Effectiveness of an Intermittent Heat Exposure Protocol to Maintain Heat Acclimation

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Game Plan

• Background
  – Exertional heat illness (EHI)
  – Risk factors and prevention strategies of EHI
    • Heat acclimatization

• Recent Heat Acclimation (HA) Maintenance Study

• Practical Applications
Learning Outcomes

• Identify intrinsic and extrinsic factors contributing to EHI
  – Importance of HA

• Understand how HA reduces EHI risk

• Summarize strategies to implement and prolong HA
Exertional Heat Illnesses

- Heat Syncope
- Heat Cramps
- Heat Exhaustion
- Heat Stroke
Heat Syncope

“Royal Wedding guardsman faints during parade rehearsal”

Maximal peripheral vasodilation

↓ venous return
↓ cardiac output
↓ blood pressure

Cerebral ischemia leading to fainting
Exercise-associated Muscle Cramp: Exertional Heat Cramps

• Bilaterally, characterized by wondering fasciculations, tremors, or contractures

• Extensive sweating over prolonged period(s) sweat-induced whole body exchangeable sodium and fluid deficit
Exertional Heat Exhaustion

Inability to continue exercise in the heat due to cardiovascular insufficiency
Exertional Heat Exhaustion

• Cardiovascular insufficiency due to
  – Dehydration
  – Heat exposure

• Other factors
  – Energy depletion
  – Central fatigue
  – Hypotension

*Core body temperature (Tc) elevated but usually < 40.5°C (105°F)
*No CNS dysfunction or elevated liver enzymes
Exertional Heat Stroke

• “…characterized by profound neuropsychiatric impairment, often accompanied by organ damage and typically involves a high Tc [rectal, gastrointestinal, esophageal] 40.5°C (105°F).”

Casa et al. *J Athl Train* 2015
McDermott et al. *J Athl Train* 2009
Pryor et al. *Prehosp Emerg Care* 2011
Pathophysiology of EHS

- EHS is **life-threatening** and requires **immediate** medical care

- Excessive Tc affect intestinal permeability leading to endotoxin release, endotoxemia, septic shock, and possibly death

- “…irreversible cascade of events resulting in death”
  --Dr. Bruce Noble

“Cool FIRST [using CWI], transport SECOND”
A striking number of exertional heat illnesses (EHI) occur annually.

### High School and Collegiate Sport Heat Stroke Fatalities

<table>
<thead>
<tr>
<th>Period</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975-1979</td>
<td>8</td>
</tr>
<tr>
<td>1980-1984</td>
<td>9</td>
</tr>
<tr>
<td>1985-1989</td>
<td>5</td>
</tr>
<tr>
<td>1990-1994</td>
<td>2</td>
</tr>
<tr>
<td>1995-1999</td>
<td>13</td>
</tr>
<tr>
<td>2000-2004</td>
<td>11</td>
</tr>
<tr>
<td>2005-2009</td>
<td>18</td>
</tr>
<tr>
<td>2010-2014</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 1. Exertional heat-related injuries (EHIs) treated in U.S. emergency departments and average temperature in NEISS cities, April–October 1997–2006.

NEISS, National Electronic Injury Surveillance System.


Risk factors for EHI

**Intrinsic**
- Improper acclimatization
- Overzealousness
- Reluctance to report symptoms
- Recent illness
- Poor physical fitness
- Dehydration
- Sleep restriction/deprivation
- Overweight (BMI>22)
- Medication or supplements
- Excessive alcohol
- Previous EHS
- Heat intolerance (genetic?)
- Diabetes
- Anhidrosis
- Excessive scar tissue (burn victims)

**Extrinsic**
- Environment
  - WBGT, RH, ambient temp
  - WBGT the day before
  - Solar radiation
  - Time of day
- Workload unmatched to fitness
- Improper work-rest cycles
- Inadequate hydration intervals
- Lack of access to hydration
- Equipment or clothing
- Peer, parent, or coach pressure
When are athletes at greatest risk for EHI?

- 1/3 occur after 2 hours of practice
- 11.3x greater rate in football than all other sports combined
- Most occur during August (60%)
  - >90% of these EHI occur during pre-season

Rates of EHI among U.S. high school athletes in football

Greatest EHI Risk During First Week in Unacclimatized, Unfit, Unaccustomed Athletes

Incidence of heat syncope among 45 test subjects living in a hot environment for 24 hours each day and undergoing exercise trials

Adapted from Bean and Eichna. *Federation Proceedings* 2:144-158, 1943.
Prevention Strategies

- Presence of an Athletic Trainer
- Heat Acclimation (HA)
- Exercise Intensity
- Equipment/Exercise Modification
- Cooling Modalities
- Hydration
- Environmental Conditions
Acclimatization to heat...

...one of most remarkable and dynamic physiological adjustments humans are capable of making.
Terminology

Acclimation

Acclimatization
Several HA protocols exist

- Repeated exercise-heat exposures ($\uparrow T_c \geq 38.5^\circ C$)

- Common Protocols
  - Average aerobic fitness
    - 100 min/day at 40-50% VO$_{2\text{max}}$ for 10-14 days
  - More aerobically fit
    - 30-45 min/day at 75% VO$_{2\text{max}}$ for 5-9 days

## High School HA Protocol: First Week of Pre-season

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gear</strong></td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td><strong>Max Practice Time</strong></td>
<td>3 hours</td>
<td>3 hours</td>
<td>3 hours</td>
<td>3 hours</td>
<td>3 hours</td>
<td>5 hours</td>
</tr>
<tr>
<td><strong>Contact</strong></td>
<td>None</td>
<td>None</td>
<td>Sleds</td>
<td>Sleds</td>
<td>Sleds</td>
<td>No restrictions</td>
</tr>
</tbody>
</table>

After 6 days...
1. allow ≥ 1 hr between multiple practices totaling < 5 hr
2. allow 1 day between two-a-days

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Casa & Csillan. *J Athl Train 2009*  
Casa et al. *J Athl Train 2015*
HA Induction

75% of HA adaptations occur within 4-6 days of exercise-heat exposure but full acclimation may require up to 10-14 days.

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Days of heat acclimatisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate decrease</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14</td>
</tr>
<tr>
<td>Plasma volume expansion</td>
<td></td>
</tr>
<tr>
<td>Rectal temperature decrease</td>
<td></td>
</tr>
<tr>
<td>Perceived exertion decrease</td>
<td></td>
</tr>
<tr>
<td>Sweat Na⁺ and Cl⁻ concentration decrease^a</td>
<td></td>
</tr>
<tr>
<td>Sweat rate increase</td>
<td></td>
</tr>
<tr>
<td>Renal Na⁺ and Cl⁻ concentration decrease</td>
<td></td>
</tr>
</tbody>
</table>

^a While consuming a low NaCl diet.
Several consecutive exercise-heat exposures result in a complex of key physiological adaptations termed HA

Wyndham et al. *J Appl Physiol* 1964

Consequences of HA lead to improved thermoregulation, cardiovascular, and aerobic performance

<table>
<thead>
<tr>
<th>INCREASED</th>
<th>DECREASED</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sweat rate</td>
<td>• Resting Tc</td>
</tr>
<tr>
<td>• Sweat sensitivity</td>
<td>• Exercising Tc</td>
</tr>
<tr>
<td>• Skin blood flow rate</td>
<td>• Exercising skin temperature (T_{sk})</td>
</tr>
<tr>
<td>• Skin blood flow sensitivity</td>
<td>• Sub-maximal heart rate</td>
</tr>
<tr>
<td>• Plasma volume</td>
<td>• Perceptual responses</td>
</tr>
<tr>
<td>• Stroke volume</td>
<td>• Core-to-skin temp gradient</td>
</tr>
<tr>
<td>• Max cardiac output</td>
<td>• CHO metabolism</td>
</tr>
<tr>
<td>• VO_{2max}</td>
<td>• Sodium loss</td>
</tr>
<tr>
<td>• Lactate threshold</td>
<td>• Blood and muscle lactate</td>
</tr>
<tr>
<td>• Total body water</td>
<td></td>
</tr>
<tr>
<td>• Lactate threshold</td>
<td></td>
</tr>
<tr>
<td>• Running economy</td>
<td></td>
</tr>
<tr>
<td>• Heat shock proteins</td>
<td></td>
</tr>
<tr>
<td>• Cytoprotection</td>
<td></td>
</tr>
<tr>
<td>• Thirst sensation</td>
<td></td>
</tr>
</tbody>
</table>

↑ exercise-heat tolerance and ↓ risk of exertional heat illness
HA can help reduce risk of heat syncope

Problem: heat dissipation and insufficient venous return
  • Highest risk in first 5 days

HA: expanded plasma volume

HA: blood pressure better defended

HA: improved dry and wet heat loss mechanisms
HA can help reduce risk of heat cramps

Problem: fluid-electrolyte imbalance, fatigue

HA: enhanced sodium retention and thirst drive via aldosterone

HA: improved exercise-heat tolerance
HA can help reduce risk of heat exhaustion

Problem: cardiovascular insufficiency, hypotension, fatigue

HA: enhanced sodium retention and thirst drive via aldosterone

HA: expanded plasma volume

HA: blood pressure better defended

HA: improved exercise-heat tolerance
HA can help reduce risk of EHS

Problem: heat gain > heat loss

HA: increased sweat rate and sensitivity

HA: increased skin blood flow rate and sensitivity

HA: improved hydration status

HA: reduced resting and exercising Tc and Tsk
HA adaptations must be sustained for continued safety of those periodically exerting themselves in hot conditions.
Compared to HA induction,
sparse data exist regarding HA decay

We don’t have a definitive idea for how long HA lasts…
The beneficial adaptations associated with HA are **transient**

<table>
<thead>
<tr>
<th></th>
<th>HEART RATE</th>
<th></th>
<th>RECTAL TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Week</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Williams et al. (1967)</td>
<td>65</td>
<td>87</td>
<td>92</td>
</tr>
<tr>
<td>Pandolf et al. (1977)</td>
<td>23</td>
<td>20</td>
<td>29</td>
</tr>
<tr>
<td>Saat et al. (2005)</td>
<td>29</td>
<td>35</td>
<td>--</td>
</tr>
<tr>
<td>Weller et al. (2007)</td>
<td>--</td>
<td>33</td>
<td>27</td>
</tr>
<tr>
<td>Poirier et al. (2014)</td>
<td>42</td>
<td>58</td>
<td>--</td>
</tr>
<tr>
<td>Ashley et al. (2015)</td>
<td>--</td>
<td>127</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>40</td>
<td>60</td>
<td>39</td>
</tr>
</tbody>
</table>

%Loss = \( \frac{\text{Average value after day of decay} - \text{Average acclimation value}}{\text{Average unacclimated value} - \text{Average acclimation value}} \times 100 \)

(+ number = decay, (-) number = gain)
$V_{O2\max}$ and physical training related to HA induction and decay(?) rate

PLATEAU DAY = 14.49 - 0.165 $V_{O2\ max}$

$r = -0.68$

Pandolf et al. *Ergonomics* 1977
What about HA reduction?

• 1-4 days of consecutive exercise-heat exposures 2-4 weeks after initial HA appears effective

• CONS:
  – Periodically reassessed HA status
  – Some, but not all studies tracked physical activity
  – May be logistically difficult
  – Sacrifice training days (intensity?)

Pandolf et al. *Ergonomics* 1977
Ashley et al. *J Occup Environ Hygiene* 2015
Some suggestions for Intermittent Heat Exposure (IHE) exist... but remain untested and efficacy unknown

• General rule of thumb:
  – every 2 days w/o heat exposure, 1 day of HA is lost

• From previous literature, ratios of heat exposure days to days w/o heat exposure were calculated
  – ranged 1:6 to 1:9

• Taylor (2000) conservatively hypothesized 1 day of heat exposure for every 5 days without

Pandolf et al. Ergonomics 1977
Williams et al. J Appl Physiol 1967
Ashley et al. J Occup Environ Hygiene 2015
Research Question

Does an intermittent heat exposure (IHE) every five days after initial HA prolong the beneficial adaptations of HA after 25 days?
Participants

– 16 recreationally active college-aged males

• 1-5 sessions of physical activity per week

• $\text{VO}_{2\text{max}} > 45 \text{ ml/kg/min}$

• Assumed to be not heat acclimated
  – Testing occurred Oct-Mar in northeast US
  – $10.4 \pm 2.2^\circ\text{C}$ and $70.5 \pm 6.5 \%\text{RH}$
Experimental Design

**Baseline Testing** (n=16)

IHE (n=9)

Pre HA → HA → Post HA

CON (n=7)

Heat Stress Tests
120 min
10 min rest period
45% VO_{2max}

**RED** = 40°C / 40% RH

**BLUE** = 20°C / 20% RH

💧 = Blood draw
Exercise duration and intensity affect HA induction rate

• However, it is unknown how these variables influence HA decay

• Intensity (HR) and duration (min) of outside-of-lab physical activity was recorded during the 25 day intervention

Pandolf. *Ergonomics* 1977
Demographics were similar between groups at baseline.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subject demographics at baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IHE (n=9)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>23.9 ± 3.7</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>72.8 ± 6.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.5 ± 4.9</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.91 ± 0.10</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>8.8 ± 4.8</td>
</tr>
<tr>
<td>VO₂max (ml·kg⁻¹·min⁻¹)</td>
<td>53.5 ± 5.2</td>
</tr>
<tr>
<td>Physical activity (min·wk⁻¹)</td>
<td>279.1 ± 138.4</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
Both groups heat acclimated

* p < 0.05 from Pre HA. No group or interaction effects (p > 0.20). Groups collapsed and mean difference (Pre- Post HA) reported. Data are means and 95% CI.
Both groups heat acclimated

* $p < 0.05$ from Pre HA. No group or interaction effects ($p > 0.20$). Groups collapsed and mean difference (Pre-Post HA) reported. Data are means and 95% CI.
Both groups heat acclimated

• Post-exercise perceptual responses were lower
  – Fatigue
    • Mean difference (Pre HA-Post HA) [MD] = 2, 95% CI [1, 4], p = 0.017
  – Thermal
    • MD = 1, 95% CI [0.5, 1.5] p = 0.003
  – OMNI (effort)
    • MD = 3, 95% CI [1, 5], p = 0.001

• 50% (8/16) subjects prematurely terminated Pre HA due to EHI symptomology or $T_{re} = 40.0^\circ$C

• No subjects prematurely terminated Post HA due to EHI symptomology and only 1 subject reached $T_{re} = 40.0^\circ$C
25 day IHE intervention

- 4.1 ± 0.8 days between heat stress tests

- Environmental conditions at +5, 10, 15, and 20 d were different between groups
  - IHE: 39.8 ± 1.3°C; 37.1 ± 5.5 % RH
  - CON: 23.8 ± 1.2°C; 21.7 ± 13.5% RH

- By design, several physiological responses were lower in CON vs. IHE at +5, 10, 15, and 20 d
  - post-exercise $T_{re}$ and $T_{sk}$
  - thermal sensation
  - HR
  - sweat rate
Post-exercise HR at +25 d was lower in IHE compared to CON

* p = 0.002 from Pre HA. ** p = 0.001 from Post HA. † p ≤ 0.01 between groups. MD = mean difference (Pre- Post HA). Data are means and 95% CI.
IHE post-exercise $T_{re}$ at +25 d was lower than Pre HA

* $p < 0.05$ from Pre HA. MD = mean difference (Pre- Post HA).

Data are means and 95% CI.
In CON, post-exercise $T_{sk}$ at +25 d was lower than Pre HA.

*Different from Pre HA, $p \leq 0.021$. MD = mean difference (Pre- Post HA).
Data are means and 95% CI.
At +25 d, sweat rate was similar to Pre and Post HA in both groups.

* $p = 0.04$ from Pre HA. MD = mean difference (Pre- Post HA).
Data are means and 95% CI.
Post-exercise cortisol was lower at +25 d in IHE

* p ≤ 0.04 from pre-exercise of that trial. † p ≤ 0.046 between groups. Data are means and 95% CI.
Post-exercise epinephrine was lower at +25 d in IHE

Data are means and 95% CI.

* p ≤ 0.048 from Pre HA. ** p = 0.048 from Post HA. † p ≤ 0.046 between groups.
Perceptual Responses

- In IHE, perceptuals during the 25 day intervention were lower than Pre HA ($p \leq 0.022$) and approached significance compared to Post HA ($p \geq 0.056$)

- +25 d post-exercise perceptuals were similar between IHE and CON
  
  - Thermal
    - mean difference (CON-IHE) [MD] = 0.5, 95% CI [-1.5, 0.5], ES = 0.63, $p = 0.30$
  
  - Fatigue
    - MD = 2, 95% CI [-0.5, 4.0], ES = 0.82, $p = 0.14$
  
  - OMNI (effort)
    - MD = 1, 95% CI [-4, 2], ES = 0.40, $p = 0.45$
IHE better sustained adaptations 25 days after initial HA

Group comparison of adaptation decay 25 days after initial heat acclimation. Negative value denotes a loss of adaptation.
• Both groups were euhydrated ($U_{sg} \leq 1.021$) with similar % body mass loss ($p = 0.20$)

1. HR $\uparrow$ 7 bpm per 1°C increase in body temperature
2. $\uparrow$ Epinephrine in CON
3. $\uparrow T_{sk}$, subsequent $\uparrow$ skin blood flow create competition for limited cardiac output
4. Reduced physical activity in CON during 25 d intervention

Jose et al. *Am Heart J* 1970
Wyss et al. *J Appl Physiol* 1974
Lee et al. *Med Sci Sport Exerc* 2015
Ganio et al. *AJP: Heart Circ Physiol* 2012
<table>
<thead>
<tr>
<th></th>
<th>IHE</th>
<th>CON</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration/wk (min)</td>
<td>245.6 ± 245.6</td>
<td>220.6 ± 159.3</td>
<td>0.74</td>
</tr>
<tr>
<td>Range (min)</td>
<td>0 - 600</td>
<td>0 - 471</td>
<td>--</td>
</tr>
<tr>
<td>Intensity (%HRmax)</td>
<td>61.9 ± 10.4</td>
<td>68.3 ± 10.6</td>
<td>0.07</td>
</tr>
<tr>
<td>Range (%HRmax)</td>
<td>61.1 - 79.6</td>
<td>51.5 - 68.2</td>
<td>--</td>
</tr>
</tbody>
</table>

Date are mean ± SD.
HR significantly decayed in CON

- 163% loss by +25 d

- Detraining?
  - 2/7 CON subjects did not exercise out-of-lab
  - 5/7 CON subjects reduced out-of-lab activity

- Regular exercise aids in HA induction and adaptation retention (positive cross adaptation)

- Out-of-lab exercise intensity was strongly correlated to +25 day post-exercise HR in IHE
  \[ r = -0.89, \quad p = 0.017 \]

Pandolf et al. *Ergonomics* 1977
Recap

- HR was attenuated and clinically important reductions in $T_{re}$ and $T_{sk}$ were observed in IHE vs CON at +25 d
  - ↓ physiological strain corroborated by biochemical data
  - At +25 d, adaptations were better preserved in IHE

- Evidence to guide best practices to mitigate heat adaptation decay for sustained protection against thermal injury

Compared to previous work...

| Table 1. Percent decay/loss of HA adaptations in select medium term HA studies. |
|----------------------------------|----------------------------------|
|                                  | HEART RATE                       | RECTAL TEMPERATURE               |
|                                  | 1<sup>st</sup> | 2<sup>nd</sup> | 3<sup>rd</sup> | 1<sup>st</sup> | 2<sup>nd</sup> | 3<sup>rd</sup> |
| Week                             |                  |                  |                  |                  |
| Williams et al. (1967)           | 65              | 87              | 92              | 26              | 35              | 45              |
| Current study: CON group         | --              | --              | 163             | --              | --              | 87              |
| Pandolf et al. (1977)            | 23              | 20              | 29              | 13              | 18              | 4               |
| Saat et al. (2005)               | 29              | 35              | --              | 24              | 35              | --              |
| Weller et al. (2007)             | --              | 33              | 27              | --              | 15              | -9              |
| Poirier et al. (2014)            | 42              | 58              | --              | 30              | 28              | --              |
| Ashley et al. (2015)             | --              | 127             | 6               | --              | 75              | --              |
| Current study: IHE group         | 100             | 80              | 53              | 0               | 29              | 3               |

(+) number = decay, (-) number = gain
Practical applications

• How much heat exposure is required to sustain HA?

• Objective credibility to the hypothesis of exercise-heat exposure once every fifth day

• A single periodic day of exercise-heat exposure affords logistical and training flexibility

• Recommend intense physical activity sufficient to…
  – ↑ $T_{re}$
  – initiate sweating
  – ↑ cutaneous blood flow
  …providing additional stimuli to sustain HA adaptations
Future Research

1. Optimize characteristics of periodic exercise-heat exposures
   – Balance between intensity and duration

2. Less fit subjects
   – Firefighters, military, laborers

3. Extend findings to field setting
   – Preseason American football

4. Alternate HA induction methods, do they prolong decay?
Take Home Points

• HA reduces EHI risk but adaptations are transient

• One exercise-heat exposure every 5th day prolonged HA

• Intense physical activity after induction of HA can help sustain adaptations, but not without periodic heat exposure

• Many questions remain on how to prolong HA adaptation duration
THANK YOU!!!

Committee
• Carl M Maresh
• Doug J Casa
• Lawrence E Armstrong
• Elaine C Lee
• Lindsay J DiStefano
• Jeffrey Anderson

Heat Acc “Dream Team”
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• Lesley Vandermark
• Elizabeth Adams
• Rachel Vanscoy