Hydration and Cognition Through the Lifespan

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No conflict of interest with any interest of the Academy of Nutrition and Dietetics or the International Life Sciences Institute. Opinions are my own and do not represent official DoD or Dept. of the Army policy.
U.S. Army Research Institute of Environmental Medicine
Mission
USARIEM conducts biomedical research to improve and sustain Warfighter performance and health under all conditions.

Vision
USARIEM is the internationally recognized joint center of excellence for Warfighter performance and health research.
Biophysics & Biomedical Modeling
- Clothing biophysics
- Biomedical / predictive modeling
- Physiological modeling

Military Nutrition
- Bioenergetics and metabolism
- Healthy weight management
- Combat ration testing

Military Performance
- Physical performance optimization
- Injury reduction / bone health
- Muscle physiology
- Military biomechanics research
- Cognitive performance

Thermal & Mountain Medicine
- Cold & Heat stress physiology
- High altitude physiology
- Environmental illness & injury
- Acquired tolerance & acclimatization
- Hydration
Presentation Outline

• What constitutes dehydration?
• Fluid intake across the life span.
• Are older adults more susceptible to dehydration?
• What might be possible mechanisms for changes in cognitive function due to dehydration?
• Dehydration/cognition literature.
• Role of distracters and cognitive resilience.
• Considerations for future lines of inquiry.
When is someone dehydrated?

- Overhydration
- Hyperhydration
- Dehydration
- Dehydration/Hypohydration
- Rehydration

Adapted from: Greenleaf, MSSE, 1992
Body Water Distribution

**Total Body Water**
50% To 70% Body Weight
~45 L For 70 kg person

**Extracellular Water**
35% Tbw
~ 15 L

- **Plasma**
  8% Tbw
  ~ 3.5 L

- **Interstitial**
  27% Tbw
  ~ 11.5 L

**Intracellular Water**
65% Tbw
~ 30 L
Adolph E.F. The metabolism and distribution of water in tissues. *Physiological Reviews*, 1933

“Minimal” – 2.1 L/d  
“Average” – 3.4 L/d  
“Liberal” – 5.0 L/d  

“Roughly convenient liberal standard is ~1 ml per Kcal expended”  

“principles making these calculations are substantiated by measurements of *voluntary* water intake in rats and mice”  

“exact values derived have not been checked experimentally”
National Research Council, **Recommended Dietary Allowances, 1945**

“A suitable allowance of water for adults is 2.5 liters daily in most instances. An ordinary standard for diverse persons is 1 ml for each calorie of food.” (~2.1 L/d water)

National Research Council, **Recommended Dietary Allowances, 1989**

**Adults:** “For practical purposes, 1 ml/kcal can be recommended as the water requirement for adults under average conditions.” “Water is often increased to 1.5 ml/Kcal to cover variability in activity, sweating and solute load.” (~2.1-3.2 L/d water)
Study Goal: Determine the Dietary Reference Intake (DRI) for Total Water. (Normal healthy persons)

Total Water: Includes drinking water, beverages and moisture in food. NHANES III approximates ~81% from beverages & ~19% food.

Assumption: All absorbed water has equal bioavailability.
# TABLE 4-18 US Daily Total Water Intake of Male & Female Older Children, Adolescents, and Adults (NHANES III)

<table>
<thead>
<tr>
<th>Age (years old)</th>
<th>Men, Total Water Intake (L/d)</th>
<th>Women, Total Water Intake (L/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>9–13</td>
<td>2.54</td>
<td>2.44</td>
</tr>
<tr>
<td>14–18</td>
<td>3.40</td>
<td>3.28</td>
</tr>
<tr>
<td>19–30</td>
<td>3.91</td>
<td>3.71</td>
</tr>
<tr>
<td>31–50</td>
<td>3.85</td>
<td>3.63</td>
</tr>
<tr>
<td>51–70</td>
<td>3.55</td>
<td>3.39</td>
</tr>
<tr>
<td>71+</td>
<td>2.99</td>
<td>2.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>Males, Total Water Intake (L/d)</th>
<th>Females, Total Water Intake (L/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Least Active, Median</td>
<td>Most Active, Median</td>
</tr>
<tr>
<td>8 to 16</td>
<td>2.11</td>
<td>2.69</td>
</tr>
<tr>
<td>17 to 18</td>
<td>2.04</td>
<td>3.35</td>
</tr>
<tr>
<td>19 to 30</td>
<td>3.16</td>
<td>3.78</td>
</tr>
<tr>
<td>31 to 50</td>
<td>3.54</td>
<td>3.77</td>
</tr>
<tr>
<td>51 to 70</td>
<td>3.22</td>
<td>3.42</td>
</tr>
<tr>
<td>71 +</td>
<td>2.54</td>
<td>3.05</td>
</tr>
</tbody>
</table>


Decline in TBW throughout the life span, due to losses in lean body mass, other factors.

With this decrease, greater susceptibility to dehydration.


Aging causes changes in body water composition, renal function and thirst perception. 


Older adults eat less, rehydration occurs with meals.

Reduced swallowing capacity, decreased mobility, or comprehension and communication disorders.

Voluntary dehydration due to incontinence.

Disability or neglect, inadequate staffing in institutions.

Chronic illnesses (diabetes), hormonal changes, certain medications (laxatives, diuretics).
Study by Kenney et al. healthy, fit 60-70 year old men and 20-30 year old men exercised in a warm environment. Fluid intake was measured.

Younger subjects averaged > 1.5 liters/day of fluid than older subjects.

When confronted with a challenge that should have increased fluid intake, older subjects did not respond.

High dehydration rates of elderly patients in hospitals, nursing homes or living alone. Begum MN, Johnson CS. E J Clin Nutr Metab. 2010; 5:e47-e53.

One of the ten most frequent diagnoses for hospitalization in the U.S. for older adults.


Associated with morbidities, such as impaired cognition or acute confusion, or falling.
## Risk Factors for Dehydration Among Older Adults

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
</table>
| Normal changes of aging | Age >85 yrs  
Female  
Low TBW and body weight  
Decline in max renal water and Na+ conservation  
Decline in thirst |
| Functional          | Poor mobility  
Comprehension/communication issues  
Oral fluid intake <1500 ml/day  
Dexterity, coordination, body control issues  
Self-neglect |
| Environmental       | Hospitalization  
Care giving issues/ institution staffing issues  
Summer heat, winter (over heating)  
Isolation |
| Disease-related     | Alzheimer’s disease  
≥ 5 chronic diseases  
Fluid losses: diarrhea, fever, vomiting, bleeding, fever, tachypnea, artificial ventilation, polyuria, decubitus, burns  
Reduced intake: dysphagia, anorexia, depression, dementia  
Fear of incontinence |
| Iatrogenic          | Drug related: laxatives, diuretics, lithium, hyponotics  
High protein intake  
Dietary restriction of fluids, salts  
Procedures requiring fasting |

Health Consequences of **Acute Dehydration**

- Heat Stroke
- Heat Exhaustion
- Cardiovascular Strain
- Physical Work Performance
- Mental Performance
- Fatigue
Dehydration Reduces Orthostatic (Tilt) Tolerance

Adolph, Physiol. of Man in Desert 1947
Dehydration Reduces Cerebral Blood Flow Velocity During Orthostatic Stress

(-3% BWL; Standing, Temperate Conditions)

Carter et al. JAP 2006
Dehydration in most studies not large enough to alter blood-brain barrier permeability.
Rapoport S. 2000

Neural activity is closely related to cerebral blood flow (CBF).
Girouard H and Iadecola C. 2006

Dehydration can reduce CBF transiently when an orthostatic challenge is imposed.

CBF is maintained at rest w/ dehydration of 2-3% body mass.

Effects of mild dehydration on brain volume are inconsistent.
Most research on young fit adults, typically exercising in the heat.

Studies report alterations in cognition with body mass loss of 1-2%.
(Cian et al. 2001; Gopinathan et al. 1988; Lieberman 2007; Ganio et al. 2011; Armstrong 2011)

Marginal, but statistically significant cognitive changes.
(Ganio 2011, Armstrong 2011)

Long recovery period after exercise/heat stress or passive dehydration result in minimal changes in cognition. Adam 2008; Szinnai 2005
Limited information, few reports that dehydration affects cognition in older adults.


2.6% in TBW determine via BIA. Dehydration did not affect learning, recall, motor speed, or executive function tests.


Changes in working memory and memory skills due to dehydration were attenuated when corrected for by blood pressure.
Little support that dehydration disrupts cognition
May reflect lack of relevant evidence. Benton 2011

Results are inconsistent, confounded by:
  methods used to induce dehydration
  exercise fatigue
  elevated body temperature Patel et al. 2007; Hancock & Vasmatzidis 2003
  sensitivity and type of cognitive tests
  learning effects, lack of familiarization Benton 2011.
Hypohydration and acute thermal stress affect mood state but not cognition or dynamic postural balance

32 male volunteers
-4% body mass loss
120 min rest following dehydration
Core temperature allowed to recover
Volunteers trained on cognitive test battery
Established euhydration baseline
Tested when eu- and dehydrated in 4 temps

No changes in cognition
Hypohydration and acute thermal stress affect mood state but not cognition or dynamic postural balance

Brett R. Ely · Kurt J. Sollanek · Samuel N. Cheuvront · Harris R. Lieberman · Robert W. Kenefick
Core temperature, skin temperature, thermal sensation and thirst ratings

<table>
<thead>
<tr>
<th></th>
<th>10°C</th>
<th>20°C</th>
<th>30°C</th>
<th>40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$T_{core}$ (°C)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EUH</td>
<td>37.2 ± 0.2</td>
<td>37.1 ± 0.3</td>
<td>37.1 ± 0.3</td>
<td>37.2 ± 0.2</td>
</tr>
<tr>
<td>HYP†</td>
<td>37.7 ± 0.1</td>
<td>37.7 ± 0.2</td>
<td>37.5 ± 0.3</td>
<td>37.9 ± 0.2</td>
</tr>
</tbody>
</table>

| **$T_{sk}$ (°C)** |          |          |          |          |
| EUH             | 24.8 ± 0.8 | 28.7 ± 0.6 | 32.5 ± 0.2 | 35.6 ± 0.4 |
| HYP†            | 25.0 ± 1.0 | 29.3 ± 0.8 | 32.8 ± 0.2 | 36.1 ± 0.35 |

| **TS** |          |          |          |          |
| EUH | 1.3 ± 0.4 | 2.5 ± 1.0 | 3.6 ± 0.4 | 5.1 ± 0.6 |
| HYP† | 1.5 ± 0.7 | 2.8 ± 0.8 | 3.7 ± 0.5 | 5.7 ± 0.5 |

| **Thirst** |          |          |          |          |
| EUH | 1.1 ± 0.4 | 1.1 ± 0.4 | 1.9 ± 1.5 | 2.4 ± 1.4 |
| HYP† | 6.3 ± 2.0 | 5.9 ± 2.5 | 7.9 ± 1.2 | 7.3 ± 0.9 |
# Quantifying the Effects of Dehydration

<table>
<thead>
<tr>
<th>Dehydration</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>Threshold for thirst, thermoregulatory and performance impairment</td>
</tr>
<tr>
<td>2%</td>
<td>Stronger thirst sensation</td>
</tr>
<tr>
<td>3%</td>
<td>Dry mouth, reduced urinary output</td>
</tr>
<tr>
<td>4%</td>
<td>30 – 50% decrement in physical work performance; advanced thermoregulatory impairment</td>
</tr>
<tr>
<td>5%</td>
<td>Headache, difficulty in concentrating</td>
</tr>
<tr>
<td>6%</td>
<td>Severe impairment in work performance and thermoregulation</td>
</tr>
<tr>
<td>7%</td>
<td>Imminent collapse if combined with heat and exercise</td>
</tr>
</tbody>
</table>

Greenleaf, 1992
Dehydration related distracters

Dehydration negative effect on mood state & produces unpleasant symptoms such as dry mouth, thirst & headache.

Studies on dehydration & cognition consistently report alterations in mood state such as:

perceived tiredness  Szinnai G. et al. 2005
alertness  Neave N. et al. 2001
fatigue, confusion, anger, depression.  Adam GE. et al. 2008;
Ganio M. et al. 2011; Gopinathan PM. et al. 1988; Patel AV. et al. 2007

Kempton et al. 2011 reported that dehydration (< 2% body mass) required higher levels of neuronal activity to achieve the same performance.

Equivocal findings in literature may be due to the variation in cognitive resilience among individuals.

Interaction of aging related changes in cognition, symptomologic distracters, and cognitive resilience likely influence impact of dehydration on cognition.
Establish euhydrated hydration state.

Determine means of assessing hydration state.

Adequate pre-experimental training
Grandjean and Grandjean 2007

Determine the magnitude of importance?

How sensitive is the cognitive test?
What is the test variability?

What are possible confounders?
age related changes in cognition

Assess distracters.

Miller, Psych Rev 1956; Bartus et al., Science 1982;
Sunderland et al., Brain Res Rev, 1988
Summary

Total body water and fluid intake decline with aging.

Numerous physiological, behavioral, pathologic and socio-economic reasons for increase in dehydration in older adults.

Significant health risks associated with dehydration for older adults.

Physiological mechanisms of the impact of dehydration on cognition are unclear.

Literature, in general and for older adults is equivocal.

Dehydration does alter mood and create symptomologic distracters.

Impact of dehydration on older adults may be related to aging related changes in cognition, symptomologic distracters, and cognitive resilience.

Area is in need of carefully conducted research.
## Hydration Assessment

<table>
<thead>
<tr>
<th>Assessment Technique</th>
<th>Practicality</th>
<th>Acceptable EUH Cut-Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Body Water</td>
<td>Low</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Plasma Osmolality</td>
<td>Medium</td>
<td>&lt; 290</td>
</tr>
<tr>
<td>Urine Specific Gravity</td>
<td>High</td>
<td>&lt; 1.020</td>
</tr>
<tr>
<td>Urine Osmolality</td>
<td>High</td>
<td>&lt; 700</td>
</tr>
<tr>
<td>Urine Color</td>
<td>High</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>Body Mass</td>
<td>High</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>

Cheuvront and Sawka, 2005
Change in Body Mass

- Effective if pre-exercise BM measured when euhydrated.
- Affected by carbohydrate loading, bowel habits.
- Changes in body composition reflected grossly as changes in body mass, limiting this technique.

\[
\text{Fluid loss} \left( \frac{\text{Post exercise BM} - \text{Pre exercise BM}}{\text{Pre BM}} \right) \times 100 = \% \text{ Dehydration}
\]

1 g of lost mass = 1 ml of lost water.
USG, osmolality, and color can distinguish euhydration vs. dehydration using **first morning void** - minimizes confounders, maximizes reliability.

**Study Summary**

$r = 0.80$ for $U_{Col}$ and $USG$

$r = 0.82$ for $U_{Col}$ and $U_{Osm}$

Potentially confounded by diet/supplements

Added subjectivity

Armstrong et al., 1994
Qualitative tool for hydration assessment

Thirst works well only at rest

Thirst develops after dehydration is present alleviated before euhydration is achieved

Usually not perceived until 2% BM is already lost

Limited application to children, elderly
Drinking large volumes of hypotonic fluids - copious urine production before euhydration is achieved.

Urine concentration measures may be confounded by diet.


Exercise decreases GFR- more concentrated urine.

USG = 1.025 may be better bench-mark.
It was the only mission statement everyone could agree on.

Drink 8 glasses of water everyday
History - 8 Glasses of Water per day?

**Daily Water Input**

<table>
<thead>
<tr>
<th>Source</th>
<th>ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolism</td>
<td>350</td>
</tr>
<tr>
<td>Food</td>
<td>1000</td>
</tr>
<tr>
<td>Fluids</td>
<td>1200</td>
</tr>
</tbody>
</table>

**Daily Water Output**

<table>
<thead>
<tr>
<th>Source</th>
<th>ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feces</td>
<td>100</td>
</tr>
<tr>
<td>Lungs</td>
<td>350</td>
</tr>
<tr>
<td>Skin</td>
<td>600</td>
</tr>
<tr>
<td>Urine</td>
<td>1500</td>
</tr>
</tbody>
</table>

**TOTAL** 2550

\[
2.5 \text{ L x 0.8} = 2.0 \text{ L/d (~80% non-food)}
\]

\[
2.0 \text{ L/d x 1.06} = 2.12 \text{ qts/d = 67.8 oz/d}
\]

\[
67.8 \text{ oz / 8 oz} = 8.4 \text{ glasses /day}
\]
Dehydration Degrades Cognitive Function

Gopinathan et al. *Arch Env Health*, 1988

Graphs showing the relationship between dehydration (% of BW) and serial addition, response time, and word recognition.