Exercise Science: Theory: Hydration

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Glenshaw 1949-1967
Ohio State University 1977-1980
Boise State University 1980-1985
Oswego State University 1974-1977
Slippery Rock University 1967-1974
GSSI 1985-2008

KEY POINTS

1. Water is weird stuff. That's why it's so important.
2. Dehydration is not always bad, but it's never good.
3. Hydration = Performance
4. Things don’t often go wrong, but when they do, fast action saves lives.

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KEY POINTS

1. Water is weird stuff. That's why it's so important.

Water is a chemical.
"Not all chemicals are bad. Without chemicals such as hydrogen and oxygen, for example, there would be no way to make water, a vital ingredient in beer."
- Dave Barry

Water is not just life's solvent.

Water is the most biologically active chemical in the body.

Water is **W**eird

It's light, but not usually a gas.

\[
\begin{align*}
\text{H}_2\text{O} & \quad MW = 18 \text{ g/mol} \\
\text{O}_2 & \quad MW = 32 \text{ g/mol} \\
\text{N}_2 & \quad MW = 28 \text{ g/mol} \\
\text{CO}_2 & \quad MW = 44 \text{ g/mol} \\
\text{CO} & \quad MW = 28 \text{ g/mol}
\end{align*}
\]

Bipolar molecules stick together.

**Water is W**eird

It's bipolar!

**Water is W**eird

It's small!

One quart of water contains one septillion water molecules

1,000,000,000,000,000,000,000,000,000,000,000,000
Water is **W**eed

It's multi-talented!

- Solute
- Carrier
- Solvent
- Coolant
- Catalyst
- Reactant
- Lubricant
- Controller
- Messenger
- Ionizing agent
- Shock absorber
- Volumetric agent

It's protective!

- High heat capacity
- High thermal conductivity
- High latent heat of evaporation

It makes everything work!

- Enzymes
- Proteins
- DNA
- RNA
Water is... It’s easy to lose!

<table>
<thead>
<tr>
<th>INTAKE</th>
<th>LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beverages and foods (water + salt)</td>
<td>Respiration (water)</td>
</tr>
<tr>
<td>Water from metabolism (water)</td>
<td>Transpiration (water)</td>
</tr>
<tr>
<td></td>
<td>Saliva (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Sweat (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Urine (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Feces (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Metabolism (water)</td>
</tr>
<tr>
<td></td>
<td>Emesis (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Diarrhea (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Lactation (water + salt)</td>
</tr>
<tr>
<td></td>
<td>Menstruation (water + salt)</td>
</tr>
</tbody>
</table>

Water is... It’s easy to lose!

2. Dehydration is not always bad, but it’s never good.

Dehydration is not always bad.
Can dehydration be a good thing?

- Dehydration =
- Reduced body weight =
- Increased power:mass ratio =
- Decreased energy cost =
- Improved performance

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- N = 8
- 2-h at 53% VO2,max
- 8% grade at 88% VO2,max
- 85°F
- 0.4 or 2.4 L sports drink in first 2 h
- Carbohydrate gel with lower volume
- -2.5% or +0.3% BW at 2 h
- -5.6 min slower (-28.6%) w/ dehydration

"... dehydration-induced hyperthermia outweighed the theoretical benefit of a reduction in body mass ..."

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Nothing has changed.
Dehydration is still not good.

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Dehydration

Heat stress (Hyperthermia)

Cardiovascular function

Muscle metabolism

Central nervous system function

Brain temperature

Motivation & Effort

Central drive

Spinal reflexes

NMJ function

Poorer Performance


Physiological Characteristics of Elite Athletes

- Expanded blood volume
- High cardiac output
- High VO2max
- Increased economy
- Improved power output
- Great muscular endurance
- High muscle blood flow
- High skin blood flow
- Sustained sweating

Physiological responses to dehydration

**INCREASED**
- Incidence of GI discomfort
- Plasma osmolality
- Blood viscosity
- Heart rate
- Temp threshold for sweating
- Temp threshold for skin blood flow
- Core temperature at a given VO2
- Resting core temperature
- Skin temperature
- Brain temperature
- Muscle glycogen use
- Thermal discomfort

**DECREASED**
- Plasma volume
- Splanchnic & renal blood flow
- Central blood volume
- Central venous pressure
- Cardiac filling pressure
- Stroke volume
- Cardiac output
- Skin blood flow at a given Tc
- Maximal skin blood flow
- Muscle blood flow
- Sweat rate at a given Tc
- Maximal sweat rate
- Physical & mental performance
Deterioration in Physiological Function with Dehydration

Dehydration Affects Physiology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% Change</th>
<th>% of 20-min Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE</td>
<td>+40%</td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>+19%</td>
<td></td>
</tr>
<tr>
<td>Te</td>
<td>+8%</td>
<td></td>
</tr>
<tr>
<td>TPR</td>
<td>+10%</td>
<td></td>
</tr>
<tr>
<td>Art BP</td>
<td>-2%</td>
<td></td>
</tr>
<tr>
<td>BV</td>
<td>-4%</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>-12%</td>
<td></td>
</tr>
<tr>
<td>SBF</td>
<td>-22%</td>
<td></td>
</tr>
<tr>
<td>SV</td>
<td>-28%</td>
<td></td>
</tr>
</tbody>
</table>

0 120 minutes

65% VO\textsubscript{max} cycling; 35°C; -4.9% BW; from Coyle IJSM 19:5121-5124, 1998.

When is hydration during activity important?

- Sweating -
- Performance -

Practical advice

Drink enough to minimize weight loss.

Drink regularly throughout exercise.
Weight loss during exercise is not all sweat, but does that have any practical significance?

Body mass loss = SL + RWL + SO + UF - MW - IF

SL = sweat loss
RWL = respiratory water loss
SO = substrate oxidation
UF = urine & feces
MW = metabolic water
IF = ingested fluid

Water loss vs Fat loss

2-h workout
2000-ml sweat (68-oz water)
60-g fat (2-oz fat)
ASSESSING HYDRATION

Weigh before and after a workout:
- Weight loss > -1% BW = dehydration
- Weight gain = over-drinking
- Example: 146 - 143 = 3-lb loss
- 1.5 lb = 1% BW
- In exercise > 2 hours, -2% BW = dehydration

KEY POINTS

3. Hydration = Performance

Impaired Performance at < 2% Dehydration

- n = 6
- 32°C
- 1-h cycling @ 70% VO₂max
- Cycle to exhaustion @ 90% VO₂max
- 0 - 1.8% dehydration
- Fluid = 20 mmol/L Na+

Dehydration has a greater impact in hot weather

Dehydration is Catabolic

Hydrated muscle cells are anabolic

Dehydrated muscle cells are catabolic
- Decreased glycogen synthesis
- Increased glycogen breakdown
- Increased carbohydrate oxidation

Rehydration Speeds Glycogen Replacement

Is thirst good enough?

"On a day-to-day basis, fluid intake, driven by thirst and the consumption of beverages at meals, allows maintenance of hydration status and total body water at normal levels."

- IOM, 2005

For athletes, there is no “normal” hydration status

Midnight

Hyperhydrated

Euhydrated

Hypohydrated

Midnight

(± 0.2% BW; ± 5 oz in a 70-kg athlete)
DEHYDRATION

- Blood Volume
- Baroreceptors (arterial, cardiopulmonary, renal)
- Renin
- Angiotensin
- Aldosterone
- Salt appetite
- Salt intake
- Osmo-dilution
- Blood Osmolality
- Salt concentration
- Sodium conservation
- Blood Volume
- ADH
- Blood Osmolality
- Osmoreceptive neurons (central and visceral)
- Baroreceptors
- Neuropeptide Y
- Oxytocin
- Vasopressin
- Antidiuretic hormone (ADH)
- Serotonin
- Aldosterone
- ANP
- Salt appetite
- Thirst
- Drinking
- Osmo-dilution
- Osmo-concentration
- Salt intake
- Osmoconcentration
- Sodium conservation
- Water conservation
- Exercise
- Fever
- Hemorrhage
- Vomiting
- Diarrhea
- Sweating
- Fluid deprivation

Thirst during exercise - an adequate stimulus?

Typical Sweat Losses

<table>
<thead>
<tr>
<th>Liters/hour</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

> 5 L in 1 h cycling exercise


GSSI sweat testing: 85F; 60% RH; 2002
### Voluntary dehydration occurs in runners despite favorable conditions for fluid intake

<table>
<thead>
<tr>
<th>Sweat loss (liters)</th>
<th>How much they thought they lost.</th>
<th>How much they drank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.83</td>
<td>29%</td>
<td>0.99</td>
</tr>
<tr>
<td>0.53</td>
<td></td>
<td>0.53</td>
</tr>
</tbody>
</table>

10-mile race  
*n = 18  
64°F; 64% RH


### DRINK TO THIRST?  
Should we tell people to “eat to hunger”?  

### Practical advice  
When performance is important ...  
- Drink enough to minimize weight loss.  
- Drink regularly throughout exercise.
KEY POINTS

4. Things don’t often go wrong, but when they do, fast action saves lives.

September 2007
Arizona desert
Ta = 105°F
Started hike at 10 am
Dead at 3 pm
Tc = 140°F

Shannon Larson
1976 - 2007
Cooling Guidelines

Continue cooling until rectal temperature lowers to 39°C (102°F).

If rectal temperature cannot be measured and cold water immersion is indicated, cool for 10-15 minutes and then transport to a medical facility.

An approximate estimate of cooling via cold water immersion is 1°C for every five minutes and 1°F every 3 minutes (if the water is aggressively stirred).

This means, the cooling rate will be slower initially, and increase the longer the person is in the tub. For example, if someone is in the tub for 15 minutes they would cool approximately 3°C or 5°F during that time.

www.ksi.uconn.edu

- January 2007 -
Woman Dies After Holding Pee for Wii Radio Contest
Jennifer Strange, mother of 3, dead at 28

Fluid Intake > Urine Output = \[ \mu \text{[Na']} \]

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Sweat Sodium Loss Can Be High

For example …
24-yr-old road athlete loses 1.6 L sweat during a 2-h training session
Sweat $[\text{Na}^+] = 50 \text{ mmol/L}$
Sodium loss = 80 mmol = 1840 mg Na

Exercise-Associated Hyponatremia

- Excessive fluid intake
- Decreased urine production
- Increased sodium loss
  - Hypertonic saline IV
  - Diuretic
  - Anticonvulsant

Practical advice

When sweating
Drink to minimize weight loss.
Don’t over-drink.
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Thank You!