Chapter 3: Factors that contribute to successful endurance performance

Learning outcomes

By the end of this chapter you should be able to:

- define the term maximum oxygen consumption (VO$_2$max)
- outline at least three factors that contribute to a high VO$_2$max
- give at least one test of VO$_2$max
- explain what is meant by the onset of blood lactate accumulation (OBLA)
- explain the relationship between VO$_2$max and OBLA
- suggest at least one training regime that can be used to improve VO$_2$max
- outline the anatomical and physiological differences between males and females
- state the differences in fitness measures between males and females
- state the differences in fitness measures between trained and untrained subjects.

Introduction

You should be aware by now of the clear link that exists between

- the ability of the cardio-respiratory system to transport oxygen to the muscles
- the chemical ability of the muscle tissue to utilise this oxygen to break down fuels to release energy
- successful endurance performance.

In this chapter we will investigate the factors that enable us to exercise under aerobic conditions and also consider the differences in fitness measures that we may expect between different population groups, such as males and females and the trained and untrained.

Maximum oxygen consumption (VO$_2$max)

Lance Armstrong’s is reported as 83.8ml/kg/min, Paula Radcliffe’s is an amazing 80ml/kg/min and Matt Pinsentt has the highest ever recorded in the UK at a staggering 8.5l/min. What do these figures represent? Well, it’s their VO$_2$max of course! Indeed, if you visit the chat room of any marathon running web site, conversation soon turns to the size of your VO$_2$max.

Your VO$_2$max or maximum oxygen consumption can be defined as:

- the maximum volume of oxygen that can be utilised or consumed by the working muscles per minute.

A high VO$_2$max or maximum oxygen consumption is indeed one of the hallmark characteristics of great endurance performance in activities such as running, cycling, and swimming.
as swimming, cycling, rowing and running. However, it is elite cross-country skiers that are considered the most powerful in oxygen uptake capacity. This is probably because cross-country skiing engages just about all of the major muscle groups of the body. But this is not the only determining factor of VO₂max.

The ability of the muscles to consume the greatest volume of oxygen possible is dependent upon two key things:

1. **An effective oxygen delivery system** that brings oxygen from the atmosphere into the working muscles.
2. **An aerobic–friendly muscle structure** which possesses a large volume of myoglobin and a high density of mitochondria which can be used to produce ATP via the aerobic energy system.

So for effective endurance performance we need a big and efficient pump to deliver oxygen-rich blood to the muscles and mitochondria-rich muscles to use the oxygen and enable high rates of exercise.

**Measuring maximum oxygen consumption (VO₂max)**

You will recall from your AS study that there are a number of tests of maximum oxygen consumption (VO₂max). These tests are listed below:

- the multi-stage fitness test
- Harvard step test
- PWC170 test
- Cooper 12 minute run test.
Whilst the multi-stage fitness test gives a reasonable prediction of VO$_2$\text{max}, it cannot give a truly objective measure of the volume of oxygen actually consumed by the working muscles. The only way we can possibly do this is in a sports science laboratory where direct gas analysis can take place. In order to determine an athlete’s true maximal aerobic capacity, exercise conditions must be created that maximally stress the blood delivery capacity of the heart.

An example of a VO$_2$ max treadmill test now follows using Johnny, a typical A-level student, as a subject.

1 First of all, Johnny is weighed. This is so his VO$_2$ max can be given relative to his body weight. A simple reading of ml/min would ignore the fact that larger people have larger lungs and are capable of taking more oxygen into their bodies.

2 Following a warm up, Johnny places a mask over his mouth which is attached to the computer by a hose tubing. Johnny begins the treadmill test at a speed of 10km/h. Whilst running he breathes through a two-way valve system. The computer analyses the relative concentrations of oxygen and carbon dioxide inspired and expired respectively. From this it is possible to calculate the amount of oxygen extracted and consumed by the muscles and the amount of carbon dioxide produced over time. In order to reach an exhaustion point and get a maximum reading, the treadmill speed is increased by 1km/h every minute.

3 After two minutes the speed of running has increased to 12km/h. Figure 3.03 overleaf shows an increase in the level of oxygen breathed in and carbon dioxide breathed out. The distance between the two values shows that Johnny is working aerobically with a good supply of oxygen to the muscles. He is in, a steady state where oxygen demand is being met by oxygen supply.

4 After seven minutes the speed has increased to 17km/h and Johnny’s heart rate has increased significantly to 192bpm. His breathing rate has become faster as the levels of carbon dioxide increase further. Now the level of oxygen begins to level out. Johnny will have to call on more and more anaerobic energy to meet any other extra energy demands as his body struggles to get oxygen to his muscles.

5 After 10 minutes Johnny is racing along at 20km/h, his heart is doing overtime at over 200bpm and his lungs are working at their maximum to get oxygen into the body. This is the point where the VO$_2$\text{max} is taken. His reading is 57.6ml/kg/min. After nearly 10.5 minutes Johnny is completely exhausted – he can no longer exercise and the test is stopped.

6 Johnny’s reading of 57.6ml/kg/min is good and shows that he has some capacity to perform endurance-based activity.
Unit 4: Physiological, biomechanical and psychological factors which optimise performance

TASK 1
Use the following data in Table 3.01 to plot a bar graph illustrating the expected VO_{2max} scores for the activities shown.

Table 3.01 Typical VO_{2max} scores for a range of sporting performers

<table>
<thead>
<tr>
<th>Activity</th>
<th>Male (ml/kg/min)</th>
<th>Female (ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triathlete</td>
<td>80</td>
<td>72</td>
</tr>
<tr>
<td>Marathon runner</td>
<td>78</td>
<td>68</td>
</tr>
<tr>
<td>Distance swimmer</td>
<td>72</td>
<td>64</td>
</tr>
<tr>
<td>Middle distance runner (800-1500)</td>
<td>72</td>
<td>63</td>
</tr>
<tr>
<td>Games player</td>
<td>66</td>
<td>56</td>
</tr>
<tr>
<td>Gymnast</td>
<td>56</td>
<td>47</td>
</tr>
<tr>
<td>Weightlifter</td>
<td>52</td>
<td>43</td>
</tr>
</tbody>
</table>

**Fig 3.03 VO_{2max} timeline**

**TASK 2**
If your absolute VO_{2max} was measured at 4.0l/min and you weighed 75kg, calculate your relative VO_{2max}.

**TASK 3**
Design a training programme aimed at improving the VO_{2max} of a performer. Make sure you prescribe appropriate methods of training and clearly state the expected intensity of training.
Factors affecting maximum oxygen consumption (VO\textsubscript{2}max)

**Physiology**
The physiological make up of the body will almost certainly affect VO\textsubscript{2} max. Below are just a few physiological factors that contribute to a higher VO\textsubscript{2} max score:

- A high percentage of slow twitch (type 1) muscle fibres
- High capillary density
- High mitochondrial density and myoglobin content
- High blood volume and haemoglobin content.

**Lifestyle**
Smoking, leading a sedentary lifestyle and having a poor diet can greatly reduce VO\textsubscript{2} max values.

**Genetics**
Studies on identical and fraternal twins have suggested that genetics accounts for 25 to 50 per cent of VO\textsubscript{2} max scores. It appears that Olympic champions are born with a unique potential that is transformed into athletic performance through years of hard training.

**Age**
Typically VO\textsubscript{2} max will decrease with age. After the age of 25 years, VO\textsubscript{2} max is thought to decrease by about 1 per cent per year. Regular physical activity can slow down the rate of this decline.

**Body composition**
Research shows that VO\textsubscript{2} max scores decrease as the percentage of body fat increases. This is because fat is non-functional weight that must be carried around. Typically males should aim for a body fat per cent of between 14–17 per cent whilst females should aim for a value between 24–29 per cent.

**Gender**
When we consider absolute VO\textsubscript{2} max, the typical untrained male has a value of 3.5 l/min whilst that of a female is approximately 2 l/min – a 43 per cent difference! When we consider bodyweight to give a relative value this difference is reduced to 15 to 20 per cent.

**Training**
VO\textsubscript{2} max can only be improved by 10 to 20 per cent following training. This is somewhat surprising given the vast improvement in the delivery and transport of oxygen resulting from long-term endurance training. The best methods of training to improve VO\textsubscript{2} max include continuous training, Fartlek and aerobic interval training.

Fig 3.04 the main factors that affect an individual's maximum oxygen consumption
Onset of blood lactate accumulation (OBLA)

We have established that a large VO₂max sets the ceiling for endurance performance: it is an indication of the size of our performance engine. However, it is the onset of blood lactate accumulation (OBLA) that determines the actual percentage of that engine power that can be utilised.

The onset of blood lactate accumulation describes the point at which lactic acid starts to accumulate in the muscles. During normal resting conditions the normal amount of lactic acid circulating in the blood is 1–2 millimoles/litre (mmol/l). This rises dramatically during intense exercise. Quite simply, the more intense the exercise the greater the extent of lactic acid production. The onset of blood lactate accumulation (OBLA) is said to occur when concentrations of lactic acid in the blood reach 4mmol/l.

Just like VO₂max, OBLA occurs at different intensities of exercise for different people. It is expressed as a percentage of VO₂max. For the average untrained individual, OBLA occurs at around 55–60 per cent of VO₂max, whilst trained endurance performers can delay OBLA until they have utilised 85–90 per cent of their VO₂max.

Measuring OBLA

OBLA can only truly be measured in a sports science laboratory. The test should be conducted using a mode of exercise most suited to the performer, usually a treadmill, bicycle ergometer, rowing ergometer or swimming bench. Typically the test is conducted in four to six stages. During the first stage the exercise intensity is set at about 50 per cent of VO₂max and increases in intensity at the start of each of the subsequent stages. Each stage generally lasts about five minutes. At the end of each stage, heart rate is recorded, oxygen consumption measured, and blood samples are taken by a small prick on the finger or earlobe and the concentration of blood lactate is analysed. The point at which blood lactate levels rise to 4mmol/l of blood usually signals OBLA. The exercise intensity, oxygen consumption and heart rate at this point can now be recorded and used to monitor progress and assess exercise intensity during training.
OBLA and training

Improvements in endurance capacity can be observed where lower lactate levels are recorded for any given exercise intensity. This shows that the body has adapted to cope with higher levels of blood lactate and speeds up removal through effective buffering. You will recall that untrained individuals usually reach OBLA at about 55–60 per cent of VO₂max. With training this figure can increase to 70 per cent or even higher. Elite endurance athletes such as Lance Armstrong have values approaching 90 per cent. Whist OBLA is a much greater product of training than VO₂max, it is still influenced by genetics.

**TASK 4**

Using the information from Table 3.02, plot a graph of blood lactate accumulation (mmol/l) (y-axis) against running speed (ms⁻¹) (x-axis).

Table 3.02

<table>
<thead>
<tr>
<th>Blood lactate (mmol/l)</th>
<th>2.9</th>
<th>3.7</th>
<th>5.7</th>
<th>9.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running speed ms⁻¹</td>
<td>3.5</td>
<td>4.0</td>
<td>4.5</td>
<td>4.9</td>
</tr>
</tbody>
</table>

1. On your graph show the point of OBLA. Give a brief explanation as to why you have chosen this point on the graph.
2. At what running speed did OBLA occur?

A word on lactic acid

You will recall that lactic acid is produced when there is insufficient oxygen available to sustain a given exercise intensity. The pyruvic acid produced during glycolysis is converted to lactic acid by the enzyme lactate dehydrogenase. Once formed, lactic acid quickly dissociates into lactate and hydrogen ions (H⁺). It is the presence of hydrogen ions that make the muscle acidic and ultimately causes muscle fatigue. The acidic environment slows down enzyme activity and ceases the breakdown of further glycogen. High levels of acidity can also irritate nerve endings which can cause some degree of pain. The ‘heavy legs’ often associated with lactic acid can thus be blamed on the hydrogen ions.

However, lactic acid is not always the bad guy it is made out to be. The heart, the liver, the kidneys and inactive muscles are all locations where lactic acid can be taken up from the blood and either converted back into pyruvate and metabolised in the mitochondria producing energy or converted back to glycogen and glucose in the liver. Table 3.03 summarises what happens to the lactic acid once it has been removed from the muscle.

**Table 3.03 The fate of lactic acid**

<table>
<thead>
<tr>
<th>Conversion into CO₂ and H₂O</th>
<th>Up to 65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion into glycogen</td>
<td>Up to 20%</td>
</tr>
<tr>
<td>Conversion into protein</td>
<td>Up to 10%</td>
</tr>
<tr>
<td>Conversion into glucose</td>
<td>Up to 5%</td>
</tr>
<tr>
<td>Conversion into sweat and urine</td>
<td>Up to 5%</td>
</tr>
</tbody>
</table>
Factors influencing the rate of lactate accumulation

**Exercise intensity**

The higher the exercise intensity the greater the ATP demand, (type 2) muscle which can only be sustained using glycogen as a fuel. As fast twitch (type 2) muscle, fibres possess greater stores of glycogen (and therefore lactate dehydrogenase), pyruvate is soon converted to lactic acid.

**Muscle fibre type**

Slow twitch (type 1) fibres produce less lactate at a given workload than fast twitch fibres. As slow twitch muscle fibres possess greater amounts of mitochondria, pyruvate will tend to be converted into acetyl-coenzyme-A and move into the mitochondria with little lactate production.

**Rate of blood lactate removal**

If the rate of lactate removal equals the rate of production then blood lactate concentrations should remain constant. When the rate of lactate production exceeds the rate of removal then blood lactate will accumulate as OBLA is reached.

**The trained status of the working muscles**

If muscles are trained then they benefit from the associated adaptive responses. These include improved capacity for aerobic respiration due to higher mitochondrial and capillary density, improved use of fatty acids as a fuel (which do not produce lactic acid!) and increased stores of myoglobin.

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**TASK 5**

The graph in Figure 3.06 provides data gained from an OBLA test on a middle-distance runner.

1. Use Figure 3.06 to calculate OBLA of the runner given that she has a VO₂max of 61ml/kg/min.

2. If her HR max is 182bpm, at what percentage of HR max does OBLA occur?

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Fig 3.06 The relationship of oxygen consumption to heart rate and lactate concentration of a middle distance runner during a maximal test to exhaustion.
Gender differences in athletic performance – the battle of the sexes!

For many years social issues, misunderstandings and presumptions concerning physical and medical issues excluded many females from participating in vigorous physical activity, leading to the slow development of female athletic performance. Thankfully those times are gone now and female athletes are rapidly closing the gap on their male counterparts.

Contrary to popular belief the following variables show very little or no difference between the sexes:

- distribution of muscle fibre types
- lactate threshold when measured as a percentage of VO$_2$max
- muscular concentrations of ATP and PC.

Having said that, we know that there are some anatomical and physiological differences between the sexes and we need to consider just how these differences affect fitness levels and competition performance.

Table 3.04 considers the major performance differences between the sexes that are of particular interest to the exercise physiologist and attempts to explain these differences using knowledge of anatomy and physiology.

<table>
<thead>
<tr>
<th>Performance factor (females compared to males)</th>
<th>Anatomical/physiological explanation (females compared to males)</th>
</tr>
</thead>
</table>
| 15–20% lower maximum oxygen consumption (VO$_2$max) | Lower haemoglobin content of the blood – this limits oxygen transport and delivery  
Lower blood volume – this limits oxygen transport and delivery  
Smaller heart size – this makes a less effective pump in the delivery of oxygen  
More body fat which increases the non-functional weight using up oxygen during exercise  
Smaller lung capacity which means less oxygen is entering the body and available for aerobic respiration |
| Up to 50% lower in measures of strength and power (although these differences are smaller when adjusted for fat-free mass) | Less muscle mass  
Lower capacity of anaerobic glycolysis |
| 7–10% more body fat | The female hormone oestrogen promotes the deposition of subcutaneous fat which offers little benefit to women during endurance events |
| Biomechanical differences | A wider pelvis and forward orientation of the hips can hinder running and cycling efficiency |
Revise as you go!

1. Define VO₂max.
2. Suggest typical VO₂max values for the following:
   a) a healthy male A-level PE student
   b) a centre in netball
   c) an Olympic rower.
3. The multi-stage fitness test or ‘bleep test’ is often used to determine the VO₂max of an athlete. Briefly outline this test and give reasons why this may not be the most accurate test to use.
4. Identify and explain the procedures of a more valid test that may be used to determine an athlete’s VO₂max.
5. Outline the factors that could limit VO₂max.
6. Suggest a method to improve VO₂max.
7. Explain why the VO₂max of women is typically 15–20 per cent lower than that of men from the same activity group.
8. Explain what you understand by the term OBLA.
9. OBLA and lactate threshold are often used interchangeably. How is the lactate threshold related to VO₂max?
10. At what point does OBLA typically occur? What might cause an athlete to reach OBLA?
11. Andrew Johns represents Great Britain in triathlon. Explain how knowledge of blood lactate levels during a triathlon might assist his performance.
12. Briefly outline the factors that affect the rate of lactate accumulation.
13. Explain what you understand by the term ‘buffering’. How does the body buffer lactic acid?
14. What happens to lactic acid once it has been produced in the body?

As a rule of thumb when VO₂max is measured in relative terms (taking bodyweight into consideration), female athletes have a score of approximately 10ml lower than comparable males of the same activity group.