Nutrition in Extreme Environments

1. Learning Objectives
2. Environmental Heat Stress & Nutrition
3. Thermoregulation & Exercise in the Heat
4. Heat Tolerance and Acclimation/Acclimatization
5. Evaluating Environmental Heat Stress
6. Heat Illnesses & Nutrition
1. Lecture 8b Learning Objectives (LO8)

LO8-1: To give an overview of how & why nutritionists should be prepared to give advice to people who are active in stressful hot or cold environments.

LO8-2: To understand, describe and explain how body core temperature is regulated in humans in hot environments. This includes an understanding of the different avenues of heat exchange to and from the body as well as how adequate nutrition helps to ensure better thermoregulation during exercise in extreme environments.

LO8-3: To describe the physiological adaptations evident with heat acclimation/acclimatization so as to be able to explain how: (i) this changes nutritional needs for athletes exercising in the heat, and, (ii) brings about a reduced risk of heat injuries due to dehydration and imbalances of electrolytes in body fluids.

LO8-4: To describe as well as explain different methods and indices of evaluating heat stress in hot environments so sports and fitness nutritionists can be better prepared to advise individuals and athletes on nutritional needs in these conditions.

LO8-5: To (i) give a brief explanation of both the physiological and nutritional bases of heat cramps, heat exhaustion and exertional heat stroke and (ii) to give the nutritional and clinical methods to prevent and/or treat these disorders.
2. Environmental Heat Stress & Nutrition

Overview:

• Claude Bernard (1813-1878) *milieu intérieur*

• W. Cannon (1871-1945) *homeostasis*; pH & body temperature

• Knowledge of the physiological mechanisms underlying thermoregulation is the best means to help reduce temperature related injuries for people that are active or competing in hot or cold environments

• Provide active people, coaches, athletes, trainers and event organizers the tools to give nutritional advice to help limit *dehydration* during and after exercise

• To effectively give nutritional advice during exercise or competition in hot environments, it is important to be able to understanding how to quantify the stress of the environment

• The focus of the sports nutritionist needs a *behavioral approach*; prudent scheduling, acclimatization/acclimation periods, choice of proper clothing, making fluid & electrolyte replacement drinks available before, during and after exercise
3. Thermoregulation & Exercise in the Heat

Body Temperatures

- Hyperthermia = \( T_{\text{CORE}} \) \geq 1°C.
- \( T_{\text{CORE}} \) = deep tissues
- Shell or peripheral body temperature: = temperature of peripheral tissues;
  - Sizes of ‘core’ & ‘shell’ \( \uparrow \) or \( \downarrow \) depending on states of the peripheral vessels
  - No definite anatomical boundaries between core & shell
- \( T_{\text{CORE}} \) rises quickly when heat gain > heat loss during vigorous exercise in a warm environment.
Hypothalamic Regulation of Core Temperature

- Hypothalamus is a central control center for temperature regulation of $T_{\text{CORE}}$
- A prevailing view is it functions as a thermostat that controls thermolytic responses in hot environments
- It initiates responses to protect the body from heat gain
- Thermogenic and heat conservation responses are also controlled here

3. Thermoregulation & Exercise in the Heat

Air Conditioner Analogy

- **semantics:** control vs. regulation
- Negative feedback
- 1960s Hammel (USA) & Benzinger (Germany)
3. Thermoregulation & Exercise in the Heat

Mechanisms of Temperature Regulation

- Become activated in two ways:
  - Local temperature changes in the hypothalamus directly stimulate this thermoregulatory control center.
  - Thermal receptors in the CNS and skin provide afferent input to modulate hypothalamic activity.

- Eccrine sweat glands in the skin and blood vessels in the subcutaneous tissue effector organs in efferent responses help to regulate temperature by dissipating heat

- After the body warms heat is lost from the body surface along with exhaled gases during hyperventilation
3. Thermoregulation & Exercise in the Heat

Avenues of Heat Gain or Heat Loss

- ± Radiation (R)
- ± Conduction (C_D)
- ± Convection (C_V)
- - Evaporation (E)
- + Metabolism (M)
- \( S = \text{net rate of heat exchange} \)
- Unit: Watt = Joule \( \cdot \) s^{-1}

\[ S = M - E \pm R \pm C_V \pm C_D \]

Fig 10.1: Factors that contribute to heat gain & heat loss to regulate core temperature at about 37.0±1.0°C
3. Thermoregulation & Exercise in the Heat

Rate of Radiation Heat Transfer

- Objects > -273°C emit electromagnetic heat waves.
- Radiant heat energy leaves the body *through air* to solid cooler objects around us.
- Human body absorbs radiant heat energy when the temperature of objects in the environment exceeds skin temperature.
- Varies with:
  - Surface temps & areas of the body plus surrounding objects
  - Rate of heat emission
  - Emissivity ($\varepsilon$) of a body = ability of body to emit energy by radiation. It is ratio of the energy emitted to that energy emitted by a black body at the same temperature.
  - Rule of thumb: $\varepsilon$ is closer to 1 for blacker, duller clothes etc.
3. Thermoregulation & Exercise in the Heat

Rate of Conductive Heat Transfer

- Transfers heat directly through a liquid, solid, or gas from one molecule to another.
- Heat transfer between 2 objects in contact.
- 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.
- Varies with fat layer as well as clothing insulation, mainly due to trapping of air.
3. Thermoregulation & Exercise in the Heat

Rate of Convective Heat Transfer

- Air or fluid movement within & over surface of the body
- Warm air/fluid next to the skin acts as a zone of insulation, *i.e. a boundary layer*
- If cool air continuously replaces the warmer air surrounding the body, heat loss increases.

- Difficult to assess but varies with:
  - Temperature difference from body to air or fluid
  - Body’s shape, dimensions & curvature
  - Fluid or gases *thermal expansion coefficient, density, viscosity and velocity.*
  - *thermal expansion coefficient = change in length/°C increase (i.e. objects expand when heated)*
3. Thermoregulation & Exercise in the Heat

**Rate of Evaporation**

- *Is the major physiologic defense against overheating in humans*
- H₂O vaporization from respiratory passages & skin surface continually transfers heat to the environment.
- In response to heat stress, 2–4 million eccrine sweat glands secrete large quantities of *hypotonic* saline solution.
- Cooling occurs when sweat *evaporates* from skin surface.
- Latent Heat of Evaporation is 2400-2500 J/g H₂O
- Evaporation depends on:
  - surface temperature
  - H₂O vapor density diff. between surface & surrounding air
  - resistance to H₂O loss by the surface

*E varies with dramatically ambient Relative Humidity (RH)*
3. Thermoregulation & Exercise in the Heat

Rate of Evaporation cont'

Fig 10.2: **Left**, Skin & underlying structures. **Right**, Dynamics of heat exchange for heat dissipation from the body; insensible perspiration
3. Thermoregulation & Exercise in the Heat

Rate of Metabolism (M)

- metabolic Heat Liberation (M)
- when a fuel is oxidized heat is liberated
- amount of heat liberated is proportional to type of fuel oxidized & rate of metabolism
- heat liberated varies with proportions of fat/CHO oxidized
  - Glucose ~17 kJ/g
  - Fatty acids ~38 kJ/g (palmitic acid)
  - Protein (urea) ~ 18 kJ/g
- (↑ fat oxidized = ↑ heat liberated)

1 kilocalorie = 4.184 kiloJoule
3. Thermoregulation & Exercise in the Heat

Fig 10.3: Heat liberation within active muscle & its subsequent transfer from the core to the skin.

- Under appropriate environmental conditions, excess body heat dissipates to the environment & core temperature stabilizes within a narrow range.
- $T_{\text{CORE}}$ increases in proportion to exercise intensity & reaches a new steady state.
3. Thermoregulation & Exercise in the Heat

Environmental Heat Stress

- Increased ambient temperature reduces the effectiveness of heat loss by conduction, convection, and radiation.

- For same exercise intensity, greater sweating rate in hot-humid vs. cool dry air

- Sweat rate increases progressively with increasing exercise intensity

- Fluid lost must be replaced to allow effective thermoregulation

**Fig 10.4**: Sweat rate as a function of exercise intensity.
4. Heat Tolerance and Acclimation/Acclimatization

**Acclimation/Acclimatization**

- Heat acclimation/acclimatization refers to the physiologic adaptations that improve heat tolerance.
- An acclimatized individual has 8 main physiological adaptations:
  1. larger quantities of blood shunt to cutaneous vessels
  2. more effective distribution of cardiac output ($Q$)
  3. an onset of sweating at lower $T_{\text{CORE}}$
  4. $2 \times$ sweat capacity after 10 d of acclimation to heat
  5. Sweat is more dilute $\downarrow[\text{Na}^+]$
  6. More effective sweat distribution
  7. Lower $T_{\text{CORE}}$ & HR for given exercise
  8. Less reliance on CHO as a fuel
4. Heat Tolerance and Acclimation/Acclimatization

**Acclimation/Acclimatization**

**Fig. 10.11**: Average rectal temperature, heart rate, and sweat loss during 100 minutes of daily heat-exercise exposure for 9 consecutive days.
Age Differences

- 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 rate of recovery from dehydration

- Younger ages:
  - More sweat glands but ↓sweat/gland & longer to acclimate vs. adults = limited exercise capacity in heat
4. Heat Tolerance and Acclimation/Acclimatization

Factors Impacting Physical Strain from Heat

- Body size and fatness
- Level of training
- Duration of Activity
- Acclimation/Acclimatization
- Adequacy of hydration
- External factors: e.g. exercise clothing, ambient conditions,
Other Factors Affecting Heat Tolerance

- Sex
  - Men sweat more than women
  - Women show similar heat tolerance as men.

- Body fat
  - Specific heat of fat is greater vs. lean tissue
  - Lower Body Surface Area BSA/Weight = less area for sweat evaporation
  - Increased mass = increased metabolic cost of weight bearing exercise
Exercise Clothing

- Cottons and linens readily absorb moisture.
- Heavy “sweatshirts” and rubber or plastic garments produce high relative humidity close to the skin.
- Area between skin and clothing is called the microclimate.
- Dark colors absorb light rays & add to radiant heat gain.
- Light colors reflect heat rays away from the body, reduces radiant heat gain.
- Moisture-wicking fabrics provide optimal transfer of heat and moisture from the skin to the environment.
5. Evaluating Environmental Heat Stress

Relative Humidity (RH):

- For increasing dry bulb temperature ($T_{DB}$) there is an increasing capacity for water vapor

- $RH = \frac{\text{actual water vapor}}{\text{H}_2\text{O vapor capacity for } T_{DB}} \times 100$

- ↓ air temp = ↓ air vapor capacity

- ↑ air temp = ↑ air vapor capacity

Psychrometric Chart.
- hyperbolic lines give RH

![Psychrometric Chart](image-url)
5. Evaluating Environmental Heat Stress

Environmental Heat Stress Indices

(i) Wet Bulb-Globe Temperature (WB-GT)

- Used to evaluate the environment for its potential thermal challenge
- An index of environmental heat stress
- Incorporates ambient temperature, relative humidity, and radiant heat

\[ WB-GT = 0.1 \times DBT + 0.7 \times WBT + 0.2 \times GT \]

- DBT = dry bulb temperature
- WBT = wet bulb temperature
- GT = globe temperature
5. Evaluating Environmental Heat Stress

Environmental Heat Stress

(1) WB-GT

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

- Use discretion, especially if unconditioned or unacclimated
- Avoid strenuous activity in the sun
- Avoid exercise training

<table>
<thead>
<tr>
<th>WBT Range</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
</tr>
<tr>
<td>60</td>
<td>15.5</td>
</tr>
<tr>
<td>61 – 65</td>
<td>16.2 – 18.4</td>
</tr>
<tr>
<td>66 – 70</td>
<td>18.8 – 21.1</td>
</tr>
<tr>
<td>71 – 75</td>
<td>21.6 – 23.8</td>
</tr>
<tr>
<td>76 – 79</td>
<td>24.5 – 26.1</td>
</tr>
</tbody>
</table>

- No prevention necessary
- Alert all participants to problems of heat stress and importance of adequate hydration
- Insist that appropriate quantity of fluid be ingested
- Rest periods and water breaks every 20 to 30 minutes; limits placed on intense activity
- Practice curtailed and modified considerably

> 80 > 26.5
- Practice cancelled

Fig 10.5: Top Wet Bulb-Globe Temperature (WB-GT) and Bottom Wet Bulb Temperature Guides (WBT) guides for outdoor activities.
5. Evaluating Environmental Heat Stress

Environmental Heat Stress Indices

(iii) The Heat Index

- uses RH and $T_{DB}$; this gives an apparent temperature in °F
- for shady, light wind conditions
- if full sunlight exposure values are increased by 15°F

**Apparent temperature** is a term for perceived outdoor temperature, caused by the combined effects of air temperature, relative humidity and wind speed.

- for a perceived temperature the air feels hotter than it actually is, because of the reduction in evaporation of perspiration.

---

**Fig 10.6: The Heat Index (USA)**
5. Evaluating Environmental Heat Stress

Canadian HUMIDEX (HUMidity + InDEX)

- how hot does it feel?
- combines effect of temperature & humidity
- unitless value based on dew point and gives the perceived dry bulb temperature (DBT)
- Although unitless it gives an approximate perceived DBT
  - e.g. DBT is 25°C but it feels like approximately 35°C
- Increasing humidity gives an increasing perceived temperature

Humidex = Air temperature + 0.5555 \times (6.11 \times e^{5417.7530 \times \left( \frac{1}{273.16 - \text{dewpoint in kelvins}} \right) - 10})

Dew Point: Atmospheric temperature below which water droplets begin to condense and dew can form (varies according to pressure and humidity)
## 5. Evaluating Environmental Heat Stress

**Canadian HUMIDEX (HUMidity + InDEX)**

cont’

<table>
<thead>
<tr>
<th>Humidex 1 – Moderate physical work, unacclimatized worker. OR Heavy physical work, acclimatized worker</th>
<th>Response</th>
<th>Humidex 2 – Moderate physical work, acclimatized worker. OR Light physical work, unacclimatized worker</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>• supply water to workers on an “as needed” basis</td>
<td>32-35</td>
</tr>
</tbody>
</table>
| 30-33 | • post Heat Stress Alert notice  
• encourage workers to drink extra water  
• start recording hourly temperature and relative humidity | 36-39 |
| 34-37 | • post Heat Stress Warning notice  
• notify workers that they need to drink extra water  
• ensure workers are trained to recognize symptoms | 40-42 |
| 38-39 | • provide 15 minutes relief per hour  
• provide adequate cool (10-15°C ) water  
• at least 1 cup (240 mL) of water every 20 minutes  
• workers with symptoms should seek medical attention | 43-44 |
| 40-42 | • provide 30 minutes relief per hour in addition to the provisions listed previously | 45-46* |
| 43-44 | • if feasible provide 45 minutes relief per hour in addition to the provisions listed above  
• if a 75% relief period is not feasible then stop work until the Humidex is 42°C or less | 47-49 |
| 45 or over | • stop work until the Humidex is 44°C or less | 50* and over |

5. Evaluating Environmental Heat Stress

Canadian HUMIDEX (HUMidity + InDEX)

Limitations of Humidex

• Doesn’t account for radiant heat load which influences perceived temperature
• Doesn’t account for wind which effects evaporation
• People react differently to humidity, they sweat more or less which gives varied evaporation heat loss and perception
• Age and health, including respiratory issues and fitness levels, affect how hot it feels.
• Older person might get heat stroke in situation that causes mild discomfort in teen or child
6. **Heat Illnesses & Nutrition**

- Given in order of increasing severity, but there is no clear separation between these 3 heat illnesses

(i) **Heat Cramps**
- Involuntary muscle spasms after intense physical activity
- Likely from dehydration & changes in [electrolyte]
- More likely with ↑ sweat rate & ↑[Na⁺]_{SWEAT}

(ii) **Heat exhaustion**
- Most common heat illness
- More likely in dehydrated, untrained, unacclimated & during a heat wave
- Mechanism: CV adjustments are ineffective, depletion of ECF including plasma after excessive sweating
- ↓s central blood volume, ↓venous return & ↓Q
- $T_{\text{CORE}}$ OK, little ↓ in sweat but weak rapid pulse, low BP on standing, headache, nausea/dizziness, goose bumps or horripilation, general weakness
6. Heat Illnesses & Nutrition

(iii) Exertional Heat stroke = Medical Emergency

- Most serious & requires immediate medical attention
- Most susceptible are unfit, young, unacclimated, obese
- Failure of temp. regulation, no sweat, ↑↑ T_{CORE}, skin hot & dry
- If left untreated, disability becomes fatal from circulatory collapse, oxidative damage, systemic inflammation + damage to CNS & other organs

Immediate treatment needed is to cool patient, induce peripheral vasoconstriction to increase venous return:

- alcohol rubs (?) for cooling but ethanol dilates bvs (M,K&K)
- application of ice packs.
- whole-body cold or ice water immersion remains the most effective treatment for a collapsed, hyperthermic individual.
BPK 312 Nutrition for Fitness & Sport
Lecture 8b

Summary Slide
Nutrition in Extreme Environments

1. Learning Objectives
2. Environmental Heat Stress & Nutrition
3. Thermoregulation & Exercise in the Heat
4. Heat Tolerance and Acclimation/Acclimatization
5. Evaluating Environmental Heat Stress
6. Heat Illnesses & Nutrition