ADAPTATIONS TO ANAEROBIC TRAINING PROGRAMS

ES342—Spring 2010
Big doings starting tomorrow.
What is going on?
Activity:

- What exercises will you do to get strength in your:
  - Calves
  - Quadriceps
  - Hamstrings
  - Gluteals
  - Chest
  - Latissimus & Rhomboid Majors

- Include:
  - The exercise
  - The volume
    - Intensity (ex. % of 1RM)
    - Repetitions/sets
  - Rest time
Goals of Anaerobic Training

- Strength
- Hypertrophy
- Power development
- Rehabilitation
- Neuromuscular control
- Anaerobic metabolism

What are all of these?

Explain them from a physiologic standpoint
How might your training program…

- Change if your goal is muscle hypertrophy?
- Change if your goal is anaerobic metabolism?
- Change if your goal is neuromuscular control?
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>
<tr>
<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>
</tr>
<tr>
<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>
<td>Moderate</td>
<td>—</td>
</tr>
<tr>
<td>Golf</td>
<td>High</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ice hockey</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Marathon</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Mixed martial arts</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Powerlifting</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<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>
</tbody>
</table>
### Table 5.1

Primary Metabolic Demands of Various Sports  
*(continued)*

<table>
<thead>
<tr>
<th>Sport</th>
<th>Phosphagen system</th>
<th>Anaerobic glycolysis</th>
<th>Aerobic metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Strength competitions</td>
<td>High</td>
<td>Moderate to high</td>
<td>Low</td>
</tr>
<tr>
<td>Swimming:</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>
</tr>
<tr>
<td>Tennis</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
</tr>
<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>
</tr>
<tr>
<td>Ultra-endurance events</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Volleyball</td>
<td>High</td>
<td>Moderate</td>
<td>—</td>
</tr>
<tr>
<td>Wrestling</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Weightlifting</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

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

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### TABLE 5.2
Physiological Adaptations to Resistance Training

<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>
</tr>
<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>
<td></td>
</tr>
<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>
</tbody>
</table>

(continued)
TABLE 5.2
Physiological Adaptations to Resistance Training (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Resistance training adaptations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enzyme activity</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>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>Metabolic energy stores</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>Connective tissue</td>
<td></td>
</tr>
<tr>
<td>Ligament strength</td>
<td>May increase</td>
</tr>
<tr>
<td>Tendon strength</td>
<td>May increase</td>
</tr>
<tr>
<td>Collagen content</td>
<td>May increase</td>
</tr>
<tr>
<td>Bone density</td>
<td>No change or increases</td>
</tr>
<tr>
<td>Body composition</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.
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**Anaerobic training may elicit neural adaptations**

- **Beginning in the higher brain centers**
  - Corticospinal tract motor unit recruitment
  - Organization of motor patterns
  - Synchronization of motor units

- **Neuromuscular junctions**
  - Larger surface areas
  - More neurotransmitter receptors

- **Motor nerves**
  - Activation thresholds
  - Frequency of firing

- **Continuing down to the level of individual muscle fibers**
  - Spindle sensitivity
  - Hypertrophy
  - Muscle fiber conversion
  - Enzyme activity
Possible Sites of Adaptation in the Neuromuscular System
Neural Adaptations

- Central Adaptations
  - Motor cortex activity increases when...
    - Level of force developed increases
    - 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...
    - Increase in recruitment
    - Increased rate of firing
    - Improved synchronization of firing
    - Decreased antagonist activity
Neural Adaptations

- **Neuromuscular Junction**
  - 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
  - greater dispersion of acetylcholine receptors within the end-plate region

- **Neuromuscular Reflex Potentiation**
  - Improved reflex response improves magnitude of force development
  - Improved reflex response improves rate of force development
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%
  - Not likely with EMG
- Advanced training allows added gains in strength and power
- Dramatic increases in neural activity take place early in the training programs
- Additional findings include the following:
  1. Cross-education
  2. Bilateral deficit in untrained individuals
  3. Changes in muscle activity of the antagonists during agonist movements
Graph of Neural Contributions to Strength Gains
Muscular Adaptations

- Skeletal muscle adapts to anaerobic training primarily by
  - increasing its size
    - Hypertrophy
    - Hyperplasia?
  - facilitating fiber type transitions
  - enhancing its biochemical and ultra-structural components

- Changes result in enhanced strength, power, and muscular endurance
Motor units that contain Type I or Type II fibers are organized based on “size”

Low-threshold motor units are typically recruited first & have lower force-generating capacity than higher-threshold motor units

Exception may exist when explosive movements are trained for over time
- High-threshold MUs recruited first
- Need force immediately
- High power output
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.
key point—the process of hypertrophy

- Involves an increase in the synthesis of the contractile proteins actin and myosin within the myofibril
- Increase in the number of myofibrils within a muscle fiber
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, IIa, IIax, IIx.
Muscular Adaptations

- **Structural and Architectural Changes**
  - Increased myofibrillar volume, cytoplasmic density, sarcoplasmic reticulum & T-tubule density, & Na-K ATPase activity
  - Enhanced Ca release
  - Increased 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

(a) Longitudinal weight-bearing force causes the bone to bend creates a stimulus for new bone formation

(b) Osteoblasts lay down additional collagen fibers

(c) Previously dormant osteoblasts migrate to the area

(d) The collagen fibers become mineralized and the bone diameter increases
Key Point—Wolff’s Law

- Forces that reach or exceed a threshold stimulus (MINIMAL ESSENTIAL STRAIN—MES) initiate new bone formation in the area experiencing the mechanical strain.
Connective Tissue Adaptations—Anaerobic Training & Bone Growth

- Muscle strength & hypertrophy gains...
  - Increase the force exerted on the bones
  - May result in an increase in bone mineral density

- Principles of Training Govern Increased Bone Strength
  - Magnitude of the load (intensity)
  - Rate (speed) of loading
  - Direction of the forces
  - Volume of loading (number of repetitions)
How Can Athletes Stimulate Bone Formation?

- Exercises that directly load particular regions of the skeleton (specificity)
- Structural exercises to direct force vectors through the spine and hip & allow the use of greater loads (specificity, progressive overload)
- Progressively increase the load as the tissues become accustomed to the stimulus (progressive overload)
- Vary exercise selection (individuality, progressive overload, & specificity)
  - Change the distribution of the force vectors
  - Continually present a unique stimulus
Connective Tissue Adaptations—Tendons, Ligaments, & Fascia

- Primary stimulus is the mechanical forces created during exercise.
- Degree of tissue adaptation is proportional to intensity of exercise.
- Consistent anaerobic exercise that exceeds the threshold of strain → connective tissue changes.
Adaptations of Tendons, Ligaments, and Fascia to Anaerobic Training

- Sites where connective tissues can increase strength and load-bearing capacity are...
  - junctions between the tendon (and ligament) and bone surface
  - within the body of the tendon or ligament
  - in the network of fascia within skeletal muscle
Specific tendinous changes that contribute to size and strength increases include...

- Increase in collagen fibril diameter
- More covalent cross-links within the hypertrophied fiber
- Increase in the number of collagen fibrils
- Increase in the packing density of collagen fibrils
Connective Tissue Adaptations

- How Can Athletes Stimulate Tendons, Ligaments, Fascia Adaptations?
  - Exercise of low to moderate intensity does not markedly change the collagen content of connective tissue—MUST BE HIGH!
  - High-intensity loading ➔ a net growth of the involved connective tissues
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
- Cartilage lacks its own blood supply & must depend on diffusion of oxygen & nutrients from synovial fluid
- Joint movement
  - creates changes in pressure in the joint capsule
  - drives nutrients from the synovial fluid toward the articular cartilage of the joint
How Can Athletes Stimulate Cartilage Adaptations?

- Maintaining tissue viability
  - Weight-bearing forces
  - Complete movement throughout the ROM

- Moderate aerobic exercise seems adequate for increasing cartilage thickness

- Strenuous exercise does not appear to cause degenerative joint disease
Endocrine Responses and Adaptations to Anaerobic Training
Endocrine Responses and Adaptations to Anaerobic Training

- **Acute Anabolic Hormonal Responses**
  - Critical for exercise performance
  - Important for subsequent training adaptations
  - Up-regulation of anabolic hormone receptors is important for mediating the hormonal effects

- Consistent resistance training may improve the acute hormonal response to an anaerobic workout

- Consistent chronic changes in resting hormonal concentrations are less likely
Cardiovascular and Respiratory Responses to Acute Anaerobic Exercise
Acute CV responses to Anaerobic Training

- An acute bout of anaerobic exercise significantly increases CV responses, especially if the individual uses the Valsalva maneuver.

- Acute anaerobic exercise results in:
  - Increased cardiac output
  - Increased stroke volume
  - Increased heart rate
  - Increased oxygen uptake
  - Increased systolic blood pressure
    - Increased diastolic during heavy lifts
    - Concerning among people with heart problems
  - Increased blood flow to active muscles
Chronic Cardiovascular Adaptations at Rest

- Anaerobic training leads to decreases or no change in resting HR and BP.
- Resistance training alters cardiac dimensions.
Cardiovascular and Respiratory Responses to Acute Exercise

- Chronic Adaptations of the Acute CV Response to Anaerobic Exercise
  - Reduces the CV response to an acute bout of resistance exercise of a given absolute intensity or workload
  - In essence, more efficiently using blood supply

- Ventilatory Response to Anaerobic Exercise
  - Generally doesn’t limit resistance exercise
  - Unaffected or only moderately improved by anaerobic training
What Are the Improvements in Performance From Anaerobic Exercise? *Strength*

- The increased synchronized recruitment of motor units
- Heavier loads are most effective

- The effects of training are related
  - Exercise used
  - Exercise intensity
  - Exercise volume

- Needs of trained athletes for continued progress
  - Higher intensity of exercise
  - Higher volume of exercise
What Are the Improvements in Performance From Anaerobic Exercise? **Power**

- **Lifting light-to-moderate loads at high velocities increases**
  - force output at higher velocities
  - rate of force development

- **Peak Power Output**
  - Lower Extremity—jump squat with loads corresponding to 30% to 60% of squat 1RM
  - Upper body—maximized during the ballistic bench press throw using loads corresponding to 46% to 62% of 1RM bench press
What Are the Improvements in Performance From Anaerobic Exercise?  **Local Muscular Endurance**

- Improved oxidative ability
- Improved buffering capacity
- Increased mitochondrial density
- Increased capillary density
- Fiber type transitions
- Increased resistance to fatigue
- Increased metabolic enzyme activity
What Are the Improvements in Performance From Anaerobic Exercise?  **Body Composition**

- Increase fat-free mass
- Reduced fat mass
- Increased daily metabolic rate
What Are the Improvements in Performance From Anaerobic Exercise? **Flexibility**

- Large effects in untrained people with poor flexibility
- Important focus as bulk increases
- Prevent overuse injuries
- Increased joint range of motion
- Improved ability to generate force at end range
What Are the Improvements in Performance From Anaerobic Exercise?  *Motor Performance*

- **Magnitude of change is based on the specificity of the exercises**
- **Improved**
  - body control
  - running economy
  - vertical jump
  - sprint speed
  - tennis serve velocity
  - swinging and throwing velocity
  - kicking performance
What Are the Improvements in Performance From Anaerobic Exercise? Aerobic Capacity

- Heavy resistance training
  - Does not significantly affect aerobic capacity
  - Unless the individual is initially deconditioned
    - These people can experience increases in VO$_{2\text{max}}$ ranging from 5% to 8%

- Improved VO$_{2\text{max}}$
  - Circuit training
  - Programs using high volume and short rest periods (30 seconds or less)
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 training is high in intensity, volume, and frequency
- No adverse effects on aerobic power due to heavy resistance training
Overtraining

- **Overtraining**
  - Def.—excessive frequency, volume, or intensity of training that results in extreme fatigue, illness, or injury
  - It is often due to a lack of sufficient rest, recovery, and, perhaps, nutrient intake

- 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>Neural</th>
<th>Skeletal muscle</th>
<th>Metabolic</th>
<th>Cardiovascular</th>
<th>Immune</th>
<th>Endocrine</th>
<th>Psychological</th>
</tr>
</thead>
<tbody>
<tr>
<td>First (no effect on performance)</td>
<td>Altered neuron function</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second (probably no effect on performance)</td>
<td>Altered motor unit recruitment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Altered sympathetic activity and hypothalamic control</td>
<td></td>
</tr>
<tr>
<td>Third (probably decreased performance)</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>Fourth (decreased performance)</td>
<td>Decreased force production</td>
<td>Decreased glycolytic capacity</td>
<td></td>
<td></td>
<td>Sickness and infection</td>
<td></td>
<td>Emotional and sleep disturbances</td>
</tr>
</tbody>
</table>

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Markers of Anaerobic Overtraining

- Psychological effects
  - Decreased desire to train
  - Decreased joy from training

- Hormonal effects
  - Acute epinephrine and norepinephrine increases beyond normal exercise-induced levels (sympathetic overtraining syndrome)

- Performance decrements
  - Often occur too late to be a good predictor
Mistakes That Can Lead to Anaerobic Overtraining

- Chronic use of high intensity &/or high volume
- Progressive overload is too fast
Physiological Variables: Training and Detraining

- Relative responses of physiological variables to training and detraining