Unit 4 - Training to Improve Performance

Area of Study 2 - How is training implemented effectively to improve fitness?
Chronic Adaptations to Training
Cardiovascular Adaptations
- Aerobic Training
The heart is similar to other muscles in that it will experience hypertrophy as a result of aerobic training. Typically there will be an increase in the size of the left ventricular cavity and a slight thickening of the ventricular walls.
Increased capillary density improves blood flow to the heart itself.

The heart maintains a very high level of oxygen extraction so that 70–80% of the arterially delivered oxygen is extracted, compared with 30–40% in skeletal muscle - $O_2$ delivered to the heart is essentially used for contraction.
Influence of aerobic training on heart rate:-
- lower resting heart rate
- lower heart rate response at sub-maximal workloads
- (no real change of heart rate response at maximal workloads)
- slower heart rate increase during exercise
- lower and faster steady state
- decreased recovery heart rate following sub-maximal exercise
- decreased recovery heart rate following maximal exercise

Changes are related to:-
- increased stroke volume
- adjustments to the control mechanisms of the heart

The improved efficiency of the heart means that it works less to supply the same amount of blood to the body at rest and during exercise.

Untrained - Rest
Cardiac Output = Stroke Volume x Heart Rate
Q (6L/min) = 70mL per beat x 85 bpm

Trained - Rest
Q (6L/min) = 110mL per beat x 55 bpm
Stroke volume is the volume of blood ejected from a ventricle at each beat of the heart.

Increased stroke volume is most pronounced in endurance athletes.

The increase in stroke volume is attributed to:

- increased ventricular cavity size
- increased myocardial contractility

![Graph showing stroke volume for different conditions and levels of training.](image)
Cardiac output is the volume of blood pumped by the heart per minute.

Cardiac output (Q) = SV × HR

- **Rest:**
  - Q = 72 bpm (HR) × 70 mL (SV)
  - Q = 5040 mL/min
  - Q = 5.05 L/min

- **Maximal:**
  - Q = 180 bpm (HR) × 130 mL (SV)
  - Q = 23400 mL/min
  - Q = 23.4 L/min

The average adult body contains 5L blood - means all our blood is pumped through our heart about once every minute.

- Following aerobic training:-
  - Q at rest is unchanged or has a slight decrease.
  - Q at sub-max exercise is unchanged or has a slight decrease.
  - Q at maximal exercise is increased.
Cardiovascular Training Effects

- **Resting Heart Rate**
  - Trained: 40 bpm
  - Untrained: 70 bpm

- **Max Cardiac Output**
  - Trained: 40 L/min
  - Untrained: 20 L/min

- **Max Stroke Volume**
  - Trained: 180 mL
  - Untrained: 120 mL
Blood Pressure

- **Systolic pressure** - pressure on the arteries following contraction of ventricles as blood is pumped out of the heart.

- **Diastolic pressure** - pressure in the arteries when the heart relaxes and the ventricles fill with blood.

- Aerobic training influences the following chronic adaptations:
  - BP at rest is decreased
  - BP at sub max levels is decreased
  - BP at max levels is unchanged

- The greatest changes occur in systolic pressure which decreases due to:
  - improved vasodilation of blood vessels - less peripheral resistance to blood pressure.
  - decreased concentrations of total cholesterol.
  - reduced insulin resistance and insulin levels - significant contributing factors to the development of hypertension.

- Changes in blood pressure are most pronounced in hypertensive individuals.
Blood Vessels

- **Aerobic training** increases the size of the blood vessels (arteries and capillaries) transporting O2 to the heart.
  - results in improved blood supply to the heart and therefore improved O2 supply to the heart.
- **Myocardial O2 Consumption (MVO2)** decreases following aerobic training due to a combination of decreased heart rate & increased stroke volume.
- **Aerobic training** also results in increased capillarisation at the skeletal muscles.
- Increased number of capillaries that surround skeletal muscles:
  - greater in slow twitch muscle fibres
  - enhances the supply of O2 and other nutrients to muscle
  - improves removal of waste products
Both the total blood volume and the total amount of haemoglobin increase with AEROBIC training - improves the O₂ carrying capacity of the blood and is closely correlated with max VO₂.

Increased blood volume also assists temperature control during exercise particularly in hot temperatures as deep body heat is carried to the periphery where it can be dissipated.

The concentration of haemoglobin in the blood (grams per 100 ml of blood) is slightly lowered after prolonged aerobic training. Due to total blood volume increasing more than total haemoglobin.
Oxygen Extraction – a VO$_2$ Difference

- Arteriovenous O$_2$ difference - difference in oxygen content between the arterial and mixed venous blood. Represents the amount of O$_2$ extracted or consumed by the tissues.

- Aerobic training leads to a larger a-vO$_2$ due to:
  - Redistribution of blood flow to active muscles (particularly slow twitch).
  - Greater extraction of O$_2$ by the working muscles as a result of increased mitochondria numbers, more oxidative enzymes, and increased levels of myoglobin.

Untrained: max a-VO$_2$ - Exercise
Trained: max a-VO$_2$ - Exercise

Untrained: max a-VO$_2$ = 10 mL/100 mL
Trained: max a-VO$_2$ = 16 mL/100 mL
Lactate Production

- Prolonged AEROBIC TRAINING will result in a decrease in blood lactate production.
- Trained AEROBIC ATHLETES have an increased ability to remove lactate from the blood.

Blood Lactate Concentration - Trained vs Untrained Runner

Lactate Clearance - Trained vs Untrained Athlete

Un-trained

Trained

0 1 2 3 4 5
0 1 2 3 4 5
1 2 3 4 5 6 7
5 10 15 20 25

Lactate mmol/L

Running Speed km/hr

Mins

Lactate mmol/L

Untrained

Trained
Lactate Levels at Varying Running Intensities

When trained aerobic athletes produce less blood lactate AND have an improved ability to remove blood lactate they therefore have lower levels of blood lactate concentration. This enables athletes to work at a higher intensity (aerobically) before reaching the Lactate Inflection Point.
Lactate Inflection Point (LIP) is the highest exercise intensity point where lactate entry into and removal from the blood are balanced. Above this point blood lactate levels will begin to rise rapidly.

Lactate inflection point in:-
- Sedentary individuals typically occur at 50-60% of VO₂ max.
- Endurance-trained athletes typically occur at around 75-90% of VO₂ max - advantageous for the endurance athlete, where one can work at a higher VO₂ max, therefore a faster pace, without large increases in blood lactate levels.

Training at lactate inflection point will increase the %VO₂ max at lactate inflection point.

Following training the workload will increase allowing the athlete to work at a higher intensity without accumulating lactate and the lactate-associated effects of fatigue due to:-
- Increased mitochondrial density
- Increased capillarisation
- Increased oxidative enzymes
- Structural changes to the cardiovascular system
Lactate Inflection Point

Lactate Levels at Varying Running Intensities

Before Training

LIP 10 km/h before training

After Training

LIP 11.8 km/h Following training

Blood Lactate (mmol/L) vs. Running Speed (km/h)
### Chronic Adaptations to AEROBIC training - Cardiovascular Adaptations

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<th>Increase</th>
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<td>Myocardial Oxygen Consumption</td>
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## Chronic Adaptations to AEROBIC training - Cardiovascular Adaptations

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<td>Blood Pressure - rest</td>
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<td>Rate of Blood Lactate Production</td>
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<td>Rate of Blood Lactate Removal</td>
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<td>Lactate Inflection Point - “LIP”</td>
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</table>
Respiratory Adaptations
– Aerobic Training
Total lung capacity is about 6000 mL in males and slightly less in females due to their smaller size. Apart from Tidal Volume at Rest, Lung Volumes will generally increase as a result of aerobic training.
Vital Capacity

- Elite Endurance Values: 6.2L
- Trained: 6.0L
- Untrained: 5.8L
Tidal Volume

**Tidal Volume - Rest / Maximum**

- **Elite Endurance Values**
  - Max - 3.9L
  - Rest - 0.5L

- **Trained**
  - Max - 3.0L
  - Rest - 0.5L

- **Untrained**
  - Max - 2.75L
  - Rest - 0.5L
Diffusion

- The movement of oxygen from the alveoli into the capillaries and that of carbon dioxide from the capillaries into the alveoli is known as diffusion.

- When aerobic training brings about increases in lung volumes, and therefore surface area of the lungs, there is more opportunity for diffusion.

- Diffusion increases at rest and during sub-max & maximal bouts of exercise.
Pulmonary Ventilation (V) is the amount of air breathed per minute.

VE = RR \times TV \text{ (ventilation = respiratory rate } \times \text{ tidal volume)}

Adaptations to aerobic training:

- **Ventilation at rest** - decreases due to increased efficiencies.
- **Ventilation at sub-max exercise** decreases due to increased efficiencies.
- **Ventilation at max exercise** increases - increasing the supply of oxygen available and therefore ability to work aerobically.
Ventilation - $V_E$

### Minute Ventilation - Rest

- **Untrained**: 7L/min
- **Trained**: 6L/min
- **Elite Endurance Values**: 6L/min

### Minute Ventilation - Maximum

- **Untrained**: 110L/min
- **Trained**: 135L/min
- **Elite Endurance Values**: 195L/min
Oxygen Consumption

- Oxygen Consumption (VO2) is the volume of oxygen taken up and utilized by the body per minute per kilogram of body weight - ml/min/kg.

- Oxygen consumption at rest and during sub-maximal exercise generally remains unchanged or decreases slightly due to an increase in exercise economy.

- VO2 max increases substantially following endurance training due to improved O2 delivery to working muscles.

- Increased VO2 max is the result of adaptations to:
  - stroke volume
  - heart rate
  - arteriovenous Oxygen Difference (a - VO2 diff)

- A increase of 15% to 20% in VO2 is typical for a sedentary individual who trains at 50% to 85% of VO2 max 3 to 5 times per week/20min - 60min per session for six months (increase from 35ml/kg/min - 42ml/kg/min.
**VO₂ Max Training Effect**

Maximal Oxygen Uptake

- Untrained: 35 mL/kg/min
- Trained: 80 mL/kg/min

Elite endurance cyclists record VO₂ max scores above 80 mL/kg/min.
### Chronic Adaptations to Aerobic Training - Respiratory Adaptations

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<td>Oxygen Consumption - maximal (VO₂ max)</td>
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Muscular Adaptations
- Aerobic Training
Muscle Structure

- Aerobic training will have an effect on the structure of the skeletal muscles.

- **Slow twitch fibres** will:
  - increase in size.
  - become larger than the fast twitch fibres in the same muscle.
  - take up more of the muscle area than fast twitch fibres.
  - be recruited preferentially.
  - have their aerobic capacity improved.

- Myoglobin aids in the transport of oxygen across the cell membrane to the mitochondria in the muscle cells.

- Aerobic training increases myoglobin levels in skeletal muscles.

- Therefore,
  - increased stores of O₂ are possible.
  - Increased diffusion of O₂ is possible.
The MITOCHONDRIA are the place where the aerobic production of ATP occurs.

Endurance training increases:
- the number of mitochondria
- the size of the mitochondria
- the surface area of the mitochondria

These adaptations increase the amount of ATP that can be produced aerobically - therefore endurance athletes can perform at higher intensities whilst still relying predominantly on the aerobic pathways.
In general terms, an enzyme speeds up the rate at which a chemical reaction can take place in a cell.

Oxidative enzymes speed up the rate of oxidation and therefore the rate of aerobic ATP production.

An adaptation to endurance training is that there is an increase in oxidative enzymes.

Endurance athletes can then work aerobically at higher intensities without the accumulation of blood lactate.
Oxidation of Fat

- Fat is a rich source of fuel during aerobic activity and endurance athletes with a trained ability to oxidise fats are at an advantage.

- Aerobic training increases fat oxidation due to:
  - increased triglyceride stores in the muscle.
  - increased release of free fatty acid from adipose tissue
  - increased activity of oxidative enzymes involved in the activation, transport & breakdown of fatty acids.
At **sub-maximal levels**, if endurance athletes have an improved ability to oxidise fat they can therefore conserve their glycogen stores.

These glycogen stores may be needed for anaerobic ATP production such as a sprint to the line or an intense hill climb.
At sub-maximal levels, glycogen sparing allows trained athletes to decrease oxidation of glycogen.

At maximal levels, aerobic training increases the ability of the muscle to oxidise glycogen. This is because adaptations to aerobic training include:

- Increases in glycogen stores.
- Increased number/size/surface area of mitochondria.
- Increases in oxidative enzymes involved in aerobic metabolism.
### Chronic Adaptations to AEROBIC training - Muscular Adaptations

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Chronic Adaptations
- Anaerobic Training
Anaerobic Training

- The aim of anaerobic training is to improve the ATP-PC and Anaerobic Glycolysis energy systems.

- Anaerobic training can develop:
  - anaerobic capacity
  - speed
  - strength
  - power
  - agility
Cardiovascular Adaptations as a result of Anaerobic Training

- The following adaptations of the cardiovascular system to anaerobic training are possible:
  - Increased thickness of left ventricular wall.
  - Slight increase in stroke volume.
  - Increased force of left ventricle contraction.
  - Decrease in blood pressure:
    - At rest
    - During sub-maximal exercise.

![Graph showing ventricular wall thickness for different groups: Non-Endurance Athlete, Endurance Athlete, Non-Athlete.]
Muscular Adaptations as a Result of Anaerobic Training

- **The ATP-PC System**
- An improved capacity of the ATP-PC system is linked to:
  - increased muscle stores of ATP & PC (up to 25% more)
  - increased free creatine
  - increased activities of key enzymes involved in the ATP/CP system (e.g. ATPase)
Muscular Adaptations as a Result of Anaerobic Training

- **Anaerobic Glycolysis**
- An improved capacity of the Anaerobic Glycolysis System is linked to:
  - increased glycogen stores.
  - increased glycolytic enzyme stores and activity.
  - increased tolerance for the by-products of anaerobic glycolysis.
### Chronic Adaptations to Anaerobic Training

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<td>Tolerance for anaerobic By-products</td>
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Chronic Adaptations
- Resistance Training
Resistance training is an anaerobic method of training incorporating:
- body weight
- free weights
- specialised weights machines
- weighted balls / kettles
- resistance bands

The focus can be:
- size
- strength
- power
- endurance
Muscular Adaptations as a result of Resistance Training

- **MUSCLE HYPERTROPHY**

  - Resistance training can bring about increased muscle size.

  - This increase in cross-sectional area is due to:
    - Increased number of myofibrils.
    - Increased size of myofibrils.
    - Increased contractile proteins (actin & myosin)
    - Increased size & strength of connective tissue.
Muscular Adaptations as a Result of Resistance Training

**MUSCLE FIBRES**

- The greatest improvements in muscle size take place in FAST TWITCH B muscle fibres.
- When the fibres get bigger, they can store more fuels (ATP, PC, Glycogen) and hence anaerobic energy production is improved.

**SUBSTRATE STORES**

- Resistance training results in increases in the muscular stores of:
  - ATP
  - Phosphocreatine
  - Free Creatine
  - Glycogen
- Therefore the ability of athletes to generate rapid energy for high intensity / short duration activities is improved.
Neural Adaptations as a Result of Resistance Training

- Along with the adaptations of the skeletal muscles, neural adaptations contribute to the improvements in strength and power.

- These include:
  - increased recruitment of motor units.
  - increased rate of motor unit activation.
  - increased force of contraction.
  - increased rate of force development (power)
  - increased recruitment of fast twitch fibres.
Multiple Choice Questions

1. Which graph shows the influence endurance training has on the size of the ventricular cavity?
   - A
   - B

2. The maximal cardiac output of a trained athlete would be:-
   - a. 5 - 10 litres/ min
   - b. 10 - 15 litres/ min
   - c. 15 - 20 litres/ min
   - d. 25 - 30 litres/ min
3. Which of the following is **not** an adaptation of the heart to aerobic training:
   a. lower resting HR
   b. lower stroke volume
   c. lower recovery HR
   d. lower steady state

4. Which of the following is **not** an adaptation of the heart to aerobic training:
   a. slightly lower or unchanged cardiac output at rest.
   b. slightly lower or unchanged cardiac output at sub max exercise.
   c. slightly lower or unchanged cardiac output at max exercise.

5. Which of the following is an adaptation of the cardiovascular system to aerobic training:
   a. blood pressure at rest is lowered.
   b. blood pressure at sub maximal levels is lowered.
   c. blood pressure at maximal levels is unchanged.
   d. all of the above.

6. Blood lactate concentrations in trained aerobic athletes are lower due to:
   a. decreased production & decreased removal of lactate.
   b. decreased production & increased removal of lactate.
   c. increased production & increased removal of lactate.
   d. increased production & decreased removal of lactate.
7. Aerobic training brings about the following changes to the respiratory system:
   a. increased lung volumes.
   b. increased lung surface area.
   c. increased opportunity for diffusion.
   d. all of the above

8. An adaptation of the mitochondria of the muscular system as a result of aerobic training is:
   a. increased number/ increased size/ increased surface area
   b. increased number/ no change to size/ no change to surface area
   c. no change to number/ increased size/ increased surface area

9. Anaerobic training brings about the following adaptations to the cardiovascular system:
   a. increased thickness of left ventricular wall.
   b. slight decrease in stroke volume.
   c. increased force of left ventricle contraction.
   d. increase in blood pressure at rest.
   e. A & C above
   f. B & D above
10. An adaptation of the muscular system to resistance training is increased muscle cross sectional area. This is due to:

a. Increased number of myofibrils.
b. Increased size of myofibrils.
c. Increased contractile proteins
d. Increased size & strength of connective tissue.
e. all of the above
f. none of the above
11. Subject A has a V0₂ max of 52ml/kg/min and subject B recorded a V0₂ max of 44 ml/kg/min.

a. The heart rates were recorded during a 5km run which subject A and B completed together. Which line would you expect to indicate the heart rate response of subject A?

Answer: the blue line

b. Which subject has the higher resting heart rate? Explain why this subject's resting heart rate is higher than the other subject's heart rate at rest.

Answer: Subject B - Subject B has a lower stroke volume and less efficient cardiorespiratory system than Subject A. Subject B's heart has to beat more rapidly to provide sufficient O₂.
Revision Questions

12. a. What occurs to blood volume and haemoglobin levels following endurance training?

(i) blood volume
Answer: blood volume increases

(ii) haemoglobin levels
Answer: haemoglobin levels increase

b. Discuss the advantages of these changes to the endurance athlete.
Answer: Increases in both blood volume and haemoglobin levels enables a greater amount of O₂ to diffuse into the blood and increases the supply of O₂ to working muscles.

13. Use the following terms to fill in the table: decrease, no change, increase

<table>
<thead>
<tr>
<th>Muscular Factor</th>
<th>Change Induced by AEROBIC Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycogen Sparing at sub max</td>
<td>INCREASE</td>
</tr>
<tr>
<td>Glycogen Stores</td>
<td>INCREASE</td>
</tr>
<tr>
<td>Glycogen Oxidation at sub max</td>
<td>DECREASE</td>
</tr>
<tr>
<td>Glycogen Oxidation at max</td>
<td>INCREASE</td>
</tr>
</tbody>
</table>
14. The graph below shows the pre and post test results for the vertical jump.

PART A: Name two training methods that would result in the improvement identified in the graph.

Answer: Resistance training program focused on developing muscular power and strength. Plyometrics has also been included in the training schedule.

PART B: Identify two training adaptations at the muscular level which could account for the improvement in scores.

Answer:
- muscle hypertrophy
- increased ability to recruit motor units
- increased substrate stores
- increased contractile proteins in muscles
- Increased rate of force development