Cardio-Respiratory System

Pulmonary Systemic

External Respiration

Internal Respiration

Blood Vessels

Arteries ➔ Arterioles ➔ Capillaries ➔ Venules ➔ Veins

- Colour coding for the systemic system only

Skeletal Muscle Pump
Cardiac Output = Heart Rate x Stroke Volume

- **Cardiac Output (Q)** = the amount of blood pumped in one minute by either the right or left ventricle of the heart.
- **Stroke Volume (SV)** = the amount of blood pumped by the left or right ventricle of the heart per beat.
- **Heart Rate (HR)** = the number of heart beats per minute.

<table>
<thead>
<tr>
<th></th>
<th>Q (L/min)</th>
<th>HR (bpm)</th>
<th>SV (ml)</th>
<th>Calculated Q (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>5.6</td>
<td>70</td>
<td>80</td>
<td>70 x 80 = 5600</td>
</tr>
<tr>
<td>Heavy Exercise</td>
<td>23</td>
<td>200</td>
<td>115</td>
<td>200 x 115 = 2300</td>
</tr>
</tbody>
</table>

L/min = litres of blood per minute
bpm = beats per minute
ml/b = millilitres of blood per beat

**Respiratory System**

**Lungs**
- 4-6 litres - very large moist surface
- alveoli - more than 300 million
- thin walled, elastic hollow sacs
- vital surface for gas exchange
- millions of short, thin walled capillaries beside alveoli
- respiration maintains a fairly constant favorable pressure gradient for exchange of O₂ and CO₂ between the capillaries and alveoli
Ventilation (breathing)
- Air molecules move from an area of higher pressure to an area of lower pressure
- **Inspiration** - diaphragm and external intercostals contract
  - increase volume in thoracic cavity
  - reduce pressure in lungs
  - air flows in

Expiration
- predominantly passive
- relaxation of inspiratory muscles
- decrease volume of cavity
- air pressure higher in lungs
- air moves out
- heavy exercise - abdominal muscles and internal intercostals aid in expiration

**Minute Ventilation = Tidal Volume x Respiratory Frequency**
- Minute ventilation ($V_e$) = the volume of air inspired or expired in one minute.
- Tidal volume ($V_T$) = volume of air ventilated per breath.
- Respiratory frequency ($F_R$) = number of breaths per minute.
Ventilation During Exercise

\[ V_E = V_T \times F_R \]

<table>
<thead>
<tr>
<th>Condition</th>
<th>( V_E ) (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>6-8 = 0.5 x 12-16</td>
</tr>
<tr>
<td>Heavy Exercise</td>
<td>125-180 = 2.5-3.0 x 50-60</td>
</tr>
</tbody>
</table>

Values for average size young male

Composition of Blood

Plasma (55% of whole blood) 0.3 mL O

Leukocytes and platelets (45% of whole blood)

Erythrocytes (Hematocrit: 45% of whole blood) 19.7 mL O (15 g Hb)

Gas Exchange

Internal Respiration

\[ \text{CO}_2 \downarrow \text{O}_2 \uparrow \]
Gas Transport

Haemoglobin + oxygen ⇔ oxyhaemoglobin

\[ \text{Hb} + \text{O}_2 \Leftrightarrow \text{HbO}_2 \]

- Normal values for haemoglobin:
  - **Men** - 15.5 grams/100 ml blood
  - **Women** - 13.5 grams/100 ml blood

Blood Pressure

- Pressure exerted on the walls of the arteries by blood
- **Systolic Blood Pressure** - pressure on walls when the left ventricle contracts and pushes bolus of blood through arteries
  - Normal range 100-140 mmHg
- **Diastolic Blood Pressure** - pressure between contractions
  - Normal range - 60 - 90 mmHg
- **Hypertension** - high blood pressure
  - Heart works harder
  - Greater risk of arterial damage

BP During Exercise

- **During rhythmic dynamic exercise**
  - Running, cycling
  - Systolic BP increases as exercise intensity increases (170-200 mmHg)
  - Diastolic BP remains constant or increases slightly (can even decrease slightly)
- **During static exercise (weight lifting)**
  - Significant increase in resistance to blood flow
  - Large rise in both systolic and diastolic BP (more significant with arms overhead for similar effort)

Oxygen Uptake (\(\text{VO}_2\) max)

**Fick Equation**

\[ \dot{\text{VO}}_2 = Q \times (a - \overline{v})\text{O}_2\text{diff} \]

\[ \dot{\text{VO}}_2 = \text{SV} \times \text{HR} \times (a - \overline{v})\text{O}_2\text{diff} \]

- Arterial minus mixed venous oxygen difference ((a-v)\(\text{O}_2\) difference) is a measure of how much oxygen is extracted from the blood by the systemic system
Cross-sectional comparison of variables that contribute to aerobic capacity in untrained and trained persons and elite athletes

<table>
<thead>
<tr>
<th></th>
<th>Max VO₂ (L/min)</th>
<th>HR max (beats/min)</th>
<th>SV max (mL/beat)</th>
<th>Δ-VO₂ (mL/L)</th>
<th>Q (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untrained</td>
<td>2.8</td>
<td>156</td>
<td>104</td>
<td>137</td>
<td>20.4</td>
</tr>
<tr>
<td>Trained</td>
<td>3.5</td>
<td>195</td>
<td>124</td>
<td>143</td>
<td>24.2</td>
</tr>
<tr>
<td>Elite Athlete</td>
<td>5.6</td>
<td>193</td>
<td>167</td>
<td>156</td>
<td>36.1</td>
</tr>
</tbody>
</table>

Acute Exercise

- HR usually increases linearly with increasing workload to Max HR
- Cardiac output required for a given workload is similar for trained and untrained subjects
  - since training increases stroke volume, trained athletes can perform a given workload at a lower heart rate
- Max SV at ≈ 40 % VO₂ maximum
- changes during acute exercise accomplished by:
  - increased filling of ventricles
  - increased strength of contraction
  - hormonal response
  - ejection fraction

Stroke Volume vs Oxygen Uptake
Interval Training above VO$_2$ max
- During interval training stroke volume reaches higher levels more often because of the numerous relief intervals. Stroke volume is highest during the recovery period from exercise (Cummings 1972).
- Stroke Volume (ml/beat)
  - Rest 78
  - Exercise 93
  - Recovery 107.5
- http://www.exrx.net/Aerobic/IntervalTraining.html

Blood Flow and Exercise
- Rest - approximately 15-20% of systemic blood flow to skeletal muscles
- Max exercise ≈ 85% of total blood flow to working skeletal muscles
- results from
  - increased blood pressure
  - dilation of arterioles in working muscles
  - constriction of arterioles to non-working muscles and viscera (liver, stomach, intestines...)
  - maintain blood flow to brain and heart
  - skin blood flow for heat dissipation

**Maximal Oxygen Uptake**
- the ability of the heart to pump blood (Q)
- the oxygen carrying capacity of the blood (haemoglobin content)
- the ability of the working muscles to accept a large blood supply (amount of capillarization within a muscle)
- the ability of the muscle cells (fibres) to extract oxygen from the capillary blood and use it to produce energy (number of mitochondria and aerobic enzymes).
Maximal Oxygen Uptake vs. Workrate

A graph for a less trained individual would show a peak at a lower workrate. Can you draw this curve?

Typical Canadian Values for VO₂ max (ml/kg.min)

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-athletes</td>
<td></td>
<td>40-49</td>
<td>38-46</td>
</tr>
<tr>
<td>20-29</td>
<td></td>
<td>43-52</td>
<td>33-42</td>
</tr>
<tr>
<td>60-69</td>
<td></td>
<td>31-38</td>
<td>22-30</td>
</tr>
<tr>
<td>Baseball</td>
<td>18-32</td>
<td>48-56</td>
<td></td>
</tr>
<tr>
<td>Cycling</td>
<td>18-26</td>
<td>62-74</td>
<td></td>
</tr>
<tr>
<td>Football</td>
<td>20-36</td>
<td>42-60</td>
<td></td>
</tr>
<tr>
<td>Gymnastics</td>
<td>18-22</td>
<td>52-58</td>
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</tr>
<tr>
<td>Ice Hockey</td>
<td>10-30</td>
<td>50-63</td>
<td></td>
</tr>
<tr>
<td>Rowing</td>
<td>20-35</td>
<td>60-72</td>
<td></td>
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Values in Cardiorespiratory lecture notes

Average VO₂ max (ml/kg.min) for Non-Athletes and Athletes

<table>
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<th>Group or Sport</th>
<th>Age</th>
<th>Male</th>
<th>Female</th>
</tr>
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<tbody>
<tr>
<td>Non-athletes</td>
<td></td>
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Average VO₂ max (ml/kg.min) for Non-Athletes and Athletes

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<tr>
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<th>Age</th>
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<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-athletes</td>
<td></td>
<td>57-68</td>
<td>50-55</td>
</tr>
<tr>
<td>20-28</td>
<td></td>
<td>65-95</td>
<td>60-75</td>
</tr>
<tr>
<td>22-28</td>
<td></td>
<td>54-64</td>
<td></td>
</tr>
<tr>
<td>Skiing – Alpine</td>
<td>18-30</td>
<td>56-73</td>
<td></td>
</tr>
<tr>
<td>20-24</td>
<td></td>
<td>44-55</td>
<td></td>
</tr>
<tr>
<td>Skiing – Cross-country</td>
<td>18-28</td>
<td>56-70</td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td></td>
<td>40-60</td>
<td></td>
</tr>
<tr>
<td>Soccer</td>
<td>22-28</td>
<td>54-64</td>
<td></td>
</tr>
<tr>
<td>Speed Skating</td>
<td>18-24</td>
<td>56-73</td>
<td></td>
</tr>
<tr>
<td>Swimming</td>
<td>10-25</td>
<td>50-70</td>
<td></td>
</tr>
<tr>
<td>Weight Lifting</td>
<td>20-30</td>
<td>38-52</td>
<td></td>
</tr>
<tr>
<td>Wrestling</td>
<td>20-30</td>
<td>52-65</td>
<td></td>
</tr>
</tbody>
</table>

VO₂ and Gender

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max VO₂ (L/min)</td>
<td>2</td>
<td>3.5</td>
<td>-43%</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>50</td>
<td>70</td>
<td>-29%</td>
</tr>
<tr>
<td>Percent Fat</td>
<td>25</td>
<td>15</td>
<td>+67%</td>
</tr>
<tr>
<td>Lean Body Mass [LBM] (kg)</td>
<td>37.5</td>
<td>59.7</td>
<td>-37%</td>
</tr>
<tr>
<td>Max VO₂ (ml/kg/min)</td>
<td>40</td>
<td>50</td>
<td>-20%</td>
</tr>
<tr>
<td>Max VO₂ (ml/kg LBM/min)</td>
<td>53.3</td>
<td>58.8</td>
<td>-9.3%</td>
</tr>
</tbody>
</table>

Lactate Threshold

- "The point during exercise of increasing intensity at which blood lactate begins to accumulate above resting levels, where lactate clearance is no longer able to keep up with lactate production."
- Many of you will have heard of it and realize it is relevant to aerobic endurance performance.
- However, a basic understanding of energy metabolism during exercise is helpful to appreciate some of the current issues surrounding lactate and muscle fatigue so we will discuss this during the “energy systems” lecture.
**Is VO₂ max the Sole Determinant of Endurance Performance**

- **Answer = No**
- **Why?**
  - Mechanical Efficiency
  - Lactate Threshold
  - Motivation
  - State of Training (Fatigue), Daily variation

**Midterm Question?**

- **Describe the systemic cardiorespiratory effects you would observe in an individual who undergoes 4 months of aerobic conditioning.**
  - at rest
  - during sub-maximal exercise
  - during maximal exercise

**Changes at Rest**

- Systemic refers to changes in the delivery of oxygen to the muscles rather than changes at the cellular level in the muscles. E.g., an increase in stroke volume is a systemic change whereas an increase in mitochondrial enzymes concentration is a biochemical or cellular change.
- The weight and volume of the heart generally increase with long-term aerobic training.
- Decrease in heart rate and an increase in stroke volume with no change in cardiac output.
- Increase in blood volume (up to 20%) and total body haemoglobin content. Haemoglobin concentration, however, does not increase.

**Changes During Sub-maximal Exercise**

- Decrease in heart rate and an increase in stroke volume for a given sub-maximal workload.
- Slight decrease in cardiac output for a given sub-maximal workload (better a-vO₂diff and less work for the heart).
- No change or slight decrease in oxygen consumption at a given sub-maximal workload. Any decrease is probably due to an increase in mechanical efficiency.
- Decrease in the amount of air breathed at a particular rate of sub-maximal oxygen consumption.

**Changes During Maximal Exercise**

- No change or more likely a slight decrease in maximal heart rate.
- Increase in maximum stroke volume.
- Increase in maximum cardiac output.
- Increase in maximal difference.
- Hence if the two factors above increase, there must also be an increase in maximum oxygen consumption. Refer to the Fick equation discussed above if you are not sure about this statement.
- Increase in endurance performance.
- Increase in maximum minute ventilation.

**Multiple Choice**

- One result of developing cardiovascular fitness is to
  - a) decrease stroke volume
  - b) decrease resting heart rate
  - c) decrease blood volume
  - d) decrease maximum breathing capacity
  - e) increase haemoglobin concentration