CQ2/C

PHYSIOLOGICAL ADAPTATIONS IN RESPONSE TO AEROBIC TRAINING

In response to aerobic training, the body makes adaptations or adjustments to the level of stress imposed on it. These adaptations allow it to function more comfortably at existing levels of stress and respond more efficiently to new levels of stress. The time taken before improvements are noticed will vary from one individual to another and depends on the biological systems affected. Although progressive improvements will be seen throughout a training program, it usually takes about 12 weeks to realise the entire benefits.

Aerobic training will cause adaptations to a number of capacities, including resting heart rate, stroke volume, cardiac output, oxygen uptake, lung capacity, haemoglobin levels and blood pressure.

Resting heart rate

Heart rate measurement at rest and during exercise is a reliable indicator of how hard the heart is working. All things being equal, the trained athlete has a lower resting heart rate than the untrained athlete. This is due to the efficiency of the cardiovascular system and, particularly, a higher stroke volume. Training decreases resting heart rate. For example, a sedentary person with a resting heart rate of 72 bpm can expect it to reduce by about one bpm each week for the first few months of training. After 10 weeks of endurance training, the resting heart rate of the same subject should decrease from 72 to about 60 bpm. Highly conditioned endurance athletes have resting heart rates below 40 bpm and some are less than 30 bpm. Figure 7.12 illustrates the benefits of a training program on heart rate. The most appreciable difference is evident in the recovery period. Figure 7.13 illustrates the difference between trained and untrained individuals at rest and during maximal exercise.

Stroke volume

Stroke volume (SV) is the amount of blood ejected by the left ventricle during a contraction. It is measured in mLs/beat. A substantial increase in is a long-term effect of endurance training (see figure 7.14). In other words, stroke volume will be notably higher at maximal exercise following an endurance training program. This occurs because training causes the left ventricle to fill more completely during diastole (the relaxation phase of cardiac contraction) than it does in an untrained heart. There is also more blood in circulation following training as a consequence of an increase in blood plasma volume. This means that more blood is able to enter the ventricle. In fact, blood volume can increase by half a litre after only eight days of endurance training. This causes the ventricular walls to stretch further which, in turn, increases the elastic recoil of the chamber. The enlarged ventricle causes contractions that are more powerful, resulting in less blood remaining in the ventricles following systole. The increased oxygen available to the working muscles results in improved performance.

Cardiac output

Cardiac output (CO) is the volume of blood ejected by the heart per minute. It is determined by multiplying heart rate and stroke volume. A
large cardiac output is the major difference between untrained people and endurance athletes. Untrained individuals may have a CO of 15 to 20 litres per minute. For trained athletes, CO is 20 to 25 litres per minute. In highly trained endurance athletes, CO may even rise as high as 40 litres per minute. What is more exceptional is that the maximal heart rate of the trained athlete may be slightly lower than that of the untrained person even when each person is working to their highest capacity. It follows that the trained athlete achieves a considerably higher cardiac output not from heart rate but as a direct result of a huge increase in stroke volume. This is illustrated in figure 7.15. However, as shown in figure 7.16, maximal values for cardiac output, stroke volume and heart rate are affected by age, decreasing gradually as we grow older.

**Oxygen uptake**

The most significant improvements in response to aerobic training are in oxygen uptake. Oxygen uptake is sometimes called aerobic power or VO$_2$. The body consumes only small amounts of oxygen at rest. However, as we begin to exercise, the mitochondria in the cells demand more oxygen to enable them to provide additional energy. Maximal oxygen uptake, or VO$_2$ max, is regarded as the best indicator of cardiorespiratory endurance because it indicates the maximal amount of oxygen that muscles can absorb and utilise at that level of work. Maximal oxygen uptake is relatively easy to estimate using tests such as bicycle ergometry in the laboratory, or a range of field tests such as the 12-minute run, Balke 15-minute run, or the multitask fitness test. A high VO$_2$ max indicates a superior oxygen delivery system and contributes to outstanding endurance performance. Most tests that measure VO$_2$ max are able to take account of individual differences. Measurements are expressed in millilitres of oxygen per kilogram of body weight per minute (mL/kg/min). Average VO$_2$ max values are about 45 mL/kg/min for 17-year-old boys and 40 mL/kg/min for girls. The lower value for girls reflects the fact that females have less muscle tissue as a percentage of total body weight (less lean body mass) than males and less oxygen-carrying capacity due to lower haemoglobin levels. Oxygen uptake decreases at the rate of about 1 per cent per year after the age of 25, but is influenced greatly by aerobic training.

Training appreciably increases VO$_2$ max even in an eight- to 12-week period. A 15 per cent to 20 per cent increase is typical for the average inactive person who applies the FITT formula for a six-month period. This reflects an improvement of 35 to 42 mL/kg/min. The highest recorded value for a female, world class, endurance athlete is 75 mL/kg/min and the highest for a male athlete is 85 mL/kg/min. If VO$_2$ max readings are higher in the pre-training state, the improvements will be smaller. In other words, sedentary people will make significant improvements when compared to trained athletes following similar training programs. Increases in VO$_2$ max readings are accompanied by a remarkable jump in the number of oxidative enzymes. This causes mitochondria numbers and size to increase. The mitochondria use the oxygen to produce energy, leading to higher VO$_2$ max readings. Some increase in VO$_2$ max is also due to increased blood volume as a result of the endurance training program.

**Lung capacity**

No matter how efficient the cardiovascular system is in supplying adequate blood to the tissues, endurance is hindered if the respiratory system does not supply enough oxygen to meet demand. Oxygen is absorbed in the lungs, where lung capacity is important. Total lung capacity is about 6000 mL in males and slightly less in females due to their smaller size. In general, lung volumes and capacities change little with training. Vital capacity (the amount of air that can be expelled after maximal inspiration) increases slightly. Residual volume (the amount of air that cannot be moved out of the lungs) shows a slight decrease. Overall, total lung capacity remains relatively unchanged. Following training, tidal volume (the amount of air breathed in and out during normal respiration) is unchanged at rest and submaximal exercise. However, it appears to increase at maximal levels of exercise.

**Haemoglobin level**

Haemoglobin is contained in the red blood cells of the body. Each red blood cell contains about 250 million haemoglobin molecules, all capable of carrying considerable quantities of oxygen. The average male has about 14.3 grams of haemoglobin per 100 mL of blood, while the average female has 13.9 grams per 100 mL of blood. Women’s lower levels of haemoglobin contribute to lower VO$_2$ max values. Most oxygen in the body is transported by the haemoglobin in the red blood cells. Some oxygen is transported in body fluids such as plasma, but the amount is relatively low because oxygen does not dissolve readily in ordinary fluids. Without haemoglobin, we would need to have about 80 litres of blood (or much more than fills the average car’s petrol tank) to transport enough oxygen to enable us to remain alive at complete rest.
Haemoglobin levels increase as a result of training and this increases oxygen-carrying capacity. One important way of increasing haemoglobin levels is to train at high altitudes. Figure 7.19 shows the effect of altitude on haemoglobin levels, which partly explains the success of Kenyan endurance runners in middle- and long-distance events.

General endurance training programs increase haemoglobin levels from about 800 grams to about 1000 grams per 100 mL of blood, representing a 20 per cent increase. This is directly attributable to an increase in blood plasma (and therefore blood volume) and a boost in red blood cell numbers. However, although the total quantity of haemoglobin may increase, the concentration may in fact lessen because more plasma, which contains mostly water, has been produced. Endurance athletes, therefore, tend to have thinner blood in terms of haemoglobin concentration, but more of it than non-athletes.

**Blood pressure**

Figure 7.21: The effect of exercise on blood pressure (Source: DK Mathews and EL Fox, ibid., p. 220.)

Blood pressure changes considerably from rest to exercise and responds positively to training programs. It has two components — systolic and diastolic.

Systolic readings reflect the force exerted against the arterial walls as the ventricles contract. Diastolic readings reflect the relaxation or filling phase of the heart (when the heart is at rest). Blood pressure readings are important indicators of the health of the cardiovascular system. High blood pressure (readings above 130/80 millimetres mercury) is referred to as hypertension and can be a health risk if not treated.

While diastolic blood pressure remains almost unaffected by exercise, systolic pressure rises. This is illustrated in figure 7.21. However, the long-term effect of training is to lower blood pressure.

People who experience hypertension show the biggest improvements. The decrease amounts to about 11 mm/Hg systolic pressure and eight mm/Hg diastolic. Related health improvements that accompany endurance training include improved elasticity of arterial walls and decreased blood cholesterol.

**Creating charts**

Read the snapshot below. Use charts to explain why former world champion cyclist Lance Armstrong was able to achieve performances far better than his competitors.

**Lance Armstrong heads for triumph in the Tour de France**

By Mike Van Niekerk

Tomorrow in Paris, Lance Armstrong will call it quits. Barring an accident before the 2005 Tour de France crosses the Champs Elysees finish line, the 33-year-old American will retire with a seventh straight yellow jersey on his shoulders and a reputation as one of the greatest athletes of his generation.

Watching the devastating ease with which Armstrong this week matched every attack by his rivals in the steep climbs of the Pyrenees, you would think he was superhuman — and you would be right. Armstrong is a physical freak, spectacularly well adapted to the harsh demands of endurance bicycle racing.

His heart is a third bigger than average, pumping blood to his muscles more efficiently; at rest his heart rate is 32 beats a minute, less than half the average. His blood is more saturated than normal, even for a top-level sportsman, with energy-producing oxygen; his VO2 max rating, which measures how much oxygen the lungs can consume during exercise, is 85. An average healthy male might rate a 40.

Even in an untrained state, Armstrong is at the same level as a highly trained but less gifted athlete, according to scientist Edward Coyle. Go back to those Pyrenean climbs again. Armstrong can ride uphill generating about 500 watts of power for 20 minutes, something a typical 25-year-old could do for only 30 seconds. A professional hockey player— perhaps even an AFL footballer — might last three minutes then throw up, according to Coyle, director of the human performance laboratory at the University of Texas.

Between 1992 and 1999 Coyle had the unique opportunity to test Armstrong’s body and chart how it adapted to intense training and competition. Armstrong was an extraordinary athlete who ... dramatically improved over time. To do well, Coyle said, cyclists needed a big heart, low levels of lactic acid in their blood — the by-product of intense exercise — and the ability to efficiently generate power, measured as watts. When Armstrong, then 20, first asked Coyle for an analysis of his potential, he already had the big heart and low lactic acid. But his muscle efficiency was not very good, Coyle said. It came in at 21 per cent. That first year, two other athletes studied were better. Armstrong improved until his career was suspended in 1996: he was diagnosed with testicular cancer, which had spread to his lungs and brain. Eight months after his treatment ended, Coyle’s tests found nothing permanently wrong with Armstrong.

The last test was done in 1999, after Armstrong won his first Tour de France. In the previous two years his lactic acid had dropped further and his efficiency increased to 23 per cent. Together with the weight loss during cancer treatment he was delivering 18 per cent more power — meaning he could go faster up mountains with less effort.
Coyle’s study, Improved Muscular Efficiency Displayed as Tour de France Champion Matures, in the June issue of the *Journal of Applied Physiology*, reveals the combination of natural gifts and focused hard work that took Armstrong to the top.

Stimulated by years of training intensely for up to six hours most days, Armstrong’s muscles changed from 60 per cent slow-twitch fibre — the kind that doesn’t burn out quickly — to 80 per cent. Clearly, this champion embodies a phenomenon of both genetic natural selection and the extreme to which the human can adapt to endurance training performed for a decade or more in a person who is truly inspired, Coyle wrote...

*Source: The Age, 23 July 2005.*

**MUSCLES & BONES**

A product of metabolism, lactic acid produces the excruciating burning sensation familiar to participants in strenuous physical activity. It could be a side effect of his gruelling training regimen or the abnormally high percentage of slow-twitch muscles in his body. Armstrong produces less lactic acid than normal.

- **THIGH BONE** Unusually long, it allows Armstrong to apply more force to the pedals.
- **BODY FAT** At about 4 or 5 per cent, Armstrong’s body fat is so low that he is more susceptible to infections.

**HEART & LUNGS**

A third larger than an average man’s, Armstrong’s heart has a resting rate of an astounding 32 beats a minute. At peak exertion, it can race up to 200 beats a minute. The average human’s resting heart beats 60 to 80 times a minute. The resting heart rate is the minimum number of beats a minute needed to sustain the body.

- **LUNGS** The average healthy male’s lung capacity uses 40 millilitres of oxygen per kilogram of body weight during exercise. Armstrong’s capacity is around 85.

**STOMACH**

Teammates are responsible for bringing Armstrong food during the race. Without it, his body would run out of glycogen — the short-term supply of carbohydrates stored in muscles.

**ARMSTRONG’S BODY**

Professional cyclists such as Lance Armstrong burn 4000 to 6000 calories [16 700 to 25 000 kilojoules] during a flat stage and more than 8000 calories [33 400] during a mountain stage. Studies say the average human burns between 1400 and 2500 [5880 and 10 500 kilojoules] calories a day. All that energy has to come from somewhere. Meals during the Tour are simple and nourishing. Breakfast consists of eggs, pasta, rice, bread, yoghurt, cereals. During the race, lunch is handed to the riders in bags called musettes. They contain high carbohydrate items: small sandwiches filled with honey and banana slices, cakes, energy bars, energy gels and water or sports drinks. After a stage, team members snack on cereal and high-protein foods. Dinner consists of meats, pasta, rice, salad, bread and dessert.