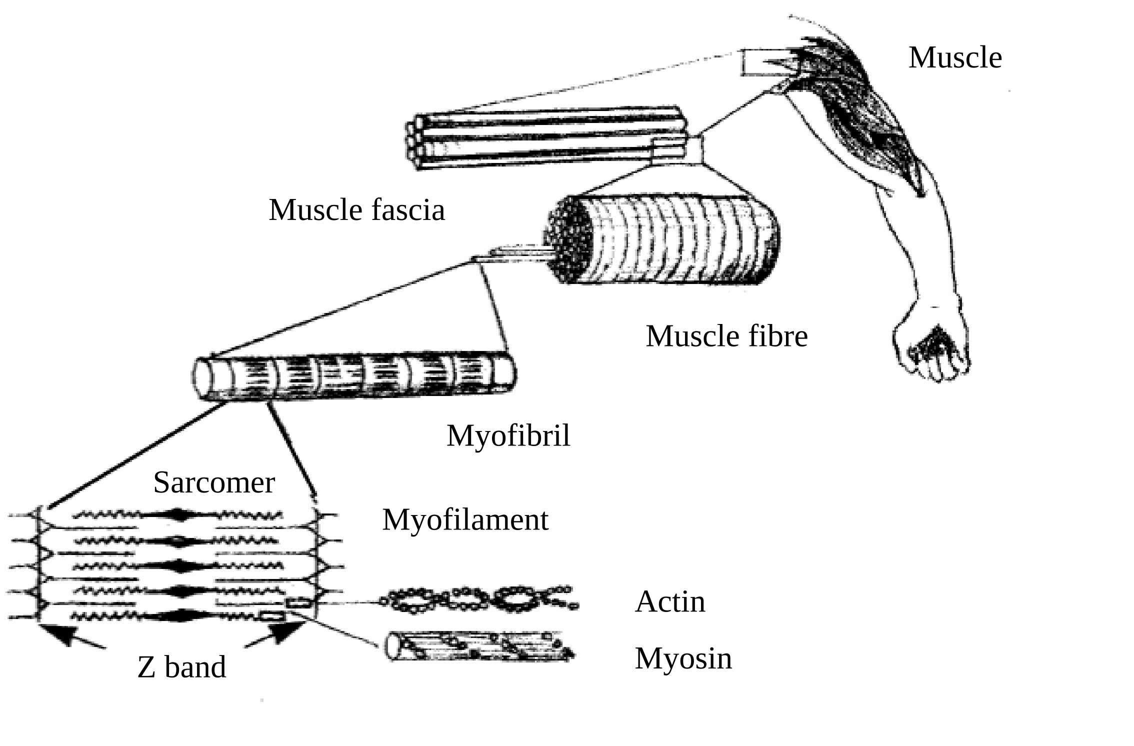
Skeletal muscles have tendons at each end which are attached to two parts of the skeleton. When the muscle works and makes a contraction, the two parts move nearer each other (see diagram). The tendon at the end of the muscle turns into a thin membrane called a fascia, which surrounds the whole muscle. This means that the muscle can glide smoothly against other muscles and organs and work independently.



The functional unit in a muscle is called a muscle fibre. These fibres stretch along the whole length of the muscle like thin threads. They are often somewhat thicker in the middle. A fibre consists in its turn of smaller units called myofibrils. The smallest units are the myofilaments, which lie linked into long rows in the fibrils. These consist of two proteins, actin and myosin. These proteins are the tools that can transform stored energy into muscle movements. When the muscle works the two proteins move into each other to shorten the filaments. The Z-band works like a concertina that moves in and out (see diagram).



The main function of the muscles is to turn energy into movement. In orienteering, which is an endurance sport, this takes place with the help of oxygen. The higher the oxygen turnover, the greater the work done by the muscle can be.



Muscle fibres have different properties and are significantly influenced by training. Different types of training will influence fibres in different ways. Training that places a significant load on the muscles such as strength training will make the fibres increase in volume, while general aerobic fitness training will improve the systems around the muscle that supply it with energy and oxygen during long periods of activity.

There are two main types of muscle fibre, slow twitch (Type I) and fast twitch (Type IIa and IIb). The names refer to their different maximum contraction speeds. The different properties of the fibres also make them suitable for different types of work.

Properties of the different fibre types

Property	*Type I*	*Type IIa, IIb*
Contraction speed	Low	High
Time to develop maximum power	Slow	Fast
Power	Moderate	High
Lactate formation	Moderate	High
Capillaries	Many	Few
Mitochondrial density	High	Low
Aerobic properties	Good	Moderate
Fat-burning capacity	High	Moderate
Resistance to tiredness	Good	Poor

In humans both types of fibre are often found in the same muscle. Each person has a different amount of each type of fibre, based on his or her genetic makeup. A potential long distance runner might be born with 80 percent slow twitch fibres while a potential sprinter could have 70 percent fast fibres. Our dominant fibre type gives us different capabilities for different types of physical work. However, an interesting feature of muscle fibres is that they are influenced by training. A muscle fibre that repeatedly undergoes a certain type of training will change slowly and develop the properties which are required by the activity carried out. Once again, the importance of training that is relevant to competition is apparent. We become good at the things we train!

Metabolism

The term metabolism covers all the chemical reactions which take place in our cells. This includes for example the breakdown of compounds from food which are needed for the body to function, and the creation of new cells. Metabolism is regulated by a very complicated chemical and hormonal system involving the different organs of the body. To be able to run, the muscles need energy. This is supplied in the form of carbohydrates and or fat which are broken down and transformed into fuel for muscle work. This fuel is an energy-packed phosphate compound, ATP, which is the only form of energy that the muscle can use directly for physical activity, such as running or cycling.

Depending on the demands of the activity carried out, we use different systems for breaking down carbohydrate and fat. This is why the intensity of our training is so important. In order to get a useful training effect we must activate the right systems, so that our metabolic processes adapt to the new load and intensity. Training breaks the body down, while rest and refuelling with food allow us to recover and benefit from that training. The training process also breaks down cells, which must then be replaced. In this way training stimulates tissue formation and repair in the muscles, tendons and skeleton. The body uses proteins for this repair process.

Different types of food provide different amounts of energy. The table below shows the relationship between the amount of food and the energy it can release when metabolised:

Fuel	*Energy from complete metabolism*
1 gram carbohydrate	4 kcal (17 kJ)
1 gram fat	9 kcal (39 kJ)
1 gram protein	4 kcal (17 kJ)

As a store for energy, fat is a clear winner. On long walks in the mountains or long training sessions on a bike fat is the best source of energy.

However, carbohydrate is a richer fuel in some ways. It burns more efficiently, like high-octane petrol, requiring less oxygen to release the same amount of energy. Given the same amount of oxygen, carbohydrate supplies 6-8 percent more energy than fat.

Energy production

In order to work, muscles need access to ATP (adenosine triphosphate). There is always a small amount of ATP stored in the muscles. This energy source can only fuel a few seconds of work. If activity continues more ATP must be produced. This can either be done aerobically, with the help of oxygen, or anaerobically, without oxygen. As running speed and terrain are always changing during a race, orienteering has a continually changing balance between aerobic and anaerobic work. Energy for our muscles can be produced in the following ways:

1	ATP breakdown	Maximal effort	3-6 sec

2	Carbohydrate breakdown	Anaerobic glycolysis	10 sec-2 min, lactate produced
3	Carbohydrate burning	Aerobic glycolysis	1-2 hr, until carbohydrate runs out
4	Fat burning	Aerobic process	2-10 hr, but at a lower pace

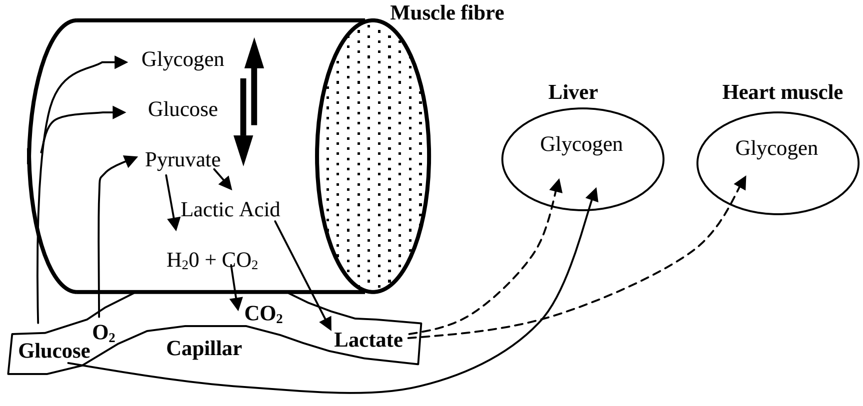
Steps 1 and 2 take place without oxygen while steps 3 and 4 require a continual supply of oxygen. Glycolysis means breakdown of glycogen - the compound that the body uses to store carbohydrate in the muscles. Carbohydrate is also stored in the liver. These two sources of fuel are called muscle glycogen and liver glycogen respectively. Fat cannot be broken down directly in the same way as carbohydrates and is therefore not able to be used for short, maximal efforts.

The muscle itself determines which of the above processes will provide energy. If the load varies, for example an increase in speed, decrease in speed, uphill or downhill running, sprinting, a change from path to forest running the muscle immediately changes to another process or uses two process simultaneously. ATP production is two times greater in the anaerobic processes, but as these processes involve breakdown without oxygen, lactate is produced. As the muscle is provided with oxygen, steps 3 and 4 will come into action.

Different effort levels activate different energy systems, resulting in increased capacity and effectiveness. This is the basis for understanding why training must be varied. We become good at the things we train.

Lactate

In short, maximal efforts such as 200 m canoeing, 400 m running or 100 m swimming, the energy requirements are very high. The muscles are unable to get enough oxygen. Step 1 and 2 produce the initial energy required. Carbohydrate is broken down directly, without oxygen, and lactate is produced as a waste product. Lactic acid is produced inside the muscle and is actually a rich source of energy in itself. But, lactic acid alters the pH value in the muscle’s internal environment and leads to less effective muscle function. Some of the lactic acid is transported away from the muscle by the smallest blood vessels, the capillaries. The lactic acid that is transported away is processed by the liver and rebuilt into new fuel for the muscles. However, the process of transporting and rebuilding the lactic acid demands a lot of energy. The lactic acid which remains in the muscle can actually also be used directly as a fuel.

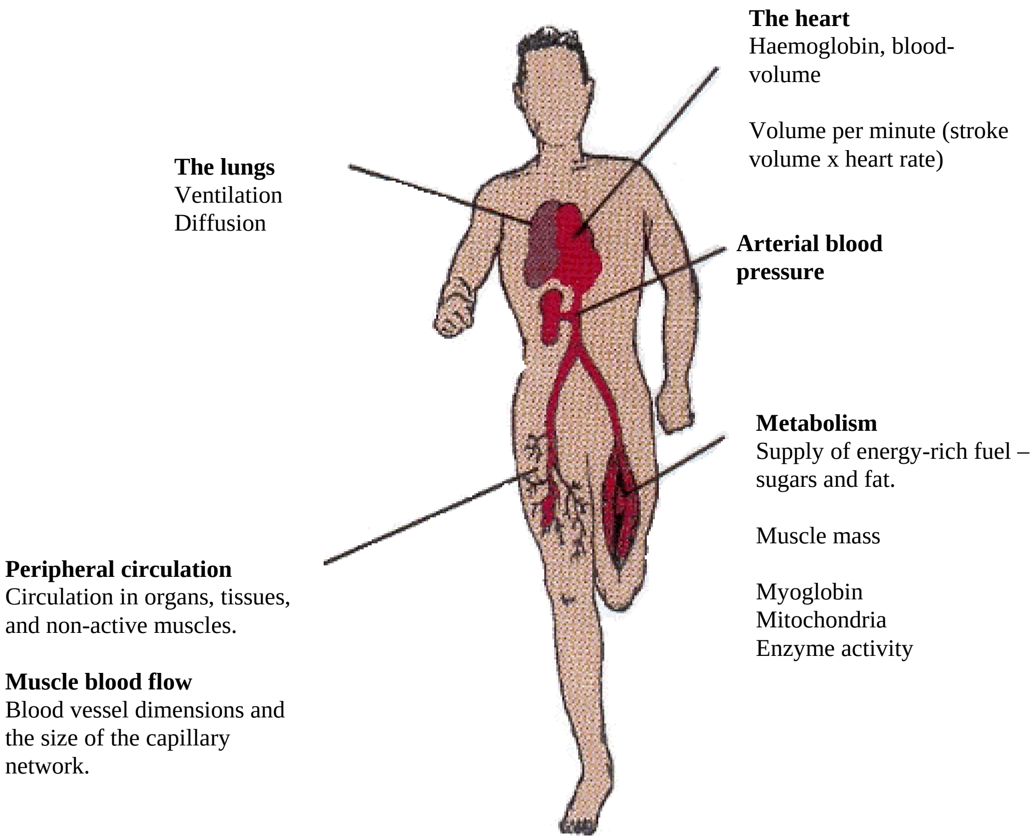


Whether lactic acid is transported away from the muscle or is recycled directly in the muscle energy system depends on the way that the energy system has been adapted through training. The processes which transport lactate away or use it in the muscle are controlled by an enzyme called LDH, lactate dehydrogenase, which exists in five different forms. If your training has been mainly based on sprinting and short intervals the enzyme which transports lactate out of the muscle will dominate. If your training has included more endurance work then more lactic acid will be recycled directly in the muscle. In other words, the content of your training indirectly determines the pathways that lactic acid will follow, by influencing the LDH enzymes in your muscles. If you have developed a rich capillary system through endurance training you will also have a much better capacity to transport lactate away from the muscle. You will be much better at clearing lactate.

Oxygen pathways to the muscles

A national team orienteer has a very high capacity in the organs responsible for transporting oxygen. On the way from the air to the working muscle cell, oxygen passes through several limiting links. These links can be improved, but also made worse, by training, nutrition and rest.

The air we breathe contains about 21 percent oxygen gas, O_2. If we are at altitude the available oxygen reduces, which also reduces our capacity for physical activity. It is possible to notice a difference even at 1000 m. We become breathless more easily, have a higher pulse and our legs become rapidly heavy with lactic acid. At extreme altitude, 7000 – 8000 m, each step is an exhausting effort.



The Lungs

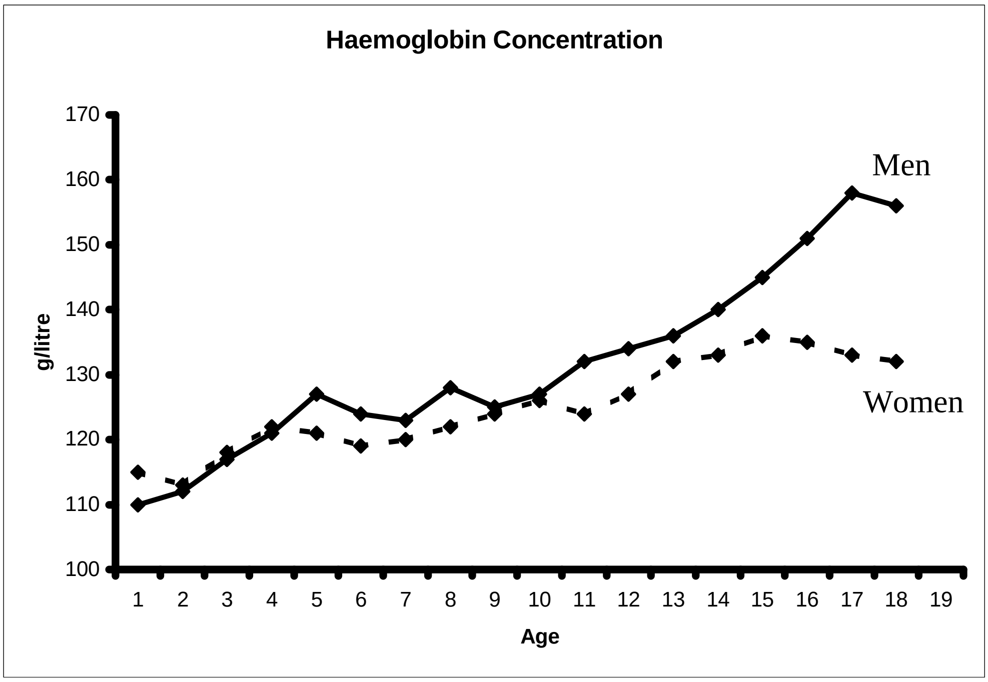
At rest lung ventilation is 5-6 litre/min and this value increases with increased activity. Each person has a theoretical ceiling which limits ventilation. Maximum ventilation is around 200-220 litre/min for men and 125-150 litre/min for women. Lung volume is not influenced significantly by training, but the muscles involved in breathing become stronger and develop better endurance.

Oxygen reaches small cavities in the lungs, the alveoli, via the windpipe and bronchi. There are millions of alveoli in the lungs. This means that the total area available for oxygen transfer is very large: 70-100 m^2. Around each lung cavity there is a very fine network of thin blood vessels. Oxygen passes through the walls by diffusion and attaches to the red blood cells in the blood. This oxygenated blood is then transported to internal organs and muscles, with the help of the heart.

The Blood

Blood volume for an adult man is approximately 4-5 litres. Women have a lower volume, around 3-4 litres. Blood consists of red blood cells and plasma. Red blood cells make up approximately 40-45 percent of the total volume. This percentage is called the haematocrit value. It is usually higher in men than women. Red blood cells contain an iron based compound called haemoglobin, which is able to bind with oxygen and enables ref blood cells to transport oxygen around the body. Each gram of haemoglobin can hold 1.34 ml of oxygen. A litre of blood contains 140-160 grams haemoglobin in men and 120-140 grams in women.

Haemoglobin concentration, the Hb value, determines how much oxygen can be bound to the red blood cells, and therefore how much oxygen can be pumped by the heart. At the same work level a woman’s heart must pump around 10 percent more blood than a man’s to compensate for her lower Hb value.



Blood volume increases with training and can be as much as 6-7 litres in well-trained athletes. However training does not increase the Hb value, indeed it actually reduces it. The food that we eat is the most important factor in maintaining or increasing the Hb value in blood.

Blood also has other important jobs, such as providing the body with nutrients and being a transport system for hormones. Blood also helps to regulate body temperature.

The heart and circulatory system

The heart is the body's most central organ. The heart is a muscle which tirelessly pumps blood around the circulatory system. There are in fact two systems – one works to collect oxygen from the lungs, and a larger one pumps oxygenated blood round the body to the muscles.

Oxygenated blood from the lungs fills the heart. When the heart muscle contracts blood is pumped out into the main artery, the aorta. Each beat of the heart contains 1-2 dl blood. This amount, the stroke volume, varies significantly between trained and untrained people. A well-trained heart can pump as much as 40 litre/min. A person who exercises lightly might be able to pump 20 – 25 litre/min. The pump capacity of the heart is an important limiting factor in oxygen transport, and can be improved with training.

Resting pulse

Increased aerobic training makes the heart increase in both size and effectiveness. Resting heart rate reduces over time and this is a sign that fitness is increasing. Normal resting pulse is around 60-70 beats/min, while the resting pulse for an elite orienteer can be around 40-45 and in certain extreme cases around 30 beats/min. The explanation for this is that the body requires the same amount of oxygen at rest, regardless of whether it we are trained or untrained. As the same volume of oxygen is required and each beat from a trained heart provides more oxygenated blood due to its higher stroke volume, the pulse will fall. The relationship can be expressed as a volume per minute:

Volume per minute = Stroke volume x Pulse

It can be useful to know your resting pulse. An increased resting pulse can be a sign of infections or the onset of overtraining. The pulse will typically increase by 5-20 beats per minute in these cases.

Maximum pulse

As our pace increases the amount of oxygen required in the muscles also increases. Work rate and pulse increase linearly. The pulse increases to an upper limit, the maximum heart rate (Max HR). This generally lies between 170-220 for adults and is somewhat higher for children. A high or low maximum pulse is not an indicator of fitness or training, but depends more on inherited factors which determine the maximum heart rate for each different person.

It can be useful to know what your maximum heart rate is, as a guide for training intensity later. When describing training intensity we often refer to percentage of maximum pulse: 70, 80, 90 percent for example. Measuring maximum heart rate can actually be difficult. A heart rate monitor is required. In the lab, an ECG machine may be used. It is possible to carry out the measurement running outside or on a treadmill inside. The procedure involves a thorough warm up, as if for a competition, and then to run for at least 4-5 minutes at a continually increasing work rate. On a treadmill you would run until you have to jump off due to tiredness.

Measurement of maximum heart rate outdoors can be done as follows:

1. Thorough competition warm-up
2. Run for 2 minutes at a continuous fast pace.
3. Run for 2 minutes at a slightly higher pace.
4. Run as hard as you can up a long hill for at least 1 minute, or until you are not able to carry on.

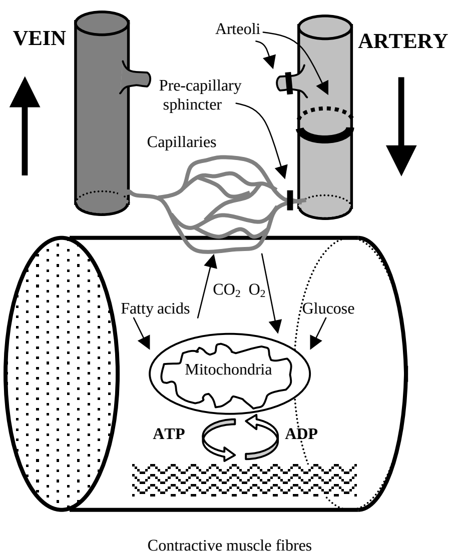
Ideally, you should repeat the whole procedure a few times during a week to get a reliable value for maximum pulse. The variation should not be more than 2-3 beats per minute.

Maximum pulse testing should only be undertaken by healthy and well-trained orienteers!

Oxygen use in the muscles

The largest arteries nearest the heart branch into smaller arteries. The blood rushes down these channels to the organs which have the greatest requirement for oxygen. After eating the stomach and intestine require oxygen and during physical work it is the muscles. The brain and nervous system always require a certain amount of oxygen regardless of how hard the body is working elsewhere. The arteries divide into smaller and smaller blood vessels which supply the smallest vessels at the end of the system, the capillaries. These small tubes surround the actual muscle cells and it is here that oxygen leaves the red blood cells and is transported by diffusion into the muscle cells. A compound related to haemoglobin, myoglobin, plays an important role in this final transport process, where oxygen is taken to its destination, the mitochondria. Metabolism of carbohydrates and fat takes place in the mitochondria and it is here the ATP is formed, providing the processed fuel that the muscles need.

The distance between the capillaries and the mitochondria is a very important factor in determining the oxygen transport rate. As the slow twitch fibres (Type I) are somewhat thinner, the distance is shorter than in the fast twitch fibres. The myoglobin content in these fibres is also greater and the capacity for aerobic work is therefore better in these muscle fibres.



Contractive muscle fibres
(actin and myosin)

Apart from energy and heat, both carbon dioxide and water are formed. These “waste products” are transported away by the blood to the lungs where they are breathed out. Deoxygenated blood is transferred via capillaries to larger blood vessels and is pumped back to the heart through the veins. The veins join together and take the blood back to the heart where it is pumped round the smaller circulatory system connecting the heart and lungs.

Mitochondria – the muscle cell’s power station

The mitochondria are the final link in the oxygen transport chain. It is in the mitochondria that power for muscle contractions is created. The more mitochondria we have, the higher our capacity for providing the energy necessary for muscle work. Training at intensities lower than the “lactate threshold” encourages the body to form more mitochondria. Too much hard training, where you are working in the “lactate zone” can both damage the mitochondria and worsen their function.

Capillaries – the body’s postmen

The more postmen who work to deliver out the post, the quicker letters and packages will get to recipients. The capillary system works in a similar manner. Through aerobic fitness training, mainly at low and moderate intensities, it is possible to double the number of capillaries with time. This means that the mitochondria are provided with more oxygen and the oxygen supply during hard work will be much better. This capacity must be continually maintained by orienteers. If training ceases both mitochondria and capillaries will decrease to a normal level.

Central and Local Capacity

The idea of ”central” and ”local” capacity is an essential concept in all physical training. Local refers to the capacity we have in the parts of the body that are most involved in the movements specific to our sport. For an orienteer this means the muscles used when running in the forest, and expressed simply our training should be in the forest, not on the road. The stride required on the road is very different to the running style needed in the forest. On the other hand road running, mountain biking, swimming, cross-country skiing and a whole variety of aerobic sports can be excellent training for our central capacity.

Central capacity

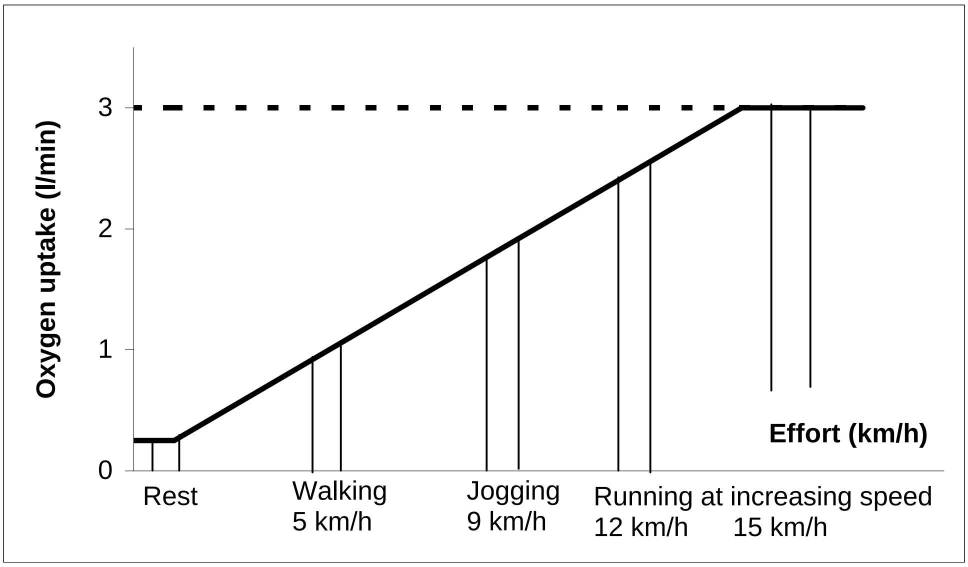
The heart’s pump capacity, the capacity of the lungs and the capability of the blood to transport oxygen are referred to as our central capacity. This capacity is the basis for all aerobic training. The stroke volume of the heart and the blood’s haemoglobin value are two important factors in the central capacity. The stroke volume can be improved through training at different intensities, both low and high intensities in sports which recruit large muscle groups, such as the aerobic sports named above. The haemoglobin value can be maintained through nutrition, recovery and rest. Building the central capacity up to a high level takes many years, but when we have developed a high central capacity it is possible to have short breaks or even train less for longer periods without decreasing this capacity significantly. When building up the central capacity is a good idea to vary the training methods and sports we use, so that the heart and lungs can be worked without repeated stress on the same muscles and joints.

Local capacity

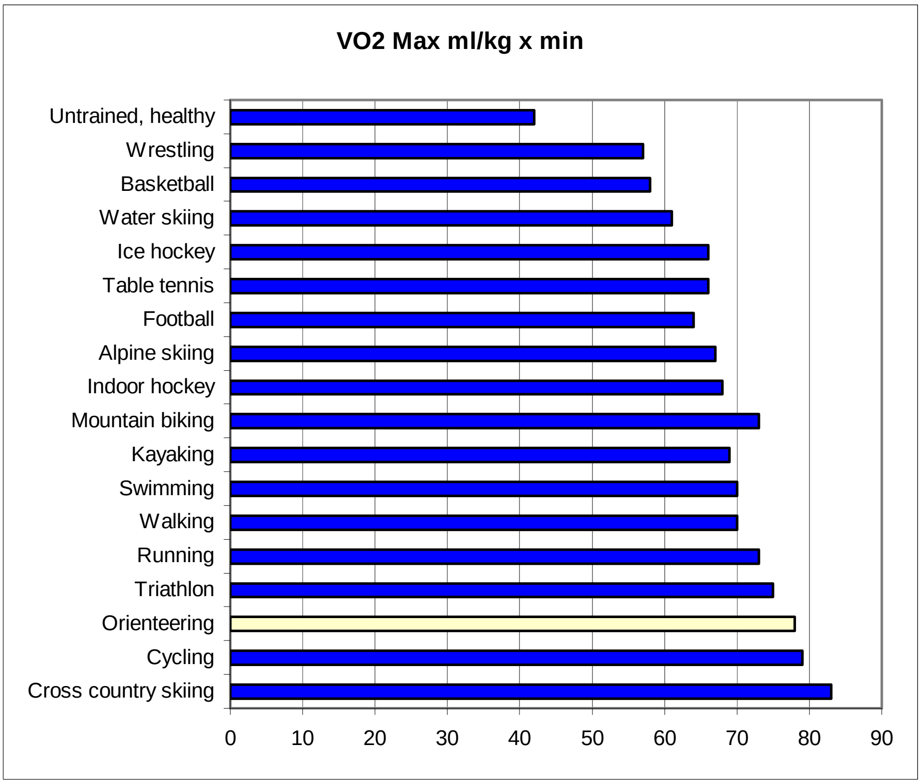
Local capacity is directly related to the movement that we actually carry out. For an orienteer it is important that we try to transfer the important aspects of competitive orienteering into our training. Similar intensity, speed, effort and similar underfoot conditions are important to be able to train local capacity optimally. Orienteers need muscle mass to move themselves over rough terrain, but also need a rich network of capillaries round these muscles. The muscles must be well coordinated with the right nerve impulses providing a smooth, efficient movement. In the muscle cells there must be a high density of mitochondria and a high enzyme activity. The type of energy metabolism that the muscle will perform in competition must also be recreated in training. There is only one way that an orienteer can maintain and improve local capacity: Train in the same way that you compete.

Oxygen uptake

Oxygen is essential to the body, whether it is resting or working. At rest oxygen is about 0.2 – 0.3 litres per minute and at maximal work level for an orienteer, oxygen uptake is about 4-4.5 litres per minute for women and 5-6 litres per minute for men. At rest oxygen is used to supply the brain, the nervous system and the internal organs, and at work it is used to create energy in the muscle cells, together with glycogen. At rest the body uses about 1 kcal per kilogram of body weight: Around 70 kcal for a man who weighs 70 kg. Energy consumption during a competition can increase to approximately 14-15 kcal per kilogram and hour, or about 1000 kcal for the same man.



Oxygen uptake and work load increase linearly until oxygen uptake reaches the individuals maximum level (see diagram). The work level cannot be increased any more at this point and the muscles rely on anaerobic, and produce lactic acid. A high maximal oxygen uptake is one of the most important factors to be a good elite orienteer - see more information in the Profile of physiological demands. Compared with other sports orienteering has one of the highest maximal oxygen uptake value (see table). The test value for an orienteer or runner, who carries his or her body weight during activity, is often expressed as millilitres per kilogram of body weight per minute: ml/kg x min.



The data in the above table comes from male Swedish national teams.