Cardiovascular (and Thermal) Strain of Firefighting

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- Pathology, sickness behavior
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- Firefighter training protocols and communications research
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  - Brian Brauer
Section 1 – Firefighter Injury and Fatality Statistics

Section 2 – Conceptualizing SCE in the Fire Service

Section 3 – Research Agenda
  - Framework/Approach
  - Research Projects

Section 4 – Mitigating Risks in the Fire Service
Section One
Fatality Statistics

Relative risks
Firefighter Fatality Statistics (2009)

Figure 4
Firefighter Deaths by Nature of Injury -- 2009

- Cardiovascular Events (50%)
- Sudden cardiac death (43%)
- Internal trauma (34%)
- Stroke (6%)
- Asphyxiation (6%)
- Gunshot (1%)
- Burns (4%)
- Other (6%)

Source: NPFA, 2010
Firefighter Fatality Statistics

- Heart Attacks
- Burns
- Asphyxiation

Number of Firefighter Fatalities

Year

Section Two
Conceptualizing Risks

Complex Job of FF
Theoretical Models
Firefighting Physical Demands

Strenuous work
- Climbing stairs
- Forcible entry
- Search and rescue

Heavy PPE
- > 22 kg
- ↑ Metabolic work
- ↓ Heat dissipation

Hot and Dangerous Environment
- Over 100º C routinely
- Chaotic
- Low visibility
Characterizing Physiological Responses to Firefighting

Thermoregulation/Dehydration
• ↑ Tco₂, ↑ Sweating, ↓ Plasma Volume

Core Temperature
• Cardiac; ↑ HR, ↓ SV
• Vascular
• Clotting; ↑ Platelet # & Function

Blood Chemistry
• Hemoconcentration

Hormonal Disruption

Immune Disruption

Metabolic
• ↑ VO₂ ↑ Lactate

Mean Body Fat % = 18.1
Mean Age = 31.8 yrs
n=11

Smith et al. 2001, Ergonomics
Smith et al. 2005, Ergonomics
Risk Profiles

Impairs Performance
Potential Health/Safety Risk
Life Threatening

Cardiovascular
- Higher HR
- Earlier Fatigue
- Exhaustion
- Sudden Cardiac Events

Dehydration/Heat Strain
- Heat Stress
- Hyperthermia
- Early Fatigue
- Heat Exhaustion
- Impaired Cognitive Function
- Heat Stroke
Potential Mechanism of Sudden Cardiac Events

- Dehydration
- Increased Body Temperature
- Work/Adrenaline
- Decreased Plasma Volume
- Altered Electrolytes
- Cardiac Ischemia
- Viscosity/Coag Changes
- Changes in HR and BP

- Circulatory Shock
- Arrhythmias
- Clot Formation
- Plaque Disruption

Sudden Cardiac Events
Section Three
Research Agenda

Framework/Approach

Research Projects
Research Goals

Quantify the **cardiovascular strain** (cardiac, vascular, blood) associated with firefighting activity

and test interventions designed to lessen cardiovascular strain and the risk of injury or fatality, and improve performance
Theoretical Model: Physiological Stress of Firefighting

Types of Firefighting:
- Structural
- Wild land
- Ship Board
- Industrial
- Aviation/Aircraft

PPE

Work (Intensity, Duration)

Environment

Nervous System/Endocrine System

Muscular

Metabolic

Cardiovascular (Blood/Immune)

Thermal Balance Fluid Balance

Individual Factors:
- Age
- Aerobic Fitness
- Body Composition
- Health Status
- Medications

Systems Primarily Affected

Primarily Affected
- Muscular
- Metabolic
- Cardiovascular
- (Blood/Immune)

Measures/Response

High O₂
- ↑ Lactate

↑ HR, ↓ SV, ↑ BP
- Hemostasis
- ↑ Platelets
- ↑ Coagulation
- ↑ Fibrinolysis

↑ T_co, ↑ T_sk
- ↓ Plasma Volume
- ↓ Fluid Volume

Concern

Fatigue

↑ Myocardial O₂ Demand > Supply

Sudden Cardiac Events

Heat Illness
- Cardiovascular Collapse
## Framing a Research Agenda

### Cardiovascular Effects of FF

<table>
<thead>
<tr>
<th>Firefighting</th>
<th>Cardiac</th>
<th>Vascular</th>
<th>Blood (clotting)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Firefighting (IFSI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Short – Term</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Long- Term</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Other missions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work in PPE (Skidmore)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual Firefighting (Skidmore)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interventions (policies, pharmacological, technological)
Baseline CV health characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Body Mass Index (kg/m²)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;25.9</td>
<td>25.9-29.5</td>
<td>≥29.5</td>
</tr>
<tr>
<td></td>
<td>(Group 1)</td>
<td>(Group 2)</td>
<td>(Group 3)</td>
</tr>
<tr>
<td>Intima-media thickness</td>
<td>0.44 (0.01)</td>
<td>0.46 (0.01)</td>
<td>0.52(0.01)*†</td>
</tr>
<tr>
<td>Aortic pulse wave velocity</td>
<td>5.9(0.1)</td>
<td>6.4(0.2)*</td>
<td>6.8(0.1)*</td>
</tr>
<tr>
<td>β Stiffness</td>
<td>4.6(0.2)</td>
<td>5.1(0.2)</td>
<td>6.2(0.4)</td>
</tr>
</tbody>
</table>

* Different from group 1 (p<0.05)
† Different from group 2 (p<0.05)

Fahs et al., 2009, Am J Cardiol.

N=110 firefighters
Age= 29.7±8.0 years
Simulated Firefighter Activities
Methods

- Subjects - 23 firefighters
- Design – RM (2 conditions: control rehab vs. enhanced rehab)
- Protocol – 18 min FF drills
  - Control or enhanced Rehab
  - 10 minute dummy drag
  - 120 min RECOVERY

<table>
<thead>
<tr>
<th></th>
<th>Control Rehabilitation (15 min)</th>
<th>Post FF Data (7min)</th>
<th>Enhanced Rehabilitation (15 min)</th>
<th>Dummy Drag (10 min)</th>
<th>Recovery (120 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firefighting Drills (18 min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HR and Core Temp during FF and Recovery

[Graph showing heart rate (bpm) and core temperature (°C) during prep, firefighting, rehab, and recovery phases. The graph compares enhanced and standard conditions for both heart rate and core temperature.]
Figure 6. Changes in Rate Pressure Product (RPP) throughout the test protocol. Data from complete sets only (n=20). All timepoints are significantly different from the prefirefighting condition, dropping below this level before the 30 minute recovery time period in both conditions. (* indicates significant condition affect at these time points)
Figure 7. Changes in Subendocardial Viability Ratio (SEVR) throughout the test protocol. Data from complete sets only (n=18) (* indicates significant condition affect at these time points, dotted lines indicate the times where SEVR returns to pre-firefighting levels)
Platelet Data

![Graph showing platelet closure time over different data collection periods for EPI and ADP](image)

- **EPI**
- **ADP**

**Y-Axis:** Closure time (sec)

**X-Axis:** Data Collection Period

- Pre
- Post
- 120 Post
## Coagulatory and Fibrinolytic Factors

<table>
<thead>
<tr>
<th>Fibrinolysis</th>
<th>Pre</th>
<th>Post</th>
<th>120 Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pai-1 act</td>
<td>2.94</td>
<td>2.38</td>
<td>2.35</td>
</tr>
<tr>
<td>Pai-1 agn</td>
<td>24.17</td>
<td>26.23</td>
<td>21.94</td>
</tr>
<tr>
<td>Tpa act</td>
<td>0.53</td>
<td>1.90</td>
<td>0.55</td>
</tr>
<tr>
<td>Tpa agn</td>
<td>6.21</td>
<td>11.69</td>
<td>6.53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coagulation</th>
<th>Pre</th>
<th>Post</th>
<th>120 Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVIII</td>
<td>88.33</td>
<td>126.83</td>
<td>119.09</td>
</tr>
<tr>
<td>PTT</td>
<td>33.71</td>
<td>32.80</td>
<td>32.05</td>
</tr>
<tr>
<td>AT-III</td>
<td>97.32</td>
<td>100.15</td>
<td>101.22</td>
</tr>
<tr>
<td>TF</td>
<td>71.52</td>
<td>77.66</td>
<td>68.19</td>
</tr>
</tbody>
</table>

[Diagram of coagulatory and fibrinolytic factors showing the processes of tPA and PAI-1 involved in fibrinolysis and FDP formation]
Changes in Cardiovascular Function as a Result of Prolonged Firefighting

U.S. Department of Homeland Security - Assistance to Firefighters Grants Program (AFG)

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## Echocardiographic variables (systolic function)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEDD (mm)</td>
<td>53.0(6.1)</td>
<td>51.9(6.7)*</td>
</tr>
<tr>
<td>LVESD (mm)</td>
<td>35.6(6.3)</td>
<td>37.2(6.2)</td>
</tr>
<tr>
<td>LV SF(%)</td>
<td>33.0(6.3)</td>
<td>28.6(6.0)*</td>
</tr>
<tr>
<td>LVEDV (cm³)</td>
<td>138(37)</td>
<td>132(38)*</td>
</tr>
<tr>
<td>LVESV (cm³)</td>
<td>55(25)</td>
<td>61(25)</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>60.3(9.2)</td>
<td>54.3(9.5)</td>
</tr>
<tr>
<td>Stroke volume (ml)</td>
<td>82(20)</td>
<td>71(22)*</td>
</tr>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------</td>
<td>--------</td>
</tr>
<tr>
<td>Mitral E (cm s⁻¹)</td>
<td>81(14)</td>
<td>71(14)*</td>
</tr>
<tr>
<td>Mitral A (cm s⁻¹)</td>
<td>45(9)</td>
<td>45(14)</td>
</tr>
<tr>
<td>Mitral E/A</td>
<td>1.9(0.4)</td>
<td>1.7(0.6)</td>
</tr>
<tr>
<td>TDI E’ lateral (cm s⁻¹)</td>
<td>7.8(3.1)</td>
<td>6.3(2.7)*</td>
</tr>
<tr>
<td>TDI E’ septal (cm s⁻¹)</td>
<td>4.5(2.0)</td>
<td>4.2(1.8)</td>
</tr>
</tbody>
</table>
Laboratory Studies
Laboratory Study

Study Purpose

Investigate the physiological recovery from exercise in gear.
Subjects – 14 moderately trained FF

Design – RM (2 conditions: PPE vs shorts/Tshirt)

Protocol – 20 min exercise
– 90 min RECOVERY

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Exercise</th>
<th>RECOVERY</th>
</tr>
</thead>
<tbody>
<tr>
<td>-50min</td>
<td>-20</td>
<td>0</td>
</tr>
<tr>
<td>+30</td>
<td>+60</td>
<td>+90</td>
</tr>
</tbody>
</table>
Heart Rate during Exercise

- **Heart Rate (bpm)**
- **Time (min)**

Graph showing the heart rate over time for two groups: PPE and Control. The graph indicates an increasing heart rate over time for both groups, with the PPE group showing a steeper increase.

**Demographics**
- **N=14**
- **Age= 37.9±8.1**
- **BMI= 28.4±3.0**
Rate Pressure Product During Recovery (Myocardial oxygen consumption)

![Graph showing the change in Rate Pressure Product over time for different conditions.]

- **Baseline**
- **Post Exercise**
- **Time:** 30, 60, 90

**Group Comparison:**
- **PPE**
- **Control**

**Statistics:**
- **N=14**
- **Age:** 37.9±8.1
- **BMI:** 28.4±3.0

2009 AFG Grant
Myocardial Oxygen Supply (SEVR)

N=14
Age= 37.9±8.1
BMI= 28.4±3.0

DHS AFG EMW-2007-FP-02581
Protocol

Oxnard and Boston FDs
24 hours of monitoring – PSM
CV strain/Autonomic function

Alarm response
During FF activities
Recovery
Heart Rate Response while On Scene a Fire Call

Example of raw data from single subject
Summary

- Firefighting activity places significant strain on the CV system, affecting the heart, vessels and blood
- Firefighters must be physically fit and medically healthy to undertake such strenuous work
Risk Identification

Design Strategies to Modify Risks

- Lessen Individual Risk Factors
- Lessen Risks Associated with Job

Test Strategies (Scientific Hypothesis Testing)
Mitigating Risk

Preparing Firefighters to Meet the Unique Stresses of Firefighting

- Medically qualified
- Physically fit
- Well hydrated
- Properly trained
Mitigating Risk

Decreasing the Stress/Strain of Firefighting

- Staffing
- Approach to fire suppression (aggressive, defensive)
- Rehab (and recovery)
Discussion
Example: Decrease Strain of Firefighting

Physiological Responses

- Muscular/Metabolic Fatigue
- Dehydration
- Heat Stress

Cardiovascular Strain
- HR, BP
- Blood Clotting

Rehab

- Rest/Recovery
- Nutrition
- Fluid Replacement
- Cooling
- Climatic Relief
- Medical Monitoring
- Rest
- Cooling
- Fluid Replacement
- Medical Monitoring
Example: Decrease Risks to Firefighter

**Physiological Responses**
- Muscular/Metabolic Fatigue
- Dehydration
- Heat Stress
  - HR, BP
  - Blood Clotting

**Benefits of Physical Fitness**
- ↑ Strength/Endurance
- ↓ Fatigue
- ↑ Plasma Volume
- Improved Thermoregulation
  - Tolerance for higher temperature
- ↑ Cardiovascular capacity
  - ↓ Risk of Clot Formation