Adaptations to Anaerobic Training Programs
Chapter Objectives

• Discuss ways in which force output of a muscle can be increased.
• Discuss basic neural adaptations to anaerobic training.
• Explain responses of bone, muscle, and connective tissue to anaerobic training.
• Explain acute responses & chronic adaptations of endocrine & cardiovascular systems to anaerobic training.
• Discuss the potential for enhancement of muscle strength, muscular endurance, power, flexibility, and motor performance during anaerobic training.
• Recognize causes, signs, symptoms, and effects of overtraining and detraining.
Key Term

- **anaerobic training**: High-intensity, intermittent bouts of exercise such as weight training; plyometric drills; and speed, agility, and interval training.
<table>
<thead>
<tr>
<th>Sport</th>
<th>Phosphagen system</th>
<th>Anaerobic glycolysis</th>
<th>Aerobic metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball</td>
<td>High</td>
<td>Low</td>
<td>—</td>
</tr>
<tr>
<td>Basketball</td>
<td>High</td>
<td>Moderate to high</td>
<td>—</td>
</tr>
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<td>Boxing</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Diving</td>
<td>High</td>
<td>Low</td>
<td>—</td>
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<td>Fencing</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
</tr>
<tr>
<td>Field events</td>
<td>High</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Field hockey</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Football (American)</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>High</td>
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<td>Golf</td>
<td>High</td>
<td>—</td>
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<td>Ice hockey</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
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<td>Moderate</td>
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<td>Powerlifting</td>
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<td>Low</td>
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<td>Skiing:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-country</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Downhill</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Sport</td>
<td>Phosphagen system</td>
<td>Anaerobic glycolysis</td>
<td>Aerobic metabolism</td>
</tr>
<tr>
<td>------------------------------</td>
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<td>------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Soccer</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
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<tr>
<td>Strength competitions</td>
<td>High</td>
<td>Moderate to high</td>
<td>Low</td>
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<tr>
<td>Swimming:</td>
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<td></td>
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</tr>
<tr>
<td>Short distance</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
</tr>
<tr>
<td>Long distance</td>
<td>—</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Tennis</td>
<td>High</td>
<td>Moderate</td>
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<tr>
<td>Track (athletics):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short distance</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
</tr>
<tr>
<td>Long distance</td>
<td>—</td>
<td>Moderate</td>
<td>High</td>
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<tr>
<td>Ultra-endurance events</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Volleyball</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
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<tr>
<td>Wrestling</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Weightlifting</td>
<td>High</td>
<td>Low</td>
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</tr>
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</table>

Note: All types of metabolism are involved to some extent in all activities.

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<table>
<thead>
<tr>
<th>Variable</th>
<th>Resistance training adaptations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Muscular strength</td>
<td>Increases</td>
</tr>
<tr>
<td>Muscular endurance</td>
<td>Increases for high power output</td>
</tr>
<tr>
<td>Aerobic power</td>
<td>No change or increases slightly</td>
</tr>
<tr>
<td>Maximal rate of force production</td>
<td>Increases</td>
</tr>
<tr>
<td>Vertical jump</td>
<td>Ability increases</td>
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<tr>
<td>Anaerobic power</td>
<td>Increases</td>
</tr>
<tr>
<td>Sprint speed</td>
<td>Improves</td>
</tr>
<tr>
<td><strong>Muscle fibers</strong></td>
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<tr>
<td>Fiber size</td>
<td>Increases</td>
</tr>
<tr>
<td>Capillary density</td>
<td>No change or decreases</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>Decreases</td>
</tr>
<tr>
<td>Myofibrillar packing density</td>
<td>No change</td>
</tr>
<tr>
<td>Myofibrillar volume</td>
<td>Increases</td>
</tr>
<tr>
<td>Cytoplasmic density</td>
<td>Increases</td>
</tr>
<tr>
<td>Myosin heavy-chain protein</td>
<td>Increases in amount</td>
</tr>
<tr>
<td>Variable</td>
<td>Resistance training adaptations</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td><strong>Enzyme activity</strong></td>
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<tr>
<td>Creatine phosphokinase</td>
<td>Increases</td>
</tr>
<tr>
<td>Myokinase</td>
<td>Increases</td>
</tr>
<tr>
<td>Phosphofructokinase</td>
<td>Increases</td>
</tr>
<tr>
<td>Lactate dehydrogenase</td>
<td>No change or variable</td>
</tr>
<tr>
<td>Sodium-potassium ATPase</td>
<td>Increases</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>May increase</td>
</tr>
<tr>
<td><strong>Connective tissue</strong></td>
<td></td>
</tr>
<tr>
<td>Ligament strength</td>
<td>May increase</td>
</tr>
<tr>
<td>Tendon strength</td>
<td>May increase</td>
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<tr>
<td>Collagen content</td>
<td>May increase</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>Increases</td>
</tr>
</tbody>
</table>

ATP = adenosine triphosphate; ATPase = adenosine triphosphatase.
Note: The initial strength gains that occur during the first 1-6 weeks of a new strength training program are primarily due to neural factors, and strengths gains from muscle hypertrophy start occurring later around weeks 7-8 and beyond.
Potential Sites of Adaptation in the Neuromuscular System

- **Central Adaptations**
  - Motor cortex activity increases when the level of force developed increases and when new exercises or movements are being learned.
  - Many neural changes with anaerobic training take place along the descending corticospinal tracts.

- **Adaptations of Motor Units**
  - Maximal strength and power increases of agonist muscles result from an increase in recruitment, rate of firing, synchronization of firing, or a combination of these factors.
Key Point

• With heavy resistance training, all muscle fibers get larger because they are all recruited in consecutive order by their size to produce high levels of force. In advanced lifters, the central nervous system might adapt by allowing these athletes to recruit some motor units not in consecutive order, recruiting larger ones first to help with greater production of power or speed in a movement.
Size Principle

- Motor units that contain Type I (slow-twitch) and Type II (fast-twitch) fibers are organized based on some “size” factor.
- Low-threshold motor units are recruited first and have lower force capabilities than higher-threshold motor units.
- Typically, to get to the high-threshold motor units, the body must first recruit the lower-threshold motor units.
- Exceptions exist, especially with respect to explosive, ballistic contractions that can selectively recruit high-threshold units to rapidly achieve more force and power.
Size Principle

Motor units

Type II

Type I

Recruitment electrical threshold

Low

High

Force production

Low

High

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Neural Adaptations

• Neuromuscular Junction (NMJ)
  – Possible changes with anaerobic training include
    • increased area of NMJ.
    • more dispersed, irregularly shaped synapses and a greater total length of nerve terminal branching.
    • increased end-plate perimeter length and area, as well as greater dispersion of acetylcholine receptors within the end-plate region.

• Neuromuscular Reflex Potentiation
  – Anaerobic training may enhance the reflex response, thereby enhancing the magnitude and rate of force development.
Neural Adaptations

- Anaerobic Training and Electromyography (EMG) Studies
  - An increase in EMG indicates greater neural activation.
  - Studies have shown strength and power increases of up to 73%.
  - Advancement in training contributes to further gains in strength and power.
  - Dramatic increases in neural adaptations take place early in the training program.
  - Additional findings include the following:
    - Cross-education
    - Bilateral deficit in untrained individuals
    - Changes in muscle activity of the antagonists during agonist movements
Muscular Adaptations

• Skeletal muscle adapts to anaerobic training primarily by increasing its size, facilitating fiber type transitions, and enhancing its biochemical and ultrastructural components. These changes result in enhanced muscular strength, power, and muscular endurance.
Muscular Adaptations

• Muscular Growth
  – Muscle hypertrophy refers to muscular enlargement from an increase in the cross-sectional area of the existing fibers.
  – Hyperplasia results in an increase in the number of muscle fibers via longitudinal fiber splitting.
• The process of hypertrophy involves both an increase in the synthesis of the contractile proteins actin and myosin within the myofibril and an increase in the number of myofibrils within a muscle fiber. The new myofilaments are added to the external layers of the myofibril, resulting in an increase in its diameter.
Muscular Adaptations

• Fiber Size Changes
  – Resistance training results in increases in both Type I and Type II muscle fiber area.
  – Type II fibers have greater increases in size than Type I fibers.

• Fiber Type Transitions
  – There is a continuum of fiber types: I, Ic, IIc, IIac, Ila, IIax, IIx.
Muscle Fiber Transitions

- Muscle fiber transitions occur during training.
- This means that a shift of the type of myosin adenosine triphosphatase (ATPase) and heavy chains takes place during training.
- Transformations from IIx to IIax to IIa can be seen, and then small percentages change to IIac and IIc.
- Exercise activities that recruit motor units with Type IIx muscle fibers initiate a shift toward IIa fibers.
Muscular Adaptations

• **Structural and Architectural Changes**
  – Resistance training increases myofibrillar volume, cytoplasmic density, sarcoplasmic reticulum and T-tubule density, and sodium-potassium ATPase activity.
  – Sprint training enhances calcium release.
  – Resistance training increases angle of pennation.

• **Other Muscular Adaptations**
  – Reduced mitochondrial density
  – Decreased capillary density
  – Increased buffering capacity (acid-base balance)
  – Changes in muscle substrate content and enzyme activity
Bone Modeling

creating a stimulus for new bone formation at the regions experiencing the greatest deformation

Collagen fibers become mineralized & bone diameter increases.
Connective Tissue Adaptations

• General Bone Physiology
  – Trabecular bone responds more rapidly to stimuli than does cortical bone.
  – Minimal essential strain (MES) is the threshold stimulus that initiates new bone formation.
  – MES is approximately 1/10 of the force required to fracture bone.

• Anaerobic Training and Bone Growth
  – Muscle strength and hypertrophy gains increase the force exerted on the bones, which may result in a corresponding increase in bone mineral density (BMD) or the quantity of mineral deposited in a given area of bone.
Key Point

- Forces that reach or exceed a threshold stimulus initiate new bone formation in the area experiencing the mechanical strain.
Connective Tissue Adaptations

- Principles of Training to Increase Bone Strength
  - Magnitude of the load (intensity)
  - Rate (speed) of loading
  - Direction of the forces
  - Volume of loading (number of repetitions)
Connective Tissue Adaptations

• How Can Athletes Stimulate Bone Formation?
  – Use exercises that directly load particular regions of the skeleton.
  – Use structural exercises to direct force vectors through the spine and hip and allow the use of greater absolute loads in training.
  – Overload the musculoskeletal system, and progressively increase the load as the tissues become accustomed to the stimulus.
  – Vary exercise selection to change the distribution of the force vectors to continually present a unique stimulus.
• Programs designed to stimulate new bone formation should incorporate the concepts of specificity of loading, proper exercise selection, progressive overload, and variation. The exercises selected should be structural and weight bearing.
Connective Tissue Adaptations

- Adaptations of Tendons, Ligaments, and Fascia to Anaerobic Training
  - The primary stimulus for growth of tendons, ligaments, and fascia is the mechanical forces created during exercise.
  - The degree of tissue adaptation is proportional to the intensity of exercise.
  - Consistent anaerobic exercise that exceeds the threshold of strain stimulates connective tissue changes.
Formation of a Collagen Fiber

- The primary structural component of all connective tissue is the collagen fiber (Type I for bone, tendon, and ligaments and Type II for cartilage).
Connective Tissue Adaptations

• Adaptations of Tendons, Ligaments, and Fascia to Anaerobic Training
  – Sites where connective tissues can increase strength and load-bearing capacity are
    • at the junctions between the tendon (and ligament) and bone surface,
    • within the body of the tendon or ligament, and
    • in the network of fascia within skeletal muscle.
Connective Tissue Adaptations

• Adaptations of Tendons, Ligaments, and Fascia to Anaerobic Training
  – Specific tendinous changes that contribute to size and strength increases include
    • an increase in collagen fibril diameter,
    • a greater number of covalent cross-links within the hypertrophied fiber,
    • an increase in the number of collagen fibrils, and
    • an increase in the packing density of collagen fibrils.
Connective Tissue Adaptations

• How Can Athletes Stimulate Connective Tissue Adaptations?
  – Tendons, Ligaments, Fascia
    • Exercise of low to moderate intensity does not markedly change the collagen content of connective tissue.
    • High-intensity loading results in a net growth of the involved connective tissues.
    • Forces should be exerted throughout the full range of motion of a joint.
Connective Tissue Adaptations

• Cartilage Adaptations to Anaerobic Training
  – The main functions of cartilage are to
    • provide a smooth joint articulating surface
    • act as a shock absorber for forces directed through the joint
    • aid in the attachment of connective tissue to the skeleton.
Connective Tissue Adaptations

- **Cartilage Adaptations to Anaerobic Training**
  - Cartilage lacks its own blood supply and must depend on diffusion of oxygen and nutrients from synovial fluid.
  - Therefore, joint mobility is linked with joint health.
  - Movement about a joint creates changes in pressure in the joint capsule that drive nutrients from the synovial fluid toward the articular cartilage of the joint.
Connective Tissue Adaptations

• How Can Athletes Stimulate Connective Tissue Adaptations?
  – Cartilage
    • Weight-bearing forces and complete movement throughout the range of motion seem to be essential to maintaining tissue viability.
    • Moderate aerobic exercise seems adequate for increasing cartilage thickness.
    • Strenuous exercise does not appear to cause degenerative joint disease, but overuse can be problematic.
Endocrine Responses and Adaptations to Anaerobic Training

• Acute anabolic hormonal responses
  – The acute anabolic hormonal response to anaerobic exercise is critical for exercise performance and subsequent training adaptations.
  – Upregulation of anabolic hormone receptors is important for mediating the hormonal effects.
    • Resistance training has been shown to upregulate androgen receptor content within 48 to 72 hours after the workout.

• Chronic changes in the acute hormonal response
  – Consistent resistance training may improve the acute hormonal response to an anaerobic workout.
Cardiovascular and Respiratory Responses to Acute Anaerobic Exercise

• Acute anaerobic exercise results in increased:
  – Cardiac output
  – Stroke volume
  – Heart rate
  – Oxygen uptake
  – Systolic blood pressure
  – Blood flow to active muscles
Cardiovascular and Respiratory Responses to Acute Anaerobic Exercise

- **Chronic Cardiovascular Adaptations at Rest**
  - Anaerobic training leads to decreases or no change in resting HR and BP.
  - Resistance training alters cardiac dimensions.

- **Ventilatory Response to Anaerobic Exercise**
  - Ventilation generally does not limit resistance exercise and is either unaffected or only moderately improved by anaerobic training.
Compatibility of Aerobic and Anaerobic Modes of Training

• Combining resistance and aerobic endurance training may interfere with strength and power gains primarily if the aerobic endurance training is high in intensity, volume, and frequency.

• No adverse effects on aerobic power result from heavy resistance exercise.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Muscular Strength
    • A review of more than 100 studies showed that mean strength increased approx 40% in “untrained,” 20% in “moderately trained,” 16% in “trained,” 10% in “advanced,” and 2% in “elite” participants over 4 week to 2 year periods.
    • Heavier loads are most effective for fiber recruitment.
    • The effects of training are related to the type of exercise used, its intensity, and its volume.
    • With trained athletes, higher intensity and volume of exercise are needed in order for adaptations to continue.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Power
    • Heavy resistance training with slow movement velocities leads primarily to improvements in max strength, whereas power training (i.e., light-to-moderate loads at high velocities) increases force output at higher velocities & rate of force development.
    • Peak power output is maximized during the jump squat with loads corresponding to 30% to 60% of squat 1RM.
    • For the upper body, peak power output can be maximized during the ballistic bench press throw using loads corresponding to 46% to 62% of 1RM bench press.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Local Muscular Endurance
    • Cross-sectional data in anaerobic athletes have shown enhanced muscular endurance and subsequent muscular adaptations consistent with improved oxidative and buffering capacity.
    • Skeletal muscle adaptations to anaerobic muscular endurance training may include increased mitochondrial and capillary number, fiber type transitions, buffering capacity, resistance to fatigue, and metabolic enzyme activity, especially in the untrained.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Body Composition
    • Resistance training can increase fat-free mass and reduce body fat by 1% to 9%.
    • Increases in lean tissue mass, daily metabolic rate, and energy expenditure during exercise are outcomes of resistance training.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Flexibility
    • Anaerobic training potentially can have a positive impact on flexibility, primarily if the individual has poor flexibility to begin with.
    • The combination of resistance training and stretching appears to be the most effective method to improve flexibility with increasing muscle mass.
Compatibility of Aerobic and Anaerobic Modes of Training

• What Are the Improvements in Performance From Anaerobic Exercise?
  – Aerobic Capacity
    • Heavy resistance training does not significantly affect aerobic capacity unless individual is initially deconditioned.
    • Relatively untrained people can experience increases in VO\textsubscript{2}max ranging from 5% to 8% as a result of resistance training.
    • Circuit training and programs using high volume and short rest periods (i.e., 30 seconds or less) have been shown to improve VO\textsubscript{2}max.
What Are the Performance Improvements From Anaerobic Exercise? (continued)

• Motor performance
  – Anaerobic training enhances motor performance; the magnitude of change is based on the specificity of the exercises or modalities performed.
  – Resistance training has been shown to increase
    • Running economy
    • Vertical jump
    • Sprint speed
    • Tennis serve velocity
    • Swinging and throwing velocity
    • Kicking performance
Overtraining

• Overtraining is defined as excessive frequency, volume, or intensity of training that results in extreme fatigue, illness, or injury (which is often due to a lack of sufficient rest, recovery, and perhaps nutrient intake).

• Mistakes that can lead to anaerobic overtraining include chronic use of high intensity or high volume (or a combination of the two) or too rapid a rate of progression.

• Excessive training on a short-term basis is called overreaching.
### Table 5.3

**Theoretical Development of Anaerobic Overtraining**

<table>
<thead>
<tr>
<th>Stages of overtraining</th>
<th>Day(s)</th>
<th>Performance</th>
<th>Neural</th>
<th>Skeletal muscle</th>
<th>Metabolic</th>
<th>Cardiovascular</th>
<th>Immune</th>
<th>Endocrine</th>
<th>Psychological</th>
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</thead>
<tbody>
<tr>
<td>Acute fatigue</td>
<td>Days</td>
<td>No effect or increase</td>
<td>Altered neuron function</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Functional overreaching (FOR)</td>
<td>Weeks to months</td>
<td><strong>Temporary decrease, returns to baseline</strong></td>
<td>Altered motor unit recruitment</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Altered sympathetic activity and hypothalamic control</td>
</tr>
<tr>
<td>Nonfunctional overreaching (NFOR)</td>
<td>Many months to years</td>
<td><strong>Stagnation or decrease</strong></td>
<td>Decreased motor coordination</td>
<td>Altered excitation-contraction coupling</td>
<td>Decreased muscle glycogen</td>
<td>Increased resting heart rate and blood pressure</td>
<td>Altered immune function</td>
<td>Altered hormonal concentrations</td>
<td>Mood disturbances</td>
</tr>
<tr>
<td>Overtraining syndrome (OTS)</td>
<td>—</td>
<td><strong>Decrease</strong></td>
<td>Decreased force production</td>
<td>Decreased glycolytic capacity</td>
<td>—</td>
<td>Sickness and infection</td>
<td>—</td>
<td>Emotional and sleep disturbances</td>
<td></td>
</tr>
</tbody>
</table>

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Overtraining

• What are the markers of anaerobic overtraining?
  – Psychological effects: decreased desire to train, decreased joy from training
  – Acute epinephrine and norepinephrine increases beyond normal exercise-induced levels (sympathetic overtraining syndrome)
  – Performance decrements, although these occur too late to be a good predictor

(continued)
Overtraining (continued)

• Mistakes that can lead to anaerobic overtraining
  – Chronic use of high intensity or high volume or a combination of the two
  – Too rapid a rate of progression

• Hormonal markers of anaerobic overtraining
  – Increased cortisol

• Psychological factors in overtraining
  – Psychological alterations are often observed before actual decrements in performance occur.
### Physiological Variables: Training and Detraining

<table>
<thead>
<tr>
<th>Physiological variable</th>
<th>Trained (resistance)</th>
<th>Detrained</th>
<th>Trained (aerobic endurance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle girth</td>
<td><img src="image1" alt="Muscle girth" /></td>
<td><img src="image2" alt="Muscle girth" /></td>
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</tr>
<tr>
<td>Muscle fiber size</td>
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<td>Capillary density</td>
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<td><img src="image8" alt="Capillary density" /></td>
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<tr>
<td>% fat</td>
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<td><img src="image11" alt="Fat percentage" /></td>
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<tr>
<td>Aerobic enzymes</td>
<td><img src="image13" alt="Aerobic enzymes" /></td>
<td><img src="image14" alt="Aerobic enzymes" /></td>
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<td>Short-term endurance</td>
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<td>Maximal oxygen uptake</td>
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<tr>
<td>Mitochondrial density</td>
<td><img src="image22" alt="Mitochondrial density" /></td>
<td><img src="image23" alt="Mitochondrial density" /></td>
<td><img src="image24" alt="Mitochondrial density" /></td>
</tr>
<tr>
<td>Strength and power</td>
<td><img src="image25" alt="Strength and power" /></td>
<td><img src="image26" alt="Strength and power" /></td>
<td><img src="image27" alt="Strength and power" /></td>
</tr>
</tbody>
</table>