BPK 312 Nutrition for Fitness & Sport
Lecture 8a

Exercise, Fluid Balance & Hydration/Rehydration

1. Effects of Exercise on GI Function & Gastric Emptying Rate (GER)
2. Gastric Emptying Rate (GER) and Heat Stress
3. Digestion & Absorption of Water
4. Fluid Losses and Rehydration
5. Hydration During Competition & Exercise
6. Hyponatremia
7. Macro- & Micro-Nutrients in Hot Environments
8. Exercise & Disorders of the GI Tract
Lecture 8a Learning Objectives (LO8)

LO8-1: To describe and explain Gastric Emptying Rate (GER) plus the effects of exercise and heat stress on GER.

LO8-2: To describe and explain the digestion and absorption of water during exercise and during heat stress.

LO8-3: To describe and explain the best nutritional strategies for rehydration during exercise and competition plus to describe physiological mechanisms underlying carbohydrate, electrolyte and water uptake from the GI.

LO8-4: To define and explain the condition of hyponatremia. This includes a description of the physiological mechanisms underlying this condition as well as the nutritional strategies to take so as to avoid it.

LO8-5: To describe, if, and how, the dietary needs for macro- & micro-nutrients change in athletes exercising in hot environments.

LO8-6: As a sports and fitness nutritionist to: i) describe disorders of the GI tract (ii) be ready to describe what dietary interventions can be taken, when possible, to help correct these disorders and (iii) suggest dietary strategies to improve fluid, micro- and macronutrient uptakes for individuals with GI tract disorders.
1. Effects of Exercise GI on Function

A common measure is Gastric Emptying Rate (GER)
• *GER is widely variable btwn individuals, espec. @<VO$_{2\text{MAX}}$*
• ↓GER with: ↓food/fluid solution volume*, ↑temperature, ↑caloric content, ↑meal osmolality & ↑acidity
  * very important since b/c GER ↓’s exponentially w/ food/fluid solut. volume

- Acute & chronic exercise both effect GI function (fxn)
- Acutely for ingested CHO beverages or H$_2$O:

**Intensity**- light/mod. intensity of 20-60% VO$_{2\text{MAX}}$ = ↑GER vs rest
  \[ \geq 75\% \text{ VO}_ {2\text{MAX}} = \downarrow \text{GER vs rest} \]

**Mxns?** ↑GER may be due to: i) in mod. intensity exercise.
   ↑abdominal contractions & ↑gastric pressure & ii) ↑rate of transit vs. rest in descending colon with light/mod. intensity exercise

**Mode** –light to moderate intensity running ↑GER vs. cycling

**Duration** – limited information, 1 study showed no Δ vs rest over 2 h exercise at 80% VO$_{2\text{MAX}}$
Gamma camera scintigraphy w images at intervals 1- 4 h post meal
- most common method/gold standard
- non-invasive, but radiation exposure limits its use
- standard meal, with radiolabelled meal Technetium-99m (\(^{99m}\)Tc)
- images used to assess % left in stomach from t=0 h, gives a GER measure

1. Effects of Exercise GI on Function

Gastric Emptying Rate (GER)

Szarka & Camiller 2009
Am J Physiol - GI
296:G461-G475
2. Gastric Emptying Rate and Heat Stress

- GER probably ↓s during heat stress, mxns unclear
- A dehydrated state ↓s splanchnic blood flow during exercise
- ↑T_{CORE} slows gastric and intestinal motilities
- overall decreased GI fxn during exercise
3. Digestion & Absorption of Water

Fig. 3.13 Estimated daily volumes of H₂O that enters the small & large intestines as well as the amount absorbed by each section of the GI.

GI absorbs ~9000 mL/day

Oral intake 2000 mL

Secretions from/into:
- Saliva glands 1500 mL
- Bile 500 mL
- Stomach 2000 mL
- Pancreas 1500 mL
- Small & Large Intestines 1500 mL

% of total excretions or secretions absorbed:
- Proximal Small Intestine = 6500mL/9000mL = 72%
- Distal Small Intestine = 1800mL/9000mL = 20%
- Large Intestines 700mL/9000 mL = 8% (Fig 3.13 gives 5.6%)

Water absorption - passively by osmosis from SI
4. Fluid Losses and Rehydration

Heat-Dissipating Mechanisms

- **Circulation**
  - “Workhorse” to maintain thermal balance; venous vessels dilate heat loss from skin; ↑HR and ↑Q with 15-25% of Q to skin in extreme heat stress

- **Evaporation**
  - sweating is in proportion to intensity of work/T_{CORE}

- **Hormones** - to conserve water and electrolytes
  - Antidiuretic hormone (ADH)-from pituitary gland; ↑H₂O reabsorption from kidney tubules & concentrates urine
  - Aldosterone - from adrenal cortex; ↑Na⁺ reabsorption from kidney tubules & ↓sweat osmolality by ↓[Na⁺]_{SWEAT}
4. Fluid Losses and Rehydration

**Water Loss in Hot Environments**

- Dehydration is when fluid losses > fluid intake
- Dehydration Definition: refers to an imbalance in fluid dynamics when fluid intake does not replenish water loss from either hyper-hydrated or normally hydrated states.
- Considerable water loss occurs during several hours of intense exercise in a hot environment.
- Both intracellular and extracellular compartments contribute to fluid deficit.
- Risk of heat illness greatly increases if a dehydrated person exercises in hot or cold environ. conditions
- Dehydration of 3% of body weight slows gastric emptying rate & gives epigastric cramps
- Sweat is hypotonic wrt other body fluids; w/ dehydration plasma volume ↓’s & there is an ↑ of plasma osmolality.
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:
  - ↓sweating, ↓peripheral blood flow, ↑HR, earlier fatigue vs. the euhydrated
  - for each 1 L loss of sweat ↑HR by 8 bpm & Q ↓ x 1 L

- Large proportion of this fluid loss is from plasma; progressively impairs CV function

- The risk for dehydration increases during vigorous cold-weather exercise.
4. Fluid Losses and Rehydration

- vigorous cold-weather exercise, very low air humidity

**Fig 10.7:** Factors increasing potential for dehydration during exercise in cold.
4. Fluid Losses and Rehydration

Water Replacement: Rehydration

- Properly scheduling fluid replacement maintains plasma volume so circulation and sweating progress optimally.
- A well-hydrated individual always functions at a higher physiologic & performance level than a dehydrated person.
- Achieving *hyperhydration* before exercising in a hot environment protects against heat stress because it:
  - delays dehydration
  - ↑ sweating during exercise
  - ↓ rise in $T_{\text{CORE}}$
- Consume: ↑ fluids for 24 h prior and 400-600 mL 20’ prior to exercise in heat ↑’s GER
- Structured fluid replacement is important since sweat & fluid losses are often 2.0 L/h whereas max GER is 1 L/h

*cf hyponatremia
4. Fluid Losses and Rehydration

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
4. Fluid Losses and Rehydration

- Thirst is not enough
- Drink 125-150% of fluid loss gauged by weight loss; 25-50% is lost as urine
- Flavored drinks aid in rehydration

1 lb or 0.455 kg needs 450 ml fluid replaced

Mackinzie should drink ~1000 mL of fluid/hr of activity to remain well hydrated (250 mL/15 min).

*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

Fig 10.8: Computing the magnitude of sweat loss & rate of sweating in exercise.
4. Fluid Losses and Rehydration

**Sodium and Rehydration**

- A moderate amount of Na\(^+\) added to a rehydration drink provides more complete rehydration.

- Maintaining a relatively high plasma concentration of Na\(^+\) helps:
  - Sustain the thirst drive
  - Promote retention of ingested fluids
  - More rapidly restore lost plasma volume during rehydration
4. Fluid Losses and Rehydration

Sodium & Rehydration

• N = 6, 1.9% loss of body mass
• Na⁺ at 100 mmol/L best facilitates rehydration (cf #6, Lec 8)
• Plasma [Na⁺] = 138-142 mmol/L

• Seems prudent to add 1/3 teaspoon NaCl per liter for prolonged exercise in the heat

Fig 10.9: Cumulative urine output during recovery from exercise-induced dehydration. The oral rehydration beverage consisted of four test drinks containing sodium in a concentration of 2 (A), 26 (B), 52 (C), or 100 (D) mmol/L.
5. Hydration During Competition & Exercise

a) Factors Affecting

Fig. 8.6: Major factors that affect emptying and fluid absorption

### Intestinal Fluid Absorption

- **Carbohydrate:** low to moderate level of glucose + sodium
  - Increases fluid absorption
- **Sodium:** low to moderate level
  - Increases fluid absorption
- **Osmolality:** hypotonic to isotonic fluids containing NaCl and glucose
  - Increases fluid absorption

### Gastric Emptying

- **Volume:** increased
  - Increases gastric volume emptying rate
- **Caloric content:** increased
  - Energy content decreases emptying rate
- **Osmolality:** increased
  - Solute concentration decreases emptying rate
- **Exercise:** intensity exceeding rate of 75% of maximum
  - Decreases emptying rate
- **pH:** marked deviations from 7.0
  - Decrease emptying rate
- **Hydration level:** dehydration
  - Decreases gastric emptying and increases risk of gastrointestinal distress

Temperature: Cooler vs. warmer food solutions increase GER

Blood osmolality = 285-295 mOsmoles/kilogram
5. Hydration During Competition & Exercise

b) Net absorption vs. Osmolality

↓ gastric emptying rates (GER):
- for fluids with > m280 Osmol/kg
- high caloric content fluids

- GER is less affected if plasma volume is maintained & drink includes maltodextrin - glucose polymer 3-20 glucose units facilitates fluid movement from stomach

- Adding Na\(^+\) passively facilitates glucose uptake in co-transport from SI

- 2\(^{nd}\) & 3\(^{rd}\) transportable substrates ↑H\(_2\)O absorption by osmosis

Fig. 8.7: Net water movement vs. osmolality in the intestinal test segment

*NB* H\(_2\)O absorption from GI tract (-) value & secretion to the GI tract is (+) value\(^{17}\)
5. Hydration During Competition & Exercise

c) Oral Rehydration Solutions

- Provide additional glucose
- Minimize the effects of dehydration on:
  - Cardiovascular dynamics
  - Temperature regulation
  - Exercise performance
- Adding electrolytes aids:
  - Maintaining thirst mechanism
  - Reducing risk of hyponatremia

- Table 8.2 Gives Examples of Beverages for hydration/rehydration
### 5. Hydration During Competition & Exercise

#### TABLE 8.2 Comparison of Various Beverages Used by Athletes to Replace Fluid Lost in Exercise

<table>
<thead>
<tr>
<th>Beverages</th>
<th>Flavors</th>
<th>CHO Source</th>
<th>CHO conc (%)</th>
<th>Sodium (mg)</th>
<th>Potassium (mg)</th>
<th>Other Minerals and Vitamins</th>
<th>Osmolality (mOsm \cdot L^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>GATORADE&lt;sup&gt;a&lt;/sup&gt; Thirst Quencher Stokely-Van Camp, Inc., a subsidiary of the Quaker Oats Company</td>
<td>Lemon-lime, lemonade, fruit punch, orange, citrus cooler S/G (powder)</td>
<td>6</td>
<td>110</td>
<td>25</td>
<td>Chloride, phosphorus</td>
<td>280–360</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S/G syrup solids (liquid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceed&lt;sup&gt;a&lt;/sup&gt; Ross Laboratories</td>
<td>Lemon-lime, orange</td>
<td>G polymers/F</td>
<td>7.2</td>
<td>50</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quickick&lt;sup&gt;a&lt;/sup&gt; Cramer Products, Inc.</td>
<td>Lemon-lime, fruit punch, orange, grape, lemonade</td>
<td>F/S</td>
<td>4.7</td>
<td>116</td>
<td>23</td>
<td>Chloride, calcium, magnesium, phosphorus</td>
<td>250</td>
</tr>
<tr>
<td>Sqwincher, the Activity Drink Universal Products, Inc.</td>
<td>Lemon-lime, fruit punch, lemonade, orange, grape, strawberry, grapefruit</td>
<td>G/F</td>
<td>6.8</td>
<td>60</td>
<td>36</td>
<td>Calcium, chloride, phosphorus</td>
<td>305</td>
</tr>
<tr>
<td>10-K Beverage Products, Inc.</td>
<td>Lemon-lime, orange, fruit punch, lemonade, iced tea S/G/F</td>
<td>6.3</td>
<td>52</td>
<td>26</td>
<td>Chloride, phosphorus, calcium, magnesium, vitamin C</td>
<td>470</td>
<td></td>
</tr>
<tr>
<td>USA Wet Texas Wet, Inc</td>
<td>Lemon-lime, orange, fruit punch</td>
<td>S</td>
<td>6.8</td>
<td>62</td>
<td>44</td>
<td>Vitamin C, chloride, phosphorus</td>
<td>350</td>
</tr>
</tbody>
</table>
# 5. Hydration During Competition & Exercise

## TABLE 8.2 Comparison of Various Beverages Used by Athletes to Replace Fluid Lost in Exercise

<table>
<thead>
<tr>
<th>Beverages</th>
<th>Flavors</th>
<th>CHO Source</th>
<th>CHO conc (%)</th>
<th>Sodium (mg)</th>
<th>Potassium (mg)</th>
<th>Other Minerals and Vitamins</th>
<th>Osmolality (mOsm·L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coca-Cola, USA</td>
<td>Regular, Classic, Cherry</td>
<td>HFCS/S</td>
<td>10.7–11.3</td>
<td>9.2</td>
<td>trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprite, USA</td>
<td>Lemon-lime</td>
<td>HFCS/S</td>
<td>10.2</td>
<td>28</td>
<td>trace</td>
<td>Chloride, phosphorus</td>
<td>450</td>
</tr>
<tr>
<td>Cranberry juice cocktail</td>
<td></td>
<td>HFCS/S</td>
<td>15</td>
<td>10</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange juice</td>
<td></td>
<td>F/S/G</td>
<td>11.8</td>
<td>2.7</td>
<td>510</td>
<td>Phosphorus</td>
<td>600–715</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td>low&lt;sup&gt;b&lt;/sup&gt;</td>
<td>low&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PowerAde</td>
<td>HFCS/M</td>
<td>8</td>
<td>73</td>
<td>33</td>
<td></td>
<td></td>
<td>695</td>
</tr>
<tr>
<td>All-Sport</td>
<td>HFCS</td>
<td>8–9</td>
<td>55</td>
<td>55</td>
<td></td>
<td>Phosphorus, vitamin C</td>
<td>890</td>
</tr>
<tr>
<td>10 K</td>
<td>S/G/F</td>
<td>6.3</td>
<td>54</td>
<td>25</td>
<td></td>
<td>Phosphorus, calcium, iron, vitamins C and A, niacin, riboflavin, thiamine</td>
<td>690</td>
</tr>
<tr>
<td>Cytomax</td>
<td>FCS/S</td>
<td>7–11</td>
<td>10</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakthrough</td>
<td>M/F</td>
<td>8.5</td>
<td>60</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Everlast</td>
<td>S/F</td>
<td>6</td>
<td>100</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydra Charge</td>
<td>M/F</td>
<td>8</td>
<td>—</td>
<td>trace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SportaLYTE</td>
<td>M/F/G</td>
<td>7.5</td>
<td>100</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Serving size, 8 fluid oz.

<sup>b</sup>Depends on water source.

* S = sucrose; F = fructose; G = glucose; HFCS = high fructose corn syrup; M = maltodextrin
5. Hydration During Competition & Exercise

d) Carbohydrate-Electrolyte Beverages

- ideal hydration solution contains between 5% & 8% CHO.
- permits CHO replenishment without adversely affecting fluid balance and thermoregulation.
- Maintains glucose metabolism & preserves glycogen during prolonged exercise
5. Hydration During Competition & Exercise
d) Carbohydrate-Electrolyte Beverages

High Fructose Corn Syrup (HFCS) in Beverages

- HFCS- cheaper vs. sugar from sugarcane & sugar beets
- HFCS in most popular soft drinks
- independent analysis showed:
  - mean 59% HFSC by volume & as high as 85-128% higher total sugar content than on label
- HFCS also in fruit juice concentrate, energy drinks, vitamin water beverages
- helps increase risk of metabolic syndrome including Type II diabetes by 26% of those drinking 2 HFCS drinks/day vs. those drinking < 1 HFCS/month
- compare to Lec 9, fructose for pre-exercise feeding
5. Hydration During Competition & Exercise

e) Hydration during Exercise

- Adding moderate amounts of sodium to the ingested fluid helps to maintain plasma sodium concentration.
- Benefits ultra-endurance athlete at risk for *hyponatremia*.
- Maintaining plasma osmolality with added sodium in the hydration beverage reduces urine output and sustains the sodium-dependent osmotic drive to drink.
5. Hydration During Competition & Exercise
e) Hydration during Exercise

5-8% CHO-electrolyte drink consumed in the heat during exercise in the heat hydrates as well as water.

1000 mL/h is probably optimal volume to offset dehydration b/c larger volumes give GI discomfort.

Fig. 8.8: Fluid volume to ingest each hour to obtain noted amount of CHO.
6. Hyponatremia

- hyponatremia is when blood $[\text{Na}^+] < 135$ mEq/L
- Normal $[\text{Na}^+]$ range is 135 mEq/L – 145 mEq/L
- Can occur due to excessive $\text{H}_2\text{O}$ intake that is hypotonic wrt body fluids & after ↑↑Na$^+$ loss in sweat
- Sustained ↓$[\text{Na}^+]_{\text{plasma}}$ creates an osmotic imbalance across blood–brain barrier (BBB) causing rapid $\text{H}_2\text{O}$ influx
- gives swelling of brain tissue that produces a cascade of symptoms ranging from mild to severe.
  - Mild: headache, confusion malaise, nausea, cramping
  - Severe: seizures, coma, pulmonary edema, cardiac arrest, death
6. Hyponatremia

• is mainly in non-elite marathoners/ultra-marathoners

Predisposing factors include:

- (i) weight gain pre to post race

- (ii) consuming > 3 L in the race,

- (iii) marathon race time > 4 h

- (iv) low body mass index
6. Hyponatremia

**Fig 10.10A:** Factors that contribute to the development of hyponatremia.

ADH = AVP = arginine vasopressin, cystic fibrosis transmembrane conductance regulator (CFTR)
6. Hyponatremia

Fig 10.10 B: Physiologic consequences of hyponatremia.
6. **Hyponatremia**

5 Steps to avoid over hydration and hyponatremia:

i. 2-3 h pre exercise drink 400-500 mL of fluid

ii. drink 100-300 mL of fluid 30 min before exercise

iii. drink no more than 1000 mL/h of plain H$_2$O spread over 15 min intervals during or after exercise

iv. Add $\frac{1}{4}$ to $\frac{1}{2}$ teaspoon of NaCl per 1 L; sports drinks usually have lower [ ] than this but they help provide water, CHO & electrolytes

v. Do not restrict dietary salt prior to the exercise

Including glucose in the drink facilitates water uptake by glucose-Na+ transport mxn.
# 7. Macro- & Micro-Nutrients in Hot Environments

## Energy & Macronutrient Intakes vs. Mean Temperature

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hawaii</th>
<th>Guadalcanal</th>
<th>Guam</th>
<th>Iwo Jima</th>
<th>Luzon</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Temp (°F)</td>
<td>+73</td>
<td>+85</td>
<td>+81</td>
<td>+78</td>
<td>+83</td>
<td>+65</td>
</tr>
<tr>
<td>kcal-day¯¹</td>
<td>3400</td>
<td>3400</td>
<td>3500</td>
<td>3500</td>
<td>3200</td>
<td>3900</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>460</td>
<td>450</td>
<td>480</td>
<td>470</td>
<td>430</td>
<td>520</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>124</td>
<td>129</td>
<td>123</td>
<td>129</td>
<td>120</td>
<td>147</td>
</tr>
<tr>
<td>Protein total (g)</td>
<td>110</td>
<td>110</td>
<td>115</td>
<td>115</td>
<td>100</td>
<td>125</td>
</tr>
</tbody>
</table>

7. Macro- & Micro-Nutrients in Hot Environments

Energy & Macronutrient Intakes vs. Mean Temperatures

- redrawn from Table 10.5
- ↑ temperatures gave ↓ in total energy (kcal) & macronutrient intakes (g)
- negative correlation between these mean daily intakes of rations & mean ambient temperatures
- not so for macronutrient intakes expressed as % of total energy intake
- possibly due to ↓ activity in hot climates

Energy Intake (kcal/day) vs. Mean Temperature (°F)

- Energy Intake: $y = -25.3x + 5438.4$ (R² = 0.65)
- CHO Intake: $y = -3.32x + 725.7$ (R² = 0.65)
- Fat Intake: $y = -0.99x + 205.5$ (R² = 0.58)
- Protein Intake: $y = -0.81x + 175.1$ (R² = 0.53)
7. Macro- & Micro-Nutrients in Hot Environments

Micronutrient Intakes in Hot Environments

Mineral Requirements

- Prolonged exercise in heat gives $\downarrow [\text{minerals}]_{\text{PLASMA}}$ due to $\uparrow$ mineral excretion in urine or sweat; includes Cr, Cu, Zn, Fe
- Can persist for several days into recovery
- Research must confirm if there are $\downarrow$ endurance capacity, $\downarrow$ antioxidant defenses or $\downarrow$ recovery from muscle injury due to these $\downarrow [\text{minerals}]$
- Little known about effect of dietary manipulations of minerals on changes of [minerals] in hot weather exercise

Vitamin Requirements

- neglible effects of the small losses of vitamins in sweat
- WW II intakes of Vitamin C @ 250 mg/day > RDA thought to decrease stress during acclimatization
- May be prudent for a marginal increase in Vit C intake
8. Exercise & Disorders of the GI tract

- Constipation
- Diarrhea
- Diverticulosis - pouches
- Heartburn/reflux
- **Irritable Bowel Syndrome (IBS)** - is symptom-based diagnosis; spastic colon w/chronic abdominal pain, discomfort, bloating, diarrhea or constipation may persist
- **Gas** - multiple causes including but not limited to fermentation of incompletely digested protein, incomplete sugar digestion,
- **Functional Dyspepsia** - upset stomach, reason for it is unresolved & may be due to underlying medical problem or disease
1. Effects of Exercise on GI Function & Gastric Emptying Rate (GER)
2. Gastric Emptying Rate (GER) and Heat Stress
3. Digestion & Absorption of Water
4. Fluid Losses and Rehydration
5. Hydration During Competition & Exercise
6. Hyponatremia
7. Macro- & Micro-Nutrients in Hot Environments
8. Exercise & Disorders of the GI Tract