Exercise
Thermoregulation, Fluid Balance & Rehydration
HNF 610: Nutrition & Fitness
Dr. Melissa Olfert
Body Temperature

- Hyperthermia is an increase in body temperature by 5°C or more.
- Core body temperature: deep tissues
- Shell body temperature: peripheral
- Core temperature rises quickly when heat gain exceeds heat loss during vigorous exercise in a warm environment.
Hypothalamic Regulation

- Hypothalamus is the central coordinating center for temperature regulation.
- Acts as a thermostat
- Initiates responses to protect the body from heat gain or heat loss
Factors that contribute to heat gain and loss to regulate core temperature

Heat gain:
- BMR (Basal Metabolic Rate)
- Muscular activity
- Hormones
- Thermic effect of food
- Postural changes
- Environment

Heat loss:
- Radiation
- Conduction
- Convection
- Evaporation

Daily variation, °C:
- 36°
- 37°
- 38°
Heat-Regulating Mechanisms

- Become activated in two ways:
  - Temperature changes in blood perfusing the hypothalamus directly stimulate this thermoregulatory control center.
  - Thermal receptors in the skin provide input to modulate hypothalamic activity.
- Structures in the skin and subcutaneous tissue help to regulate temperature.
Heat Loss

- Can occur due to:
  - Radiation
  - Conduction
  - Convection
  - Evaporation
Radiation

- Objects emit electromagnetic heat waves.
- Body temperature is warmer than the environment.
- Radiant heat energy leaves the body through air to solid cooler objects around us.
- The body absorbs radiant heat energy when the temperature of objects in the environment exceeds skin temperature.
Conduction

- Transfers heat directly through a liquid, solid, or gas from one molecule to another
- The circulation transports most of the body heat to the shell.
- A small amount continually moves by conduction directly through the deep tissues to the cooler surface.
- Conductive heat loss then involves the warming of air molecules and cooler surfaces in contact with the skin.
Convection

- Air movement
- Warm air next to the skin acts as a zone of insulation.
- If cool air continuously replaces the warmer air surrounding the body, heat loss increases.
Evaporation

- Major physiologic defense against overheating
- Water vaporization from the respiratory passages and skin surface continually transfers heat to the environment.
- In response to heat stress, 2-4 million sweat (eccrine) glands secrete large quantities of hypotonic saline solution.
- Cooling occurs when sweat evaporates from the skin surface.
Heat production within active muscle
Environmental Temperature

- Increased ambient temperature reduces the effectiveness of heat loss by conduction, convection, and radiation.
- Sweat evaporation from the skin depends on:
  - Surface exposed to the environment
  - Temperature and relative humidity of ambient air
  - Convective air currents around the body
Hourly Sweat Rates
Heat-Dissipating Mechanisms

- Circulation
  - “Workhorse” to maintain thermal balance
- Evaporation
- Hormones
  - Antidiuretic hormone
  - Aldosterone
Exercise Clothing

- Cottons and linens readily absorb moisture.
- Heavy “sweatshirts” and rubber or plastic garments produce high relative humidity close to the skin.
- Dark colors absorb light rays and add to radiant heat gain.
- Light colors reflect heat rays away from the body.
- Moisture-wicking fabrics provide optimal transfer of heat and moisture from the skin to the environment.
Water Loss

- Dehydration
  - Considerable water loss occurs during several hours of intense exercise in a hot environment.
  - Both intracellular and extracellular compartments contribute to fluid deficit.
  - The risk of heat illness greatly increases when a person begins exercising in a dehydrated state.
  - Sweat is hypotonic with other body fluids.
Dehydration and Exercise

- Just about any degree of dehydration impairs the capacity of circulatory and temperature-regulating mechanisms to adjust to exercise demands.
- Dehydration of as little as 2% body mass impairs physical work capacity and physiologic function and predisposes to heat injury when exercising in a hot environment.
- The risk for dehydration increases during vigorous cold-weather exercise.
Factors that influence potential dehydration during cold-weather

- Significant fluid loss as respiratory passages warm and humidify incoming cold, dry air
- Back-mounted pack provides for readily-available fluid during prolonged outdoor exercise
- Cold stress stimulates kidneys to increase urine production
- Excessive clothing plus exercise energy metabolism increases fluid loss through sweating
Rehydration

- Properly scheduling fluid replacement maintains plasma volume, so circulation and sweating progress optimally.
- A well-hydrated individual always functions at a higher physiologic and performance level than a dehydrated person.
- Achieving hyperhydration before exercising in a hot environment protects against heat stress because it:
  - Delays dehydration
  - Increases sweating during exercise
  - Diminishes the rise in core temperature
Adequacy of Rehydration

- Body weight changes indicate the extent of water loss from exercise and adequacy of rehydration during and after exercise or athletic competition.

- Urine and hydration:
  - Dark yellow urine with a strong odor = inadequate hydration
  - Large volume, light color, without a strong odor = adequate hydration
Computing the magnitude of sweat loss and rate of sweating in exercise

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Body weight</th>
<th>Drink volume</th>
<th>Urine volume</th>
<th>Sweat loss</th>
<th>Exercise time</th>
<th>Sweat rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackinzie</td>
<td>9/15</td>
<td>61.7 kg</td>
<td>1400 mL</td>
<td>90 mL</td>
<td>1730 mL</td>
<td>90 min</td>
<td>19.2 mL·min⁻¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60.3 kg</td>
<td>420 mL</td>
<td>90 mL</td>
<td>1730 mL</td>
<td>1.5 h</td>
<td>1153 mL·h⁻¹</td>
</tr>
</tbody>
</table>

*Weight of urine should be subtracted if urine was excreted prior to postexercise body weight.
DBW, difference in body weight.
Sweat loss = total fluid loss during exercise.
Sweat rate = fluid loss per unit time.

<table>
<thead>
<tr>
<th>Sweat rate (mL·h⁻¹)</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1</td>
<td>1.7</td>
<td>2.2</td>
<td>3.3</td>
<td>4.4</td>
<td>5.5</td>
<td>6.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fluid intake (mL)</th>
<th>125</th>
<th>190</th>
<th>250</th>
<th>330</th>
<th>415</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>6.5</td>
<td>8.5</td>
<td>11</td>
<td>14</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehydration intervals (min)</th>
<th>15</th>
<th>15</th>
<th>15</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

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Sodium and Rehydration

- A moderate amount of sodium added to a rehydration beverage provides more complete rehydration.
- Maintaining a relatively high plasma concentration of sodium helps:
  - Sustain the thirst drive
  - Promote retention of ingested fluids
  - More rapidly restore lost plasma volume during rehydration
Cumulative urine output during recovery from exercise-induced dehydration
Hyponatremia

- Low blood level of sodium (<135 mEq/L)
- Can occur due to excessive water intake
- A sustained low plasma sodium concentration creates an osmotic imbalance across the blood–brain barrier that causes rapid water influx into the brain.
- The resulting swelling of brain tissue produces a cascade of symptoms that range from mild to severe.
Factors that contribute to hyponatremia

Excessive fluid consumption:
- Aggressive rehydration
- Misdiagnosis and treatment for rehydration
- Inappropriate IV therapy

Inadequate sodium intake:
- Sodium-free fluids
- Low-sodium foods

Excessive sodium loss:
- Prolonged sweating
- Not acclimated
- Untrained
- CFRT variant gene
- High sweat sodium

Failure to excrete excess fluid:
- Exercise
- Heat exposure
- AVP

Hyponatremia:
- Plasma sodium concentration
- Total body water

Impaired muscle function
- Altered CNS function
- Pulmonary congestion
- Cardiopulmonary failure
- Seizure, coma, death

Cerebral edema
Acclimatization

- Heat acclimatization refers to the physiologic adaptations that improve heat tolerance.
- The acclimatized individual:
  - Has larger quantities of blood shunt to cutaneous vessels
  - Has more effective cardiac output
  - Has an earlier onset of sweating
Rectal Temperature Correlation

[Image of a graph showing the correlation between rectal temperature, heart rate, and sweat loss over days.]
Age Differences in Acclimatization

- Older individuals have:
  - A decreased sensitivity of thermoreceptors
  - Limited sweat gland output
  - Dehydration-limited sweat output with insufficient fluid replacement
  - Altered structure and function of the skin and its vasculature
  - A decreased recovery from dehydration
Other Factors Affecting Acclimatization

- Children
- Gender
  - Men sweat more.
  - Women show heat tolerance similar to men.
- Body fat
Wet Bulb-Globe Temperature

- Used to evaluate the environment for its potential thermal challenge
- Index of environmental heat stress
- Incorporates ambient temperature, relative humidity, and radiant heat
- \[ WB-GT = 0.1 \times DBT + 0.7 \times WBT + 0.2 \times GT \]
Wet bulb-globe temperature for outdoor activities

<table>
<thead>
<tr>
<th>WB-GT Range</th>
<th>°F</th>
<th>°C</th>
<th>Recommendations</th>
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<tbody>
<tr>
<td>80-84</td>
<td>26.5-28.8</td>
<td></td>
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<tr>
<td>85-87</td>
<td>29.5-30.5</td>
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</tr>
<tr>
<td>&gt; 88</td>
<td>&gt; 31.2</td>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>WBT Range</th>
<th>°F</th>
<th>°C</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>15.5</td>
<td></td>
<td>No prevention necessary</td>
</tr>
<tr>
<td>61-65</td>
<td>16.2-18.4</td>
<td></td>
<td>Alert all participants to problems of heat stress and importance of adequate hydration</td>
</tr>
<tr>
<td>66-70</td>
<td>18.8-21.1</td>
<td></td>
<td>Insist that appropriate quantity of fluid be ingested</td>
</tr>
<tr>
<td>71-75</td>
<td>21.6-23.8</td>
<td></td>
<td>Rest periods and water breaks every 20 to 30 minutes; limits placed on intense activity</td>
</tr>
<tr>
<td>76-79</td>
<td>24.5</td>
<td>26.1</td>
<td>Practice curtailed and modified considerably</td>
</tr>
<tr>
<td>&gt; 80</td>
<td>&gt; 26.5</td>
<td></td>
<td>Practice cancelled</td>
</tr>
</tbody>
</table>
Heat Illnesses

- Heat cramps
  - Involuntary muscle spasms that occur after intense physical activity
- Heat exhaustion
  - Most common heat illness
- Heat stroke
  - Most serious and requires immediate medical attention
Heat Index – How hot is too hot?