**Achieving Stability**

- Stability: ability to maintain a stable, balanced position after a disruption of balance.
- Center of gravity must fall within base of support.
- Changing foot and body positions alters the base of support and center of gravity.
- A wide base of support and a lower body position increase stability.
- A narrow base of support and an elongated body position reduce stability.

**Base of Support**
Torque (Moment of Force)

- Torque: expression of rotational force.
  - All human joint movement is rotational in nature.
- The limbs act as levers that rotate around joints, acting as fulcra.
- The farther a resistance is from the axis of rotation, the greater the torque necessary to produce movement.

Torque

- Torque is the product of the magnitude of force (F) and the force arm (FA).
  - \( T = F \times FA \)
- When 2 forces produce rotation in opposite directions (gravity and muscle contraction), one is the resistance force (R) and its force arm is called the resistance arm (RA).
Torque and Exercise

• During exercise, the force arm (FA) is the perpendicular distance from the axis of rotation to the direction of application of that force.
• The resistance arm (RA) is the distance from the axis of rotation to the center of gravity of the moving limb.

Torque and Exercise

• Holding a dumbbell lengthens the resistance arm by moving the center of gravity away from the axis of rotation.
• The longer the resistance arm, the more torque is necessary to produce movement.
• Torque varies as a limb moves through the joint’s range of motion, due to change in the length of FA.

Force (F) and Force Arm (FA)
Effect of a Less-Flexed Position on the Force Arm

Resistance (R) and Resistance Arm (RA)

Modifications of Resistive Torque
Rotational Inertia
- Rotational inertia is resistance to the change of a body segment's position.
- Inertia depends on the mass of the segment and its distribution about the joint.
- A limb with a heavier mass concentrated a further distance from the joint axis is harder to move.
- Inertia depends on the mass of body segments, which cannot be changed.
- Inertia can be manipulated by changing the angle of a joint.

Angular Momentum
- Angular momentum is the product of rotational inertia and angular velocity.
- The faster a body part moves, and the greater its rotational inertia, the greater its angular momentum.
- The amount of force needed to change angular momentum is proportional to the amount of momentum.

Angular Momentum and Exercise
- Momentum during exercise is decelerated by eccentric muscle action.
- Greater mass moving at a greater speed requires more force to decelerate.
- Muscles can be injured if they are not strong enough to decelerate the force of ballistic movements.
Transfer of Angular Momentum

- Transfer of momentum from one body part to another is accomplished by stabilizing the initially moving body part.
  - In sports, angular momentum can be transferred from a body part to a ball, bat, or other apparatus.

Muscle Group Involvement in Activities

- Muscles work in groups to produce specific joint movements.
- Efficiency of movement can be improved upon by studying the mechanics of movement at a joint, and by making necessary changes.
- Training for strength and flexibility can influence the efficiency of movement.

Common Mechanical Errors: Walking and Running

- Stiff-legged running increases rotational inertia, and increases joint stress.
- Keep joint movements in the anterior–posterior direction to eliminate trunk rotation.
- Do not propel too high off the ground.
- Reduce impact by running softly and quietly.
Common Mechanical Errors: Throwing and Striking
• The more joints involved in a throwing motion, the more speed can be produced.
• Lack of trunk rotation and poor coordination of timing reduces velocity.
  – When striking, rotate the trunk to increase impact of the strike.
• Hip, trunk and upper limb movements should follow each other with fluid timing.
• Increased bat velocity results in increased impact on the ball, and greater

Overarm Throwing Movements

Common Mechanical Errors: Lifting and Carrying
• Lifting and carrying objects:
  – place the object close to or between the spread feet.
  – squat with an erect trunk.
  – activate abdominal muscles and tilt the pelvis backward.
  – use the hip and knee extensors to generate slow, smooth force.
  – carry the lifted object close to your body.
Use of Energy

- The body must break down food to a useable form that conserves energy.
- The final product must be a molecule the cell can use.

ATP (Adenosine Triphosphate)
- Used by cells as the primary energy source for biological work:
- Adenine and three phosphates linked by high-energy bonds.
- When the bond is broken, energy is released.
- $\text{ATP} \rightleftharpoons \text{ADP} + \text{Pi}$
ATP and Activity

- ATP is constantly converted to energy.
- ATP must be replaced as fast as it is used in order for muscles to continue to generate force.
- Muscle cells have the capacity to regenerate ATP under a variety of work conditions, using multiple sources.

Energy and Work

<table>
<thead>
<tr>
<th>Immediate energy sources</th>
<th>Short-term energy sources</th>
<th>Long-term energy sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic</td>
<td>Anaerobic</td>
<td>Aerobic; occurs in the mitochondria</td>
</tr>
<tr>
<td>ATP/PC</td>
<td>Glycolysis (breakdown of CHO)</td>
<td>Muscle glycogen, glucose, plasma FFA</td>
</tr>
<tr>
<td>Maximal work, 1-5 seconds</td>
<td>Maximal work, &lt;2 minutes</td>
<td>Maximal work, &gt;2 minutes, and all submaximal work</td>
</tr>
<tr>
<td>Shot put, vertical jump, short sprint (50 m)</td>
<td>200-400-meter race, 100-meter swim</td>
<td>1,500-meter race, marathon</td>
</tr>
</tbody>
</table>

Exercise Intensity and Duration and Energy Production

- Energy from both anaerobic and aerobic sources is on-going.
- Short duration, high-intensity activity relies on a greater proportion of anaerobic energy.
- Long duration, lower-intensity exercise relies on a greater proportion of aerobic energy.
Skeletal Muscle

- Converts ATP chemical energy to mechanical work.
- Muscle fiber:
  - each cylindrical fiber is one cell.
  - striated, with light and dark bands of myofibrils.
  - myofibrils are composed of long series of sarcomeres, the fundamental units of muscle contraction.

Muscle Structure
Muscle Structure

Sliding Filament Theory
• Thin actin filaments slide over thick myosin filaments.
• Z-lines pull toward the center of the sarcomere.
• Entire muscle shortens.
• Contractile proteins do not change size

Cross-Bridge Movement in Muscle Contraction
**Steps of Muscle Contraction**
- Muscle is depolarized (excited) by a motor neuron.
- Action potential spreads through transverse tubules.
- Sarcoplasmic reticulum releases calcium into sarcoplasm.
- Calcium binds with troponin.
- Actin and myosin cross-bridges interact to shorten muscle.

**Muscle Fiber Types and Performance**

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Description</th>
<th>Primary ATP source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type IIx (fast glycolytic)</td>
<td>Fast contraction, high force, easily fatigue</td>
<td>Anaerobic: PC breakdown and glycolysis</td>
</tr>
<tr>
<td>Type IIa (fast oxidative glycolytic)</td>
<td>Fast contraction, high force, resist fatigue</td>
<td>Both anaerobic, and aerobic</td>
</tr>
<tr>
<td>Type I (slow oxidative)</td>
<td>Slow contraction, low force, resist fatigue</td>
<td>Aerobic</td>
</tr>
</tbody>
</table>

**Muscle Fiber Types: Genetics**
- Distribution is highly variable and strongly influenced by genetics
- Training does not convert fast-twitch fibers to slow-twitch and vice versa
- Training increases mitochondrial number and capillary density (oxidative capacity)
**Force Development in the Muscle**

- **Muscle fiber** is excited by a low-level stimulus, single twitch occurs, followed by relaxation.
- **Summation**: If the frequency of stimulation increases, the muscle cannot relax between stimuli, and the stimulus adds to the tension of the previous contraction.
- **Tetanus**: Increased frequency of stimulation causes contractions to fuse into a smooth, sustained high-tension contraction.
- **Synchronous firing**: When many fibers contract simultaneously, the force of contraction is greater.
- **Recruitment**: The number of muscle fibers recruited for a contraction determines force of contraction.

**Muscle Fiber Type Recruitment**

![Graph showing muscle fiber type recruitment](image)

**Measuring Oxygen Consumption**

- \( VO_2 = \) volume \( O_2 \) inhaled - volume \( O_2 \) exhaled
- Measured by pulmonary ventilation.
- \( O_2 \) is used and \( CO_2 \) is produced as a waste product in the muscle mitochondria.
Path of Oxygen to Mitochondria

lungs ➞ alveoli ➞ blood (hemoglobin) ➞ muscles ➞ mitochondria ➞ ATP production

Respiratory Quotient

• Tells what type of fuel the muscles are using during exercise.
• R = VCO₂/VO₂
• R for Carbohydrate: 1.0
• R for Fat: 0.7
• @ R of .85: 50% carbs, 50% fat
• During intense exercise, lactate production can cause R values >1.0.

Exercise Intensity and Fuel Utilization

• At 40–50% VO₂ max, R increases.
• Type Ila fibers are recruited.
• Muscle glycogen fuels heavy exercise lasting < 2 hours.
• Shortage of muscle glycogen leads to premature fatigue.
• Heavy exercise requires abundant muscle glycogen stores and consumption.
Effect of Exercise Intensity on Fuel Utilization/ Changes in R

- During moderate-intensity exercise, R decreases over time.
- Reliance on fat for fuel increases.

Exercise Duration and Fuel Utilization

Changes in R During Steady State Exercise/ Effects of Fuel Utilization
Effect of Diet on Fuel Utilization

- A high-carbohydrate diet maximizes muscle glycogen stores.
- Strenuous exercise promotes maximal muscle glycogen storage.
- Consuming carbohydrates during prolonged exercise reduces the time to fatigue.
- Consuming carbohydrates after exercise replenishes glycogen stores.

Transition from Rest to Steady State

- Oxygen Deficit
  - initial stages of exercise.
  - \( O_2 \) demand > \( O_2 \) supply.
  - PC and glycolysis provide some energy
  - HR, Stroke Volume (SV) and ventilation increase to meet \( O_2 \) demand

- Steady State
  - \( O_2 \) supply = \( O_2 \) demand
  - oxidative energy pathways prevail
- EPOC (excess post-exercise oxygen consumption)
  - used to make additional ATP
  - returns muscle PC stores to normal
  - meets ATP demands of breathing and HR during recovery
Transition from Rest to Steady State

Heart Rate and Pulmonary Ventilation
- HR and ventilation follow a similar curve during exercise.
- Trained individuals reach steady state sooner, and recover faster than untrained.

GXT (Graded Exercise Test)
- Measures CRF (cardiorespiratory fitness).
- Determines maximal O₂ uptake (VO₂ max).
- Describes the greatest rate at which the body can make ATP.
- Genetics and training both determine VO₂ max.
GXT (Graded Exercise Test)

- Women's VO\(_2\) max values are 15% lower than men's.
  - higher body fat, lower hemoglobin levels, and lower stroke volume (smaller heart)
- VO\(_2\) max declines about 1% per year of age.
  - decline can be reversed by training in middle-aged individuals.

GXT (Graded Exercise Test)

- VO\(_2\) max decreases with altitude.
- Carbon monoxide in polluted air decreases VO\(_2\) max.
- Cardiovascular and pulmonary diseases reduce VO\(_2\) max.
  - diminished \(O_2\) diffusion from air to blood.
  - diminished pumping capacity of the heart.

Cardiac Output

- Heart Rate: Heart beats per minute.
- Stroke Volume:
  - amount of blood pumped with each beat.
  - the primary limiting factor influencing VO\(_2\) max.
- Cardiac Output (CO)
  - \(CO = HR \times SV\)
  - Total volume of blood circulated per minute.
Oxygen Extraction

- The amount of $O_2$ extracted from circulating blood by the cells.
- Determined by arteriovenous $O_2$ difference (a–v $O_2$ difference).
- Trained individuals extract more $O_2$
  - more capillaries feeding the cells.
  - more mitochondria in the cells.

Blood Pressure

- Balance between cardiac output and resistance to flow in the vessels.
- $BP = \text{Cardiac Output} \times \text{Resistance}$
- SBP (Systolic Blood Pressure)
  - arteriole pressure during LV contraction (systole).
  - goes up during exercise.
- DBP (Diastolic Blood Pressure)
  - arterial pressure during filling (diastole).
  - stays constant, or drops slightly, during endurance exercise.

Blood Pressure

- Training lowers blood pressure over time (SBP and DBP).
- $BP$ and $HR$ are higher during arm exercise vs. leg exercise.
  - arm work limits total work volume.
  - leg work results in lower $HR$, $BP$, and later onset of fatigue.
Effects of Endurance Training

Effects of Endurance Training

Effects of Endurance Training

Effects of Endurance Training
Transfer of Training

• Training is specific to the muscles involved.

• Training benefits do not transfer to other body parts.

Detraining

• Cessation of Training
  – maximal O$_2$ uptake decreases.
  – initial decrease due to reduced SV.
  – eventual decrease in O$_2$ extraction.

• Reduction in Training
  – O$_2$ uptake can be maintained with intense exercise, even with reduced duration and frequency.

Exercise Responses for Males and Females

• At the same relative treadmill workload, women respond with a higher HR:
  – lower SV
  – less hemoglobin
  – more body fat

• At the same relative cycle workload, women have a higher HR:
  – lower SV
  – less hemoglobin
CV Response to Isometric and Weight Training

- Initially, during exercise, both isometric exercise and weight training elicit increased blood pressure.
- Both SBP and DBP go up.

Blood Pressure Responses to Weightlifting

Heat Loss Mechanisms

The body loses heat through four processes:

- Radiation
- Conduction
- Convection
- Evaporation of sweat*

*Primary mechanism for heat loss during exercise
Body Temperature Response to Exercise

- Core temperature rises proportionately to intensity.
- During early exercise, rise in temperature triggers heat-loss mechanisms.
- After 10–20 minutes of exercise, heat loss = heat production, and core temperature remains constant.

Heat Loss During Exercise

- Evaporation is responsible for heat loss during heavy exercise.
- In hot, humid environments, evaporation is less efficient.
- Training in a hot, humid environment for 7–12 days increases heat tolerance and lowers body temperature during exercise.

Evaporation Must Increase as Temperatures Rise
Questions/Discussion?