#704 - Heat Stress: The Triggering Component of Firefighter Heart Attacks and Injuries?

Denise Smith, Ph.D.
Gavin Horn, Ph.D.
Craig Haigh, C.F.O., NREMT-P
Heat Stress:
The Triggering Component of Firefighter Heart Attacks and Injuries?

Fire Rescue International  August 2008

Denise Smith, PhD; Gavin Horn, PhD; Chief Craig Haigh
Heat Stress

• What is it?
• Why is it a problem?
• Research
  • Cardiovascular related fatalities
  • Biomechanics related injuries
  • DHS FP&S R&D study at IFSI
• What can be done about it?
What is Heat Stress?

**Heat Stress** - The various physical work and environmental components that combine to create the heat load under which an individual works.

**Heat Strain** - The physiological response and the resulting thermoregulatory processes to combat heat stress.
How Does a FF Define/Identify Heat Stress

- Hot
- Fatigued
- Woozy
- Rubbery Legs
Normal Thermoregulation

Heat Gain

Heat Loss
Cause of Heat Stress on the Fire Ground?

Heat Gain
- Muscular work (including weight of PPE)
- Radiant heat (Fire, Sun)

Heat Loss
- Encapsulating gear
- High external temp
Why is Heat Stress a Problem?

1. **Classic Heat Illness**
   - usually seen during longer duration activity

2. **Dehydration, Fatigue, Impaired Cognitive Function**
   - worsens as activity continues

3. **Increased Cardiovascular Strain** – linked to sudden cardiac events???

4. **Fatigue leading to increased slips, trips and falls??**
Exertional Heat Illness

- Heat cramps
- Syncope
- Heat exhaustion
- Heat stroke
Heat Stroke

Case Studies

U.S. Fire Administration
Emergency Incident Rehabilitation
February 2008

FEMA
Dehydration, Fatigue, and Disorientation

- Many Firefighters are dehydrated before beginning FF operations
  - MFRI, OCFD
- Firefighting leads to:
  - Decreased plasma volume
  - Fatigue
  - In severe situations, to disorientation
Cardiovascular Strain Associated With Heat Stress

- Increased HR, Cardiac Output
- Decrease in Plasma Volume and Stroke Volume
- Increased Clotting??
Heat Stress is a Problem in the Fire Service

How Do We Know its Impact?

Approach:
1. Theoretical
2. Statistical
3. Research Data
“Probably the greatest stress ever imposed on the human cardiovascular system is the combination of exercise and hyperthermia. Together these stresses can present life-threatening challenges, especially in highly motivated athletes who drive themselves to extremes in hot environments.”

Fire Service Statistics

Firefighting is a dangerous occupation
- Injuries – approx. 60-80,000 per year reported
- Fatalities – approx. 100 per year
- Highest occupational death rate for sudden cardiac events
Fatality Statistics I

Firefighter fatalities 1990-2005

- 44% Cardiac Arrest/MI
- 27% Trauma
- 11% Asphyxiation
- 8% Burns
- 10% Other

![Pie chart showing firefighter fatalities by cause: Cardiac Arrest, Trauma, Asphyxiation, Burns, Other.](chart.png)
<table>
<thead>
<tr>
<th>Occupation</th>
<th>% of On-Duty Deaths caused by CVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firefighters</td>
<td>45%</td>
</tr>
<tr>
<td>Police</td>
<td>22%</td>
</tr>
<tr>
<td>Overall*</td>
<td>15%</td>
</tr>
<tr>
<td>Construction</td>
<td>11.5%</td>
</tr>
<tr>
<td>EMS</td>
<td>11%</td>
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*Average % of all Occupational Fatalities, all Industries
## Risk of CHD Death

<table>
<thead>
<tr>
<th>Type of Duty</th>
<th>RR of CHD death</th>
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<tbody>
<tr>
<td>Fire suppression – OR** (95% CI)</td>
<td>53 (40-72)</td>
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<td>Physical training – OR** (95% CI)</td>
<td>5.2 (3.6-7.5)</td>
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<tr>
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*Kales et al 2007*
Cardiovascular Strain of FF

Physical Work

Sympathetic Nerve Stimulation (Adrenaline)

Heat Stress

Cardiovascular Strain of FF
Cardiovascular Strain of FF

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Cardiovascular Strain of FF
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Model of Sudden Cardiac Event

Plaque Accumulation

Age (years)

Heart Attack

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Simplified Schematic of Heat Stress

Perfuse sweating
- Decreased Plasma volume
  - Circulatory Shock
- Increased Body Temperature
  - Altered Electrolytes
  - Arrythmias
  - Increased viscosity
    - Clot Formation
  - Changes in HR and BP
    - Plaque Disruption
- Activation of SNS
  - Increased Body Temperature

Heart Attack
Simplified Schematic of Heat Stress

- Perfuse sweating
- Increased Body Temperature
- Activation of SNS
- Decreased Plasma volume
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- Changes in HR and BP
- Circulatory Shock
- Arrhythmias
- Clot Formation
- Plaque Disruption
- Heart Attack

- Perfuse sweating leads to:
  - Increased Body Temperature
  - Decreased Plasma volume
  - Circulatory Shock

- Increased Body Temperature leads to:
  - Activation of SNS
  - Altered Electrolytes
  - Increased viscosity
  - Changes in HR and BP

- Decreased Plasma volume leads to:
  - Circulatory Shock

- Altered Electrolytes leads to:
  - Arrhythmias
  - Clot Formation

- Increased viscosity leads to:
  - Clot Formation

- Changes in HR and BP leads to:
  - Plaque Disruption

- Circulatory Shock leads to:
  - Arrhythmias

- Arrhythmias leads to:
  - Clot Formation

- Clot Formation leads to:
  - Heart Attack

- Plaque Disruption leads to:
  - Heart Attack
Simplified Schematic of Heat Stress

Dehydration → Decreased Plasma volume → Circulatory Shock

Increased Body Temperature → Altered Electrolytes → Arrythmias

Activation of SNS → Increased viscosity → Clot Formation

Changes in HR and BP → Plaque Disruption

Heart Attack
Field-based Research to Document the Stress of Firefighting
Changes During Firefighting

- Drills: ~8min
- Rehab
- Rc1
- ~8min

= Measurement period
Heart Rate Response

* p<0.05 vs rest
Stroke Volume Response

# p<0.05 vs T₁
Effect of Firefighting on Coagulation Factors (N=10; Mean ± SD)

<table>
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<tr>
<th>Variable</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platelets (x10³/uL)</td>
<td>236.6 (48.2)</td>
<td>316.2 (83.4) *</td>
</tr>
<tr>
<td>Prothrombin Time (s)</td>
<td>10.18 (0.6)</td>
<td>10.13 (0.6)</td>
</tr>
<tr>
<td>Fibrinogen (mg/dL)</td>
<td>254.5 (17.2)</td>
<td>265.6 (21.5) *</td>
</tr>
</tbody>
</table>

* p<0.001
Fireground Injuries

In 2006

From 1990-2005

- **26%** Fall, jump, slip
- **24%** Overexertion/strain
- **13%** Contact with object
- **9%** Contact with fire products

- **6%** Struck by
- **6%** Exposure to chemicals
- **13%** Other
Fireground Injuries

![Bar chart showing the number of fireground injuries from 1990 to 2006. The chart indicates a decrease in the number of injuries over time, with a significant reduction in injuries labeled as "Other Injuries." The years 1990, 1992, 1994, 1996, 1998, 2000, 2002, 2004, and 2006 are marked on the x-axis, and the number of injuries is shown on the y-axis. The chart also indicates that "Slip, Fall, Jump" injuries are present but are not the majority of injuries.]
Damage from Slips, Trips & Falls

- **Most common types of injuries**
  - Sprains and strains, 65% of injuries
  - Fractures and dislocations, 14% of injuries
    - Houser et al. (Rand Corporation, 2004)

- **Accidents due to falls resulted in the longest work absences**
  - Cloutier and Champoux (Industrial Ergonomics, 2000)

- **Slips and falls accounted for**
  - 16% of all firefighter injuries, but
  - 25% of the total time lost
    - Ault (Advantage, 2002)
Model of Slip, Trip, Fall Event

Environment
- Smoke
- Mud
- Water
- Clutter
- (Ice)

Heat
- Heat Stress
- Conscientious
- Training
- Fatigue
- Aggressiveness
- Situation Awareness

Equipment
- Footwear
- PPE Design
- PPE Fit
- Tools
- Uneven Loading
- SCBA

Individual

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Studying Slips, Trips & Falls

- **Biomechanics of human movement**
- **Approach to understanding balance and gait in firefighters**
  - Balance / postural control
    - Static and dynamic balance assessments
  - Walking behavior
    - Level ground and stationary obstacles
  - Changes in these measures may put firefighters at higher risk for injury
What we know about FF Biomechanics

- **Firefighting SCBA significantly affects FF balance**
  - Affect of firefighting PPE is not agreed upon

- **Balance is affected by age**
  - Older FF more strongly affected by PPE than younger FF

- **Dynamic stability test has been shown to be predictive of FF at a higher risk for slipping**
What we don’t know about FF Biomechanics

- No studies on the effect of heat stress on firefighter:
  - Balance
  - Gait cycle

- Limited investigation of effects of
  - Individual characteristics
  - Environmental characteristics
Research Question

Firefighting

Heat Stress

Fatigue

Overexertion/Strain

Biomechanical Changes

Cardiovascular Changes

Slips, Trips, Falls

Sudden Cardiac Events

Leading cause of fireground injury

Leading cause of line of duty fatalities
Firefighting

Research Question

Standard gear

Enhanced gear

Heat Stress

Fatigue

Overexertion/Strain

Gait, Balance

Biomechanical Changes

Cardiovascular Changes

Slips, Trips, Falls

Sudden Cardiac Events

Leading cause of fireground injury

Leading cause of line of duty fatalities

T_{co}, T_{skin}

Platelets, Coagulation, Fibrinolysis

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Role of Individual Health Factors

Firefighting

Heat Stress

- Carotid Intimal Thickness
- Arterial Stiffness
- Flow Mediated Dilation
- CRP

Predictive?

Individual CV Variables
- Carotid Intimal Thickness
- Arterial Stiffness
- Flow Mediated Dilation
- CRP

Biomechanical Changes

- Fatigue
- Overexertion/Strain

Cardiovascular Changes

- Slips, Trips, Falls
- Sudden Cardiac Events

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Research Team

- **Cardiovascular and physiological effects of firefighting, heat stress, and rehab**
  - Denise Smith, Ph.D.

- **Firefighter tool design & testing**
  - Gavin Horn, Ph.D.

- **Psychological & cognitive function effects of heat stress**
  - Steve Petruzzello, Ph.D.

- **Biomechanics**
  - Liz Hsiao-Wecksler, Ph.D.
  - Karl Rosengren, Ph.D.

- **Cardiovascular research**
  - Bo Fernhall, Ph.D.

- **Pathology, sickness behavior**
  - Gregory Freund, M.D.

- **Firefighter training protocols and communications research**
  - Brian Brauer, M.Sc., RN
Study Design

- **2 Testing periods**
  - Cardiovascular Lab
  - Firefighting drills in a live fire burn tower

- **2 groups (n=60)**

- During FF drills subjects wore one of two types of specially designed PPE
  - Standard vs. Enhanced
  - Total Fire Group
  - International Personnel Protection

*DHS AFG EMW-2006-FP-02459*
Personal Protective Equipment

- **Standard Configuration**
  - Bunker gear with a spun Nomex® lining
  - Kevlar fully-encapsulating hood
  - Leather gloves with a Kevlar wrist gauntlet
  - Traditional-style helmet
  - Rubber boots

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Personal Protective Equipment

- Enhanced Configuration
  - Bunker gear with an Indura FR cotton lining which circulated exhaled air from the firefighter to the coat’s inner lining
  - Nomex® hood
  - Leather gloves
  - Low-profile helmet
  - Lightweight leather/Kevlar boots.

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## Results

### Descriptive Characteristics (n=110)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Standard (n=54)</th>
<th>Enhanced (n=56)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs.)</td>
<td>29.5 (3.4)</td>
<td>29.9 (5.4)</td>
</tr>
<tr>
<td>Ht. (m)</td>
<td>1.8 (0.07)</td>
<td>1.8 (0.08)</td>
</tr>
<tr>
<td>Wt. (kg)</td>
<td>86.0 (15.3)</td>
<td>89.8 (13.9)</td>
</tr>
<tr>
<td>BMI</td>
<td>27.6 (3.8)</td>
<td>28.6 (3.5)</td>
</tr>
</tbody>
</table>
Gait Data

(b) Step Length (S, L in)
- Baseline
- Pre-activity
- Post-activity

(d) Step Width (SW, in)
- Baseline
- Pre-activity
- Post-activity

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Gait Data

<table>
<thead>
<tr>
<th>Gear</th>
<th>Standard</th>
<th>Enhanced</th>
<th>Baseline</th>
<th>Pre FF</th>
<th>Post FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCL (in)</td>
<td>12.54 ± 0.48</td>
<td>12.41 ± 0.46</td>
<td>13.82 ± 0.46 † ‡</td>
<td>11.60 ± 0.35 †</td>
<td>11.99 ± 0.34 †</td>
</tr>
<tr>
<td>HCT (in)</td>
<td>10.53 ± 0.42</td>
<td>10.56 ± 0.40</td>
<td>10.51 ± 0.44</td>
<td>10.69 ± 0.32</td>
<td>10.43 ± 0.37</td>
</tr>
<tr>
<td>SLST_cycle (%)</td>
<td>38.20 ± 0.22</td>
<td>38.72 ± 0.19</td>
<td>39.49 ± 0.17 † ‡</td>
<td>38.08 ± 0.15 † ‡</td>
<td>37.82 ± 0.16 † ‡</td>
</tr>
<tr>
<td>SLST_cross (sec)</td>
<td>0.548 ± 0.010</td>
<td>0.530 ± 0.010</td>
<td>0.527 ± 0.007 †</td>
<td>0.553 ± 0.009 † ‡</td>
<td>0.539 ± 0.009 †</td>
</tr>
</tbody>
</table>

* Different than baseline
† Different than pre-firefighting
‡ Different than post-firefighting

- Performance decline increases by wearing PPE
- Enhanced PPE improves some parameters
- Limited effect due to FF activity: pre to post

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Balance Data

![Diagram of balance platform with labels for 4" Tall Platform, 6" x 10" Plank, and Bar placed at 75% subject height.]
<table>
<thead>
<tr>
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<th>Pre FF</th>
<th>Post FF</th>
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<tbody>
<tr>
<td><strong>Factor VIII (iu/mL)</strong></td>
<td>.96 ± 0.33</td>
<td>1.71 ± 0.61</td>
</tr>
<tr>
<td><strong>PF 1.2 (pmol/L)</strong></td>
<td>143 ± 51</td>
<td>153 ± 49</td>
</tr>
<tr>
<td><strong>tPA-agn (ng/mL)</strong></td>
<td>10.0 ± 10.7</td>
<td>19.2 ± 13.4</td>
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<tr>
<td><strong>PAI-1- agn (ng/mL)</strong></td>
<td>31.1 ± 19.3</td>
<td>33.4 ± 19.2</td>
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Conclusions

Cardiovascular

1. 25% - obese (BMI > 25); 75% - overweight or obese (BMI > 30)

2. 10% - hypertensive (SBP > 140 mmHg),
   65% prehypertensive or hypertensive (SBP > 120 mmHg)

3. No difference in HR, $T_{co}$, blood variables or perceptual measures between PPE Configurations

4. 18 minutes of FF activity results in an increased clotting potential
   - Increase in platelet number and activity (decrease in closure time)
   - Increased coagulatory variables (Factor VIII, PF1.2)
   - Altered fibrinolysis (increase in PAI-1 ang)
Conclusions

Biomechanics

1. Wearing PPE reduces gait and balance performance
2. New enhanced PPE design may minimize the impact of PPE on gait and possibly balance performance
3. 18 minutes of strenuous FF activity does not appear to affect gait or balance performance
Compelling evidence that heat stress is a problem in Fire Service, based on:

- Theoretical knowledge
- Anecdotal evidence
- Statistical results
- Research findings
What Can be Done About Heat Stress?

1. Know the Risk Factors for Heat Stress
2. Hydration
3. Fitness
4. Medical Status (including medications)
5. Cooling
6. Gear
7. SOPs – On-scene Rehabilitation
What Can be Done About Heat Stress?

Risk Factors for Heat Stress
1. Poor physical fitness
2. Excess body fat
3. Skin problems
4. Minor illness
5. Medications
6. Chronic disease
What Can be Done About Heat Stress?

Risk Factors for Heat Stress

7. Alcohol use
8. Age
9. Highly motivated
10. Genetics
11. Prior heat illness/injury
12. Cumulative days/ repeated exposure
Decreasing Heat Stress & Strain in the Fire Service

Pre-Event

On-Scene

Post Incident
Pre-Event

1. Hydration – days, hours
2. Fitness – weeks, years
3. Medical Readiness - years
Aerobic Fitness:

1. ↑ Thermal Tolerance
2. ↑ Plasma Volume
3. ↑ Cardiac Efficiency
   (more work – less strain)
4. ↑ Work Capacity
5. Improve Clotting Profile
Pre-Event

Appropriate Body Size:

1. ↑ Thermal Tolerance, ↓ Thermal Strain
2. ↑ Cardiac Efficiency
   (more work – less strain)
3. ↑ Work Efficiency
4. Improve Clotting Profile
Pre-Event

Medical Readiness

1. Medical conditions (cardiovascular function, kidney function, fluid and electrolyte balance, thermoregulation, fever, immune function, skin)

2. Medications (antihistamines, antidepressants, stimulants, diuretics, b-blockers)
On-Scene

Adopt Aggressive REHAB Policy

An intervention designed to mitigate against the physical, physiological, and emotional stress of firefighting in order to improve performance and decrease the likelihood of on scene injury or death.
On-Scene

Adopt Incident Rehabilitation Policies
1. Cool- “Aggressively”
2. Rehydrate
3. Provide rest and recovery
4. Monitor vitals
Post Incident

1. Need to replace water and electrolytes over the next 24 hrs. 
2. May need to replace carbohydrates before next meal depending on operation
SUMMARY

- Heat Stress is a Problem in the Fire Service, and is a greater problem than normally realized because of its association with sudden cardiac events.
SUMMARY

A great deal can be done to mitigate against heat stress by:

- Being Fit, Healthy and Hydrated before the fire and
- Adopting Aggressive REHAB policies
• Do not forget to fill out your Evaluation Forms

• Reminder: Exhibit Hall is open
  • Friday from 10:30 am – 5:00 pm
  • Saturday from 10:00 am – 5:00 pm

• Handouts available on-line at:
  http://iafc.omnibooksonline.com/fri/
Thank you

Questions?
Protocol – CV Lab

Measures

- Body fatness
- C-reactive protein (blood marker of CVD)
- Carotid artery thickness (structural measure)
- Arterial health (functional measures; stiffness, ability to dilate)

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