chapter

6

Adaptations to Aerobic Endurance Training Programs
Chapter Objectives

• Identify and describe acute responses of the cardiovascular and respiratory systems to aerobic exercise.

• Identify and describe the impact of chronic aerobic endurance training on the physiological characteristics of the cardiovascular, respiratory, nervous, muscular, bone and connective tissue, and endocrine systems.

(continued)
Chapter Objectives (continued)

• Recognize the interaction between designing aerobic endurance training programs and optimizing physiological responses of all body systems.

• Identify and describe external factors that influence adaptations to acute and chronic aerobic exercise.

• Recognize the causes, signs, symptoms, and effects of overtraining and detraining.
Acute Responses to Aerobic Exercise

• Cardiovascular Responses
  – Cardiac Output (Q): The amount of blood pumped by the heart in liters per minute, which is a function of stroke volume, SV (quantity of blood ejected with each beat) and HR: \( Q = SV \times HR \).
  • From rest to steady-state aerobic exercise, cardiac output initially increases rapidly, then more gradually, and subsequently reaches a plateau.
  • With maximal exercise, cardiac output may increase greater than 5 times the resting level.
Acute Responses to Aerobic Exercise

• **Cardiovascular Responses**
  – Stroke Volume
    • End-diastolic volume is significantly increased.
    • At onset of exercise, sympathetic stimulation ↑SV.
  – Heart Rate
    • HR increases linearly with increases in intensity.
  – Oxygen Uptake
    • Oxygen uptake increases during an acute bout of aerobic exercise and is directly related to the mass of exercising muscle, metabolic efficiency, and exercise intensity.
Key Terms

• **Maximal oxygen uptake - VO₂ Max (CO x a-v O₂ diff)**: The greatest amount of oxygen that can be used at the cellular level for the entire body.
  
  - VO₂ Max is the single best predictor of cardiorespiratory fitness

• **Resting oxygen uptake**: Estimated at 3.5 ml of oxygen per kilogram body weight per minute (ie, 3.5 ml · kg⁻¹ · min⁻¹), or in terms of kilocalories (kcal), 1 kcal per kilogram body weight per hour (ie, 1 kcal· kg⁻¹ · hr⁻¹); this value is defined as 1 metabolic equivalent (MET).
Acute Responses to Aerobic Exercise

• Cardiovascular Responses
  – Blood Pressure
    • Systolic blood pressure estimates the pressure exerted against the arterial walls as blood is forcefully ejected during ventricular contraction.
    • Diastolic blood pressure is used to estimate the pressure exerted against the arterial walls when no blood is being forcefully ejected through the vessels.
Blood Pressures in the Circulatory System

Acute Responses to Aerobic Exercise

• **Cardiovascular Responses**
  – Control of Local Circulation
    • During aerobic exercise, blood flow to active muscles is considerably increased by the dilation of local arterioles.
    • At the same time, blood flow to other organ systems (eg, the GI region) is reduced by constriction of the arterioles.
• **Acute aerobic exercise results in**
  – Increased cardiac output
  – Increased stroke volume
  – Increased heart rate
  – Increased oxygen uptake
  – Increased systolic blood pressure
  – Increased blood flow to active muscles
  – Decreased diastolic blood pressure
Cardiovascular Adaptations to Chronic Endurance Exercise

Note: HR contributes to \( \dot{Q} \) but an adaptation in HR does not occur at maximal exercise in response to chronic endurance training.
Response of Hemodynamics and Metabolic Variables During Moderately High Intensity Submaximal Upright Exercise
Acute Responses to Aerobic Exercise

• **Respiratory Responses**
  - Aerobic exercise provides for the greatest impact on both oxygen uptake and carbon dioxide production, as compared to other types of exercise.
  - Significant increases in oxygen delivered to the tissue, carbon dioxide returned to the lungs, and minute ventilation provide for appropriate levels of alveolar gas concentrations during aerobic exercise.
The tidal volume comprises about 350 ml of room air that mixes with alveolar air, about 150 ml of air in the larger passages (anatomical dead space), and a small portion of air distributed to either poorly ventilated or incompletely filled alveoli (physiological dead space).
Key Point

• During aerobic exercise, large amounts of oxygen diffuse from the capillaries into the tissues, increased levels of carbon dioxide move from the blood into the alveoli, and minute ventilation increases to maintain appropriate alveolar concentrations of these gases.
Pressure Gradients for Gas Transfer at Rest

Inspired air

\[
\begin{align*}
\text{PO}_2 & = 159 \text{ mmHg} \\
\text{PCO}_2 & = 0.3 \text{ mmHg}
\end{align*}
\]

\[
\begin{align*}
\text{PO}_2 & = 149 \text{ mmHg} \\
\text{PCO}_2 & = 0.3 \text{ mmHg}
\end{align*}
\]

Trachea

\[
\begin{align*}
\text{PO}_2 & = 100 \text{ mmHg} \\
\text{PCO}_2 & = 40 \text{ mmHg}
\end{align*}
\]

Alveolus

\[
\begin{align*}
\text{PO}_2 & = 40 \text{ mmHg} \\
\text{PCO}_2 & = 46 \text{ mmHg}
\end{align*}
\]

Venous blood (now in pulmonary artery)

\[
\begin{align*}
\text{PO}_2 & = 40 \text{ mmHg} \\
\text{PCO}_2 & = 46 \text{ mmHg}
\end{align*}
\]

Muscle capillary

\[
\begin{align*}
\text{PO}_2 & = 40 \text{ mmHg} \\
\text{PCO}_2 & = 46 \text{ mmHg}
\end{align*}
\]

Venous blood

Arterial blood

\[
\begin{align*}
\text{PO}_2 & = 40 \text{ mmHg} \\
\text{PCO}_2 & = 46 \text{ mmHg}
\end{align*}
\]

Pulmonary capillary

\[
\begin{align*}
\text{PO}_2 & = 100 \text{ mmHg} \\
\text{PCO}_2 & = 40 \text{ mmHg}
\end{align*}
\]

\[
\begin{align*}
\text{PO}_2 & = 100 \text{ mmHg} \\
\text{PCO}_2 & = 40 \text{ mmHg}
\end{align*}
\]

© 2008 Human Kinetics

Reprinted, by permission, from Fox, Bowers, and Foss, 1993.
Acute Responses to Aerobic Exercise

• Respiratory Responses
  – Blood Transport of Gases and Metabolic By-Products
    • Most oxygen in blood is carried by hemoglobin.
    • Most carbon dioxide removal is from its combination with water and delivery to the lungs in the form of bicarbonate.
    • During low- to moderate-intensity exercise, enough oxygen is available that lactic acid (converted to blood lactate) does not accumulate because the removal rate is greater than or equal to the production rate.
    • At higher intensities of aerobic exercise lactate may begin to accumulate in the blood, and this is referred to as the onset of blood lactate accumulation, or OBLA.
### Table 6.1 Physiological Adaptations to Aerobic Training

<table>
<thead>
<tr>
<th>Variable</th>
<th>Aerobic endurance training adaptations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Muscular strength</td>
<td>No change</td>
</tr>
<tr>
<td>Muscular endurance</td>
<td>Increases for low power output</td>
</tr>
<tr>
<td>Aerobic power</td>
<td>Increases</td>
</tr>
<tr>
<td>Maximal rate of force production</td>
<td>No change or decreases</td>
</tr>
<tr>
<td>Vertical jump</td>
<td>Ability unchanged</td>
</tr>
<tr>
<td>Anaerobic power</td>
<td>No change</td>
</tr>
<tr>
<td>Sprint speed</td>
<td>No change</td>
</tr>
<tr>
<td><strong>Muscle fibers</strong></td>
<td></td>
</tr>
<tr>
<td>Fiber size</td>
<td>No change or increases slightly</td>
</tr>
<tr>
<td>Capillary density</td>
<td>Increases</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>Increases</td>
</tr>
<tr>
<td>Myofibrillar:</td>
<td></td>
</tr>
<tr>
<td>Packing density</td>
<td>No change</td>
</tr>
<tr>
<td>Volume</td>
<td>No change</td>
</tr>
<tr>
<td>Cytoplasmic density</td>
<td>No change</td>
</tr>
<tr>
<td>Myosin heavy-chain protein</td>
<td>No change or decreases in amount</td>
</tr>
<tr>
<td><strong>Enzyme activity</strong></td>
<td></td>
</tr>
<tr>
<td>Creatine phosphokinase</td>
<td>Increases</td>
</tr>
<tr>
<td>Myokinase</td>
<td>Increases</td>
</tr>
<tr>
<td>Phosphofructokinase</td>
<td>Variable</td>
</tr>
<tr>
<td>Lactate dehydrogenase</td>
<td>Variable</td>
</tr>
<tr>
<td>Sodium-potassium ATPase</td>
<td>May slightly increase</td>
</tr>
<tr>
<td><strong>Metabolic energy stores</strong></td>
<td></td>
</tr>
<tr>
<td>Stored ATP</td>
<td>Increases</td>
</tr>
<tr>
<td>Stored creatine phosphate</td>
<td>Increases</td>
</tr>
<tr>
<td>Stored glycogen</td>
<td>Increases</td>
</tr>
<tr>
<td>Stored triglycerides</td>
<td>Increase</td>
</tr>
<tr>
<td><strong>Connective tissue</strong></td>
<td></td>
</tr>
<tr>
<td>Ligament strength</td>
<td>Increases</td>
</tr>
<tr>
<td>Tendon strength</td>
<td>Increases</td>
</tr>
<tr>
<td>Collagen content</td>
<td>Variable</td>
</tr>
<tr>
<td>Bone density</td>
<td>No change or increases</td>
</tr>
<tr>
<td><strong>Body composition</strong></td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td>Decreases</td>
</tr>
<tr>
<td>Fat-free mass</td>
<td>No change</td>
</tr>
</tbody>
</table>

ATP = adenosine triphosphate; ATPase = adenosine triphosphatase.
Chronic Adaptations to Aerobic Exercise

• **Cardiovascular Adaptations**
  – Aerobic endurance training requires proper progression, variation, specificity, and overload if physiological adaptations are to take place.
  – 20-30% ↑ in VO$_2$ max during 6-12 months high intensity training (>70% VO$_2$ max)
  – 10-20% ↑ in VO$_2$ max during 6-12 months low to moderate intensity training (40-60% VO$_2$ max)

• **Respiratory Adaptations**
  – Ventilatory adaptations are highly specific to activities that involve the type of exercise used in training.
  – Training adaptations include increased tidal volume and breathing frequency with maximal exercise.
Chronic Adaptations to Aerobic Exercise

• **Neural Adaptations**
  – Efficiency is increased and fatigue of the contractile mechanisms is delayed.

• **Muscular Adaptations**
  – One of the fundamental adaptive responses to aerobic endurance training is an increase in the aerobic capacity of the trained musculature.
  – This adaptation allows the athlete to perform a given absolute intensity of exercise with greater ease after aerobic endurance training.
Chronic Adaptations to Aerobic Exercise

• Bone and Connective Tissue Adaptations
  – In mature adults, the extent to which tendons, ligaments, and cartilage grow and become stronger is proportional to the intensity of the exercise stimulus, especially from weight-bearing activities.

• Endocrine Adaptations
  – Aerobic exercise leads to increases in hormonal circulation and changes at the receptor level.
  – High-intensity aerobic endurance training augments the absolute secretion rates of many hormones in response to maximal exercise.
Key Points

• One of the most commonly measured adaptations to aerobic endurance training is an increase in maximal oxygen uptake associated with an increase in maximal cardiac output.

• The intensity of training is one of the most important factors in improving and maintaining aerobic power.

• Aerobic endurance training results in reduced body fat, increased maximal oxygen uptake, increased respiratory capacity, lower blood lactate concentrations, increased mitochondrial and capillary densities, and improved aerobic enzyme activity.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Before training</th>
<th>3-6 months After training</th>
<th>Elite aerobic endurance athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (beats/min)</td>
<td>74</td>
<td>61</td>
<td>45</td>
</tr>
<tr>
<td>Maximal</td>
<td>194</td>
<td>190</td>
<td>185</td>
</tr>
<tr>
<td>Stroke volume:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (ml)</td>
<td>64</td>
<td>82</td>
<td>127</td>
</tr>
<tr>
<td>Maximal</td>
<td>122</td>
<td>142</td>
<td>201</td>
</tr>
<tr>
<td>Cardiac output:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (L/min)</td>
<td>4.5</td>
<td>4.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Maximal</td>
<td>22.3</td>
<td>25.8</td>
<td>34.9</td>
</tr>
<tr>
<td>Heart volume (ml)</td>
<td>750</td>
<td>823</td>
<td>1,250</td>
</tr>
<tr>
<td>Blood volume (L)</td>
<td>4.8</td>
<td>5.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Blood pressure:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (mmHg)</td>
<td>120/80</td>
<td>124/78</td>
<td>105/65</td>
</tr>
<tr>
<td>Maximal</td>
<td>206/85</td>
<td>202/82</td>
<td>209/69</td>
</tr>
</tbody>
</table>
## Table 6.2

Physiological Variables in Aerobic Endurance Training

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before training</th>
<th>3-6 months After training</th>
<th>Elite aerobic endurance athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PREVIOUSLY UNTRAINED SUBJECTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pulmonary ventilation, BTPS:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (L/min)</td>
<td>7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Maximal</td>
<td>123</td>
<td>142</td>
<td>201</td>
</tr>
<tr>
<td><strong>Breathing rate:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (breaths/min)</td>
<td>14</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Maximal</td>
<td>42</td>
<td>47</td>
<td>59</td>
</tr>
<tr>
<td><strong>Tidal volume (TV):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (L)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Maximal</td>
<td>2.8</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Residual volume (RV) (L)</td>
<td>1.0</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Arteriovenous oxygen difference:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting (ml/100 ml)</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Maximal</td>
<td>14.5</td>
<td>15.2</td>
<td>16.4</td>
</tr>
<tr>
<td>Maximal oxygen uptake (ml · kg⁻¹ · min⁻¹)</td>
<td>47</td>
<td>55</td>
<td>79</td>
</tr>
</tbody>
</table>

(continued)
### TABLE 6.2

**Physiological Variables in Aerobic Endurance Training**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before training</th>
<th>3-6 months After training</th>
<th>Elite aerobic endurance athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>75</td>
<td>72</td>
<td>62</td>
</tr>
<tr>
<td>% Body fat</td>
<td>16.0</td>
<td>14.9</td>
<td>6.7</td>
</tr>
<tr>
<td>% Type I fibers</td>
<td>55</td>
<td>55</td>
<td>81</td>
</tr>
<tr>
<td>Fiber area:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I (μm²)</td>
<td>4,730</td>
<td>4,820</td>
<td>4,180</td>
</tr>
<tr>
<td>Type IIA</td>
<td>6,860</td>
<td>7,150</td>
<td>4,299</td>
</tr>
<tr>
<td>Type IIX</td>
<td>6,167</td>
<td>6,433</td>
<td>3,899</td>
</tr>
<tr>
<td>Capillary density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number/mm²</td>
<td>290</td>
<td>350</td>
<td>460</td>
</tr>
<tr>
<td>Number/fiber</td>
<td>1.2</td>
<td>1.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Citrate synthetase (activity units)</td>
<td>28</td>
<td>37</td>
<td>78</td>
</tr>
<tr>
<td>Hexokinase (activity units)</td>
<td>2.4</td>
<td>2.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Lactate dehydrogenase (activity units)</td>
<td>580</td>
<td>654</td>
<td>629</td>
</tr>
<tr>
<td>Maximal fiber shortening velocity:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I (fiber lengths/s)</td>
<td>0.86</td>
<td>1.42</td>
<td>1.02</td>
</tr>
<tr>
<td>Type II</td>
<td>4.85</td>
<td>5.25</td>
<td>5.77</td>
</tr>
</tbody>
</table>

*These subjects completed a short-term (3- to 6-month) aerobic endurance training program. BTPS = body temperature and pressure, saturated.*
External Influences on the Cardiorespiratory Response

• Altitude
  – Changes begin to occur at elevations greater than 3,900 feet (1,200 m):
    • Increased pulmonary ventilation
    • Increased cardiac output at rest and during submaximal exercise due to increases in heart rate
  – Values begin to return toward normal within two weeks.
  – Several chronic physiological and metabolic adjustments occur during prolonged altitude exposure.
<table>
<thead>
<tr>
<th>System</th>
<th>Immediate adjustments</th>
<th>Longer-term adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary</td>
<td>Hyperventilation</td>
<td>Increase in ventilation rate stabilizers</td>
</tr>
<tr>
<td>Acid-base</td>
<td>Body fluids become more alkaline due to reduction in CO₂ with hyperventilation.</td>
<td>Excretion of HCO₃⁻ by the kidneys with concomitant reduction in alkaline reserve</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Cardiac output increases at rest and during submaximal exercise.</td>
<td>Continued elevation in submaximal heart rate</td>
</tr>
<tr>
<td></td>
<td>Submaximal heart rate increases.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stroke volume remains the same or is slightly lowered.</td>
<td>Decreased stroke volume at rest and with submaximal and maximal exercise</td>
</tr>
<tr>
<td></td>
<td>Maximal heart rate remains the same or is slightly lowered.</td>
<td>Lowered maximal heart rate</td>
</tr>
<tr>
<td></td>
<td>Maximal cardiac output remains the same or is slightly lowered.</td>
<td>Lowered maximal cardiac output</td>
</tr>
<tr>
<td>Hematologic</td>
<td></td>
<td>Increased red cell production (polycythemia)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased viscosity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased hematocrit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased plasma volume</td>
</tr>
<tr>
<td>Local tissue</td>
<td></td>
<td>Increased capillary density of skeletal muscle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased number of mitochondria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased use of free fatty acids, sparing muscle glycolen</td>
</tr>
</tbody>
</table>
Environmental Conditions at Altitude

- **Sea level (<500 m): no effects**
- **Low altitude (500-2,000 m)**
  - No effects on well-being
  - Performance may be ↓, restored by acclimation
- **Moderate altitude (2,000-3,000 m)**
  - Effects on well-being in unacclimated people
  - Performance and aerobic capacity ↓
  - Performance may or may not be restored by acclimation
Environmental Conditions at Altitude

• **High altitude (3,000-5,500 m)**
  – Acute mountain sickness
  – Performance ↓, not restored by acclimation

• **Extreme high altitude (>5,500 m)**
  – Severe hypoxic effects
  – Highest settlements: 5,200 to 5,800 m

• **For our purposes, altitude = >1,200 m**
  – Few (if any) physiological effects <1,200 m
Environmental Conditions at Altitude

- $P_b$ at sea level exerted by a 24 mi tall air column
  - Sea level $P_b$: 760 mmHg
  - Mt. Everest $P_b$: 250 mmHg

- $P_b$ varies, air composition does not
  - 20.93% $O_2$, 0.03% $CO_2$, 79.04% $N_2$
  - $PO_2$ always = 20.93% of $P_b$
  - 159 mmHg at sea level, 52 mmHg on Mt. Everest
  - Air $PO_2$ affects $PO_2$ in lungs, blood, tissues
Figure 13.1

<table>
<thead>
<tr>
<th>Altitude (ft) (m)</th>
<th>0 (sea level)</th>
<th>5,202</th>
<th>7,251</th>
<th>14,108</th>
<th>29,028</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1,610</td>
<td>2,210</td>
<td>4,300</td>
<td>8,048</td>
</tr>
<tr>
<td>Barometric pressure $P_b$ (mmHg)</td>
<td>760</td>
<td>631</td>
<td>585</td>
<td>430</td>
<td>253</td>
</tr>
<tr>
<td>% $O_2$ in the air</td>
<td>20.93</td>
<td>20.93</td>
<td>20.93</td>
<td>20.93</td>
<td>20.93</td>
</tr>
<tr>
<td>Partial pressure of oxygen $PO_2$ (mmHg) in the air</td>
<td>159</td>
<td>132</td>
<td>122</td>
<td>90</td>
<td>53</td>
</tr>
<tr>
<td>Typical temperature ($°C$) ($°F$)</td>
<td>15</td>
<td>9</td>
<td>2</td>
<td>–11</td>
<td>–43</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>47</td>
<td>36</td>
<td>12</td>
<td>–46</td>
</tr>
</tbody>
</table>
Figure 13.2

Sea level
\( P_0 = 760 \text{ mmHg} \)

Pulmonary artery blood
\( PO_2 = 159 \text{ mmHg} \)
\( PO_2 = 104 \text{ mmHg} \)

Pulmonary vein blood
\( PO_2 = 40 \text{ mmHg} \)
\( PO_2 = 100 \text{ mmHg} \)

Venous blood
\( PO_2 = 40 \text{ mmHg} \)
\( PO_2 = 100 \text{ mmHg} \)

Arterial blood
\( PO_2 = 27 \text{ mmHg} \)

4,300 m
\( P_0 = 460 \text{ mmHg} \)

\( PO_2 = 96 \text{ mmHg} \)
\( PO_2 = 46 \text{ mmHg} \)

\( PO_2 = 27 \text{ mmHg} \)
\( PO_2 = 42 \text{ mmHg} \)

Diffusion gradient:
\[ 100 - 40 = 60 \text{ mmHg} \]
\[ 42 - 27 = 15 \text{ mmHg} \]
Altitude: Optimizing Training and Performance

- Altitude acclimation confers certain advantageous adaptations for competing

- Training possibilities for competition
  - Train high, compete low?
  - Train high, compete high?
  - Train low, compete high?
  - Live high, train low, compete high?
Altitude: Optimizing Training and Performance

• Hypoxia at altitude prevents high-intensity aerobic training

• Living and training high leads to dehydration, low blood volume, low muscle mass

• Value of altitude training for sea-level performance not validated

• Value of live high, train low?
Altitude: Optimizing Training and Performance

• **Live high, train low: best of both worlds**
  – Permits passive acclimation to altitude
  – Training intensity not compromised by low PO$_2$

• **Outcome tested on 5 k run time trial**
  – Live high, train high: no improvement
  – Live low, train low: no improvement
  – Live high, train low: significant improvement
Altitude: Optimizing Training and Performance

• Live high, train low more recently validated
  – Lived at 2,500 m, trained at 1,250 m
  – Pre- and posttesting at sea level
  – Aerobic performance improved 1.1%
  – VO$_{2\text{max}}$ improved 3.2%
External Influences on the Cardiorespiratory Response

• **Hyperoxic Breathing**
  – Breathing oxygen-enriched gas mixtures during rest or following exercise may positively affect performance, although the procedure remains controversial.

• **Smoking**
  – Acute effects of tobacco smoking could impair performance.

• **Blood Doping**
  – Artificially increasing red blood cell mass is unethical and poses serious health risks, yet it can improve aerobic exercise performance and may enhance tolerance to certain environmental conditions.
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• Genetic Potential
  – The upper limit of an individual’s genetic potential dictates the absolute magnitude of the training adaptation.

• Age and Sex
  – \( \text{VO}_2\max \downarrow \) with age in adults (~1% \( \downarrow \) in \( \text{VO}_2\max \) each year after age 25).
  – Aerobic power (\( \text{VO}_2\max \)) values of women range from 73% to 85% that of men (8-12 ml·kg\(^{-1}\)·min\(^{-1}\) less in women due to smaller heart volume, less blood volume, 4-5 L compared to 5-6 L in men, and less hemoglobin to carry O\(_2\), 12-16 g/dL compared to 14-18 g/dL in men).
  – The general physiological response to training is similar in men and women.
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• Overtraining
  – Cardiovascular Responses
    • Greater volumes of training affect heart rate.
  – Biochemical Responses
    • High training volume results in increased levels of creatine kinase, indicating muscle damage.
    • Muscle glycogen decreases with prolonged periods of overtraining.
  – Endocrine Responses
    • May result in a decreased testosterone-to-cortisol ratio, decreased secretion of GH, and changes in catecholamine levels.
Key Point

• Overtraining can lead to dramatic performance decreases in athletes of all training levels and is caused by mistakes in the design of the training program; the most common cause is intensified training without adequate recovery.
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• What Are the Markers of Aerobic Overtraining?
  – ↓ performance
  – ↓ percentage of body fat
  – ↓ maximal oxygen uptake
  – Altered blood pressure
  – ↑ muscle soreness
  – ↓ muscle glycogen
  – Altered resting heart rate
  – Change in mood states
  – ↓ performance in psychomotor speed tests
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• What Are the Markers of Aerobic Overtraining?
  – ↑ submaximal exercise heart rate
  – ↓ lactate
  – ↑ creatine kinase
  – Altered cortisol concentration
  – ↓ total testosterone concentration
  – ↓ ratio of total testosterone to cortisol
  – ↓ ratio of free testosterone to cortisol
  – ↓ sympathetic tone (decreased nocturnal and resting catecholamines) and ↑ sympathetic stress response
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• Detraining
  – Cardiorespiratory fitness decreases within 2 weeks of stopping intense endurance training, with a return to pre-training fitness levels 10 – 32 weeks of detraining
  – With complete inactivity aerobic fitness is lost at a greater rate than it was gained
  – Reduced training frequency or duration will not significantly decrease VO₂ max acquired from aerobic training as long as the intensity is maintained, which implies training intensity is more influential in maintaining VO₂ max than is duration & frequency.
Individual Factors Influencing Adaptations to Aerobic Endurance Training

• **Detraining**
  – If inactivity, rather than proper recovery, follows exercise, an athlete loses training adaptations.

• **Tapering**
  – The planned reduction of volume in training that occurs before an athletic competition or a planned recovery microcycle.
Key Point

- Proper exercise variation, intensity, maintenance programs, and active recovery periods can adequately protect against serious detraining effects.