Understanding Heat Production & Dehydration During Exercise

Exercise increases heat production

Heat production during exercise can easily be calculated or estimated

Metabolic efficiency = ~30%

Mechanical efficiency = ~30%

Therefore, heat production can be estimated from calorimetry-based determinations of VO₂, VCO₂, and RER.
For example,

Low fitness:

\[ \text{Kcals} = \text{VO}_2 \text{ (L/min)} \times \text{Kcals/L} \times \text{Duration (min)} \]

\[ \text{Kcals} = 1.0 \text{ (L/min)} \times 4.924 \text{ Kcals/L} \times 60 \text{ (min)} \]

\[ \text{Kcals} = 295 \]

High fitness:

\[ \text{Kcals} = \text{VO}_2 \text{ (L/min)} \times \text{Kcals/L} \times \text{Duration (min)} \]

\[ \text{Kcals} = 3.0 \text{ (L/min)} \times 4.924 \text{ Kcals/L} \times 60 \text{ (min)} \]

\[ \text{Kcals} = 886 \]
What does a heat production of 900 Kcals mean for body heat loss and storage?

**Body specific heat = 0.83 Kcals/kg/°C**

For a 75 kg person,

Potential Heat gain = \( \frac{900}{0.83} \div 75 \)

Potential Heat gain = 14.5 °C

What if all this heat was to be lost as sweat?

Evaporative heat loss potential = 580 Kcals/L

Evaporative Water Loss = \( \frac{900}{580} = 1.5 \) L

*If we are 60% efficient at sweat evaporative cooling*

\( \frac{1.5}{0.6} = 2.5 \) L = 3.3% dehydration
Physiological changes during dehydration

- ↑ Core temperature
- ↓ Plasma volume
- ↓ Venous return
- ↓ Stroke volume
- ↑ Heart rate
- ↓ Cardiac output
- ↑ a-VO$_2$Δ
- ↓ Skin blood flow
- ↑ Catecholamines
- ↑ Blood lactate
- ↑ VO$_2$
- CNS dysfunction
- ↓ Exercise tolerance
- ↓ Sweat rate
- ↓ Evaporative cooling

Sawka review, 1992
Improving Exercise Tolerance During Heat Exposure

- Fluid intake (pre-, during and post-exercise)
- Do not rely on thirst mechanism
- Complete heat acclimation or acclimatization

**Acclimation** - chronic adaptations induced by exposure to artificial environmental conditions
  
  *(eg. environmental chambers, sauna, exercise)*

**Acclimatization** - chronic adaptations induced by exposure to a foreign climate
  
  *(eg. geographical relocation)*

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**Chronic adaptations to exercise in a hot environment that improve acclimation to exercise in the heat**

<table>
<thead>
<tr>
<th>Acclimation/Adaptation</th>
<th>Physiological Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>↑ Plasma Volume</strong></td>
<td>↑ Blood Volume</td>
</tr>
<tr>
<td></td>
<td>↑ Venous return</td>
</tr>
<tr>
<td></td>
<td>↑ Cardiac output @ max</td>
</tr>
<tr>
<td></td>
<td>↓ Submaximal heart rate</td>
</tr>
<tr>
<td></td>
<td>Sustained sweat response</td>
</tr>
<tr>
<td></td>
<td>↑ Capacity for evaporative cooling</td>
</tr>
<tr>
<td><strong>Earlier onset of sweating</strong></td>
<td>Improved evaporative cooling</td>
</tr>
<tr>
<td><strong>↓ Osmolality of sweat</strong></td>
<td>Electrolyte conservation (mainly Na⁺)</td>
</tr>
<tr>
<td><strong>↓ Muscle glycogenolysis</strong></td>
<td>↓ Likelihood for muscle fatigue</td>
</tr>
</tbody>
</table>
Walking at 1.56 m/s, 49°C & 20% RH, 7 consecutive days

Heat Acclimation/Acclimatization Summary

- Continuous daily 100-min exercise bouts
- Near complete exercise-heat acclimation occurs after 7-10 days of exposure
- High levels of endurance training can partially heat acclimate
- 75% of acclimation occurs within 4-6 days
- Retention of benefits from acclimation are retained longer for dry than humid heat
- High levels of aerobic fitness prolong retention of heat acclimation
- Near complete exercise-heat acclimation occurs after 7-10 days of exposure

Pandolf, 1998
Heat Illness, Heat Exhaustion and Heat Stroke

These conditions are more severe clinical symptoms of heat exposure.

**Heat Exhaustion** - the decreased cardiovascular function that accompanies dehydration and mild hyperthermia.

**Heat Stroke** - when heat stress continues, or is worsened beyond that of heat exhaustion (core temp > 39.5 °C), physiological symptoms progress to CNS dysfunction - *disorientation, confusion, psychoses*

*Heat exhaustion and heat stroke are both heat illnesses. However, heat stroke can be potentially lethal due potential organ damage and failure.*
Evaluating Environmental Conditions For Risk of Heat Injury

An index has been developed that incorporates all contributors to thermal heat stress - **Wet Bulb Globe Index (WBGI)**

*Dry bulb temperature* - measure of air temperature
*Black bulb temperature* - measure of the potential for radiative heat gain
*Wet bulb temperature* - measure of the potential for evaporative cooling

\[
WBGI = (0.7 \times Tw) + (0.2 \times Tb) + (0.1 \times Td)
\]

The relative risks for heat injury at different ranges of the WBGI

<table>
<thead>
<tr>
<th>WBGI</th>
<th>Physiological Benefit</th>
</tr>
</thead>
</table>
| 23-28 | High risk for heat injury: red flag
Make runners aware that heat injury is possible, especially for those with a history of susceptibility to heat illness |
| 18-23 | Moderate risk for heat injury: amber flag
Make runners aware that the risk for heat injury will increase during the race |
| < 18  | Low risk for heat injury: green flag
Make runners aware that although the risk is low, there is still a possibility for heat injury to occur |
| < 10  | Possible risk for hypothermia: white flag
Make runners aware that conditions may cause excessive heat loss from the body, especially for individuals who will have slow race times and when conditions are wet and windy |
GLYCEROL and HYDRATION

What you need to know!

By

Robert Robergs, Ph.D., FASEP, EPC
Exercise Physiology Laboratories
Exercise Science Program
Dep’t Physical Performance and Development
The University of New Mexico

How Much Water is in the Body?

100 %

Total body mass

60 %
How Much Water is Needed by the Body?

<table>
<thead>
<tr>
<th>INTAKE</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolism 10%</td>
<td>200 mL</td>
</tr>
<tr>
<td>Moist Foods 30%</td>
<td>700 mL</td>
</tr>
<tr>
<td>Beverages = 60%</td>
<td>1500 mL</td>
</tr>
<tr>
<td><strong>Total Intake</strong>: 2500 mL</td>
<td><strong>Total Output</strong>: 2500 mL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweat 8%</td>
</tr>
<tr>
<td>Feces 4%</td>
</tr>
<tr>
<td>Skin and Lungs 28%</td>
</tr>
<tr>
<td>Urine 60%</td>
</tr>
</tbody>
</table>

Exercise or a Hot or Humid Environment?

<table>
<thead>
<tr>
<th>Normal</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweat 200 mL</td>
<td></td>
</tr>
<tr>
<td>Feces 700 mL</td>
<td></td>
</tr>
<tr>
<td>Skin &amp; Lungs 1500 mL</td>
<td></td>
</tr>
<tr>
<td><strong>Total Normal Output</strong>: 2500 mL</td>
<td></td>
</tr>
<tr>
<td><strong>Total Output</strong>: 11.5 L</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 L</td>
</tr>
<tr>
<td>3 L</td>
</tr>
<tr>
<td>500 mL</td>
</tr>
<tr>
<td><strong>Total Heat Output</strong>: 11.5 L</td>
</tr>
</tbody>
</table>
Where is the Water Located?
From Where is it Lost?

Costill & Fink, 1976.

Dehydration

Dehydration is quantified by the amount of body weight lost.

For example

Pre-exercise weight = 70.0 kg
Post-exercise weight = 68.5 kg
Weight Loss = 1.5 kg

\[
(1.5 / 70) \times 100 = 2.1\% \]
Heat and Hydration

Dr. Robert A. Robergs, Ph.D.

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Heat Exhaustion
Heat Stroke

Urine Color Chart

Urine specific gravity < ~1.014 g/mL
Urine osmolality < ~600 mOsmol/kg

Worsening dehydration
PROBLEM #1
It is very difficult to prevent a significant dehydration

PROBLEM #2
It is very difficult to regulate the kidneys to maintain hydration

GFR = 120 L/day

~ 99% of this water is reabsorbed

For most beverages, increasing fluid ingestion causes a decreased effectiveness of water reabsorption
Can Pre-exercise Hydration Be Increased?

**YES**


![Graph showing fluid retention and hydration levels](image)

Fig. 6. Relative fluid retention resulting from glycerol hyperhydration during rest conditions. Lyons et al.[31] assessed hydration after 2.5 hours, Freund et al.[27] after 3 hours, Riedesel et al.[26] after 4 hours, Montner et al.[22] after 2.5 hours, and Montner et al.[22] after 3 hours.

How Does Glycerol Work?

1. Glycerol hyper-hydration is accompanied by a decrease in urine volume
Recent Research (in-review) from Our Laboratory

Study 1

Compared,

- Distilled water (DW)
- 100 mEq/L NaCl (80 mEq), KCl (20 mEq) solution (EL)
- Gatorade (CHO-EL)
- Glycerol hyper-hydration (1.2 g glycerol bolus + 26 mL/kg water) (GBol)
- Glycerol solution (5.75 g glycerol/100 mL = 5.75 % glycerol) (GSol)
- d + e (GG)

Subjects and Methods

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
<th>Weight (kg)</th>
<th>LBM (kg)</th>
<th>Body Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>3</td>
<td>73.2±12.8</td>
<td>62.5±11.2</td>
<td>14.2±7.8</td>
</tr>
</tbody>
</table>

**DW, EL, CHO-EL, GSol** = 4.0, 6.4, 5.2, 5.2, and 5.2 mL/kg

**GBol** = 40% glycerol, 6.4, 5.2, 5.2, and 5.2 mL/kg **DW**

**GG** = 40% glycerol, 6.4, 5.2, 5.2, and 5.2 mL/kg **GSol**

![Fluid Ingestion Diagram](image-url)
Results

Will be presented as two studies:

1. Comparing methods of glycerol ingestion to CHO-EL.

2. Comparing glycerol solution (Gsol) to EL, CHO-EL and DW

Symptoms
Osmolal Clearance

**Graph 1:**
- **Y-axis:** Osmolal Clearance (mOsmol/min)
- **X-axis:** Time (hrs)
- **Legend:**
  - GG
  - GSol
  - GBol
  - CHO-EL

**Graph 2:**
- **Y-axis:** Osmolal Clearance (mOsmol/min)
- **X-axis:** Time (hrs)
- **Legend:**
  - GSol
  - EL
  - DW
  - CHO-EL
Free Water Clearance

Free Water Clearance (mL/min)

Time (hrs)

GG
GSol
GBol
CHO-EL

Free Water Clearance

Free Water Clearance (mL/min)

Time (hrs)

GG
GSol
EL
DW
CHO-EL
What we recommend to athletes:

4-5% glycerol solution in half strength Gatorade

eg: glycerol = 1.25 g/mL

1 L of 5% glycerol solution

5 g or 4 mL of glycerol, and add half strength Gatorade to equal 1 L

Drink prior to exercise (1 to 2 L over 2 hrs)

Drink as needed during exercise

Thank you