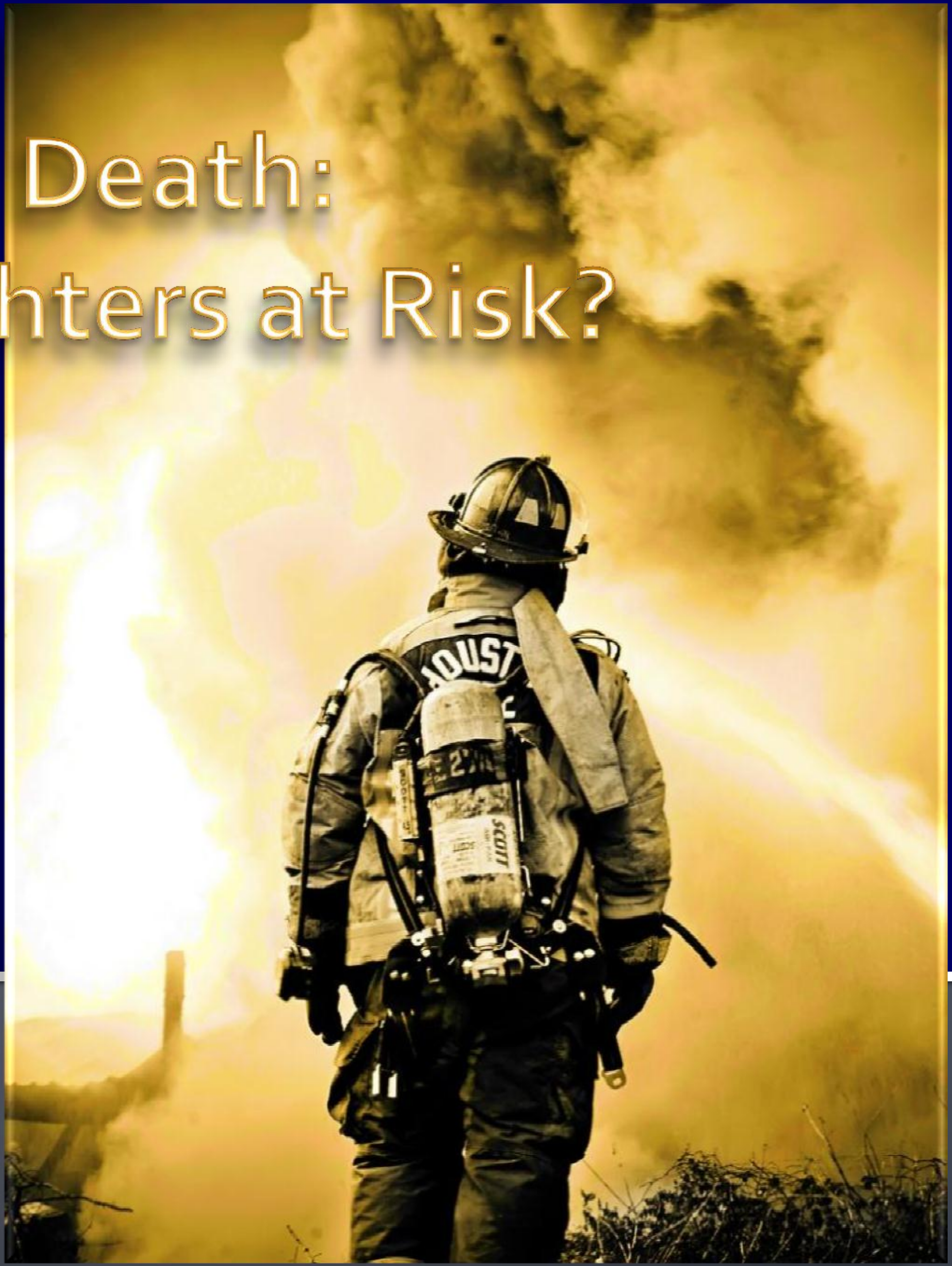
Sudden Cardiac Death: Why Are Firefighters at Risk?



Denise L. Smith, Ph.D.

Fire Department Instructors Conference (FDIC) 2011

March 21-26, 2011

Indianapolis

Outline

Section 1 – Fire Fighter Fatality Statistics

Section 2 - Pathology of Sudden Cardiac Events

Section 3 – Physiological Stress of Fire Fighting

Section 4- Minimizing Cardiac Death

- Potential Role of Technology

Section One

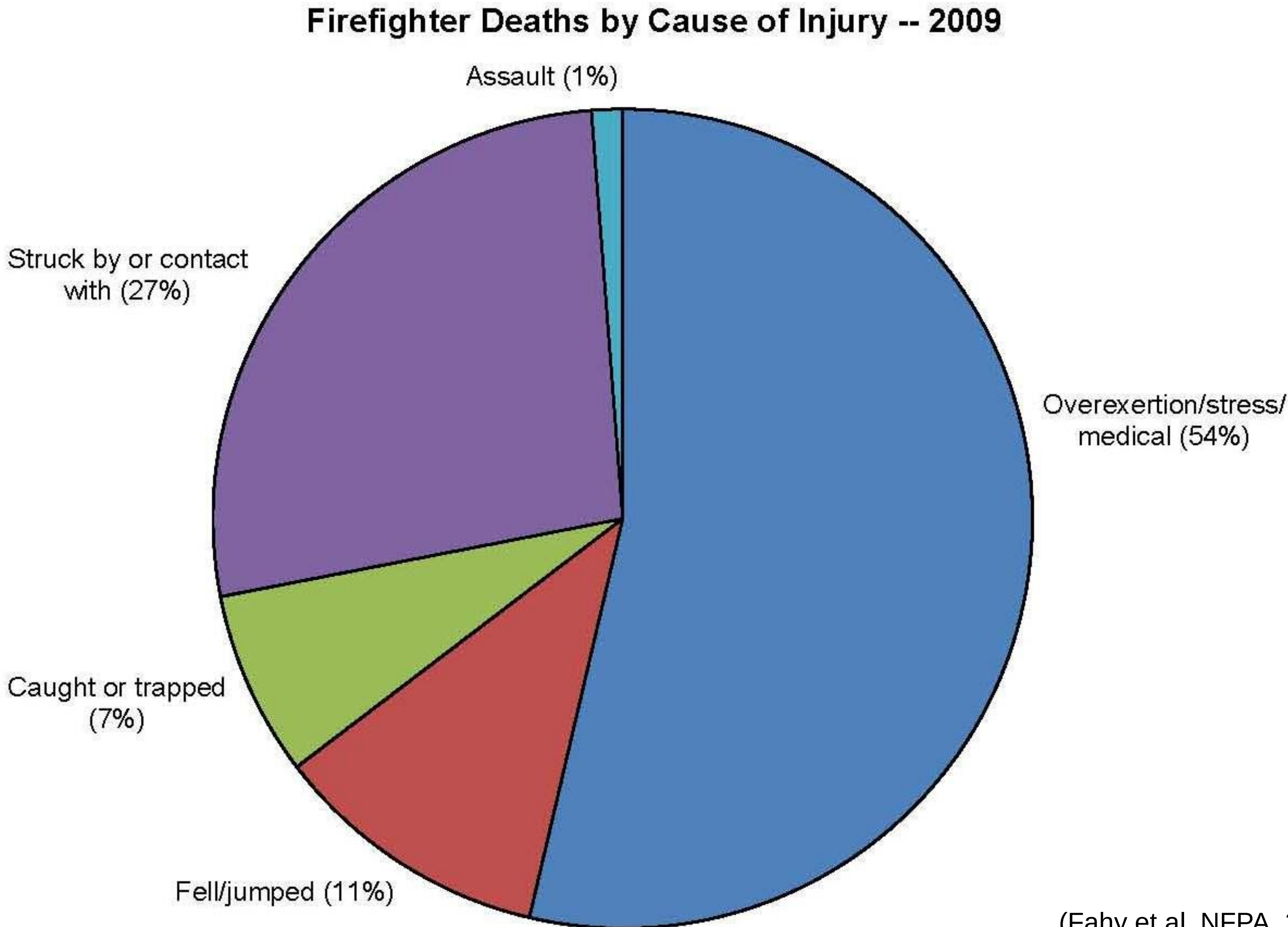
Firefighter Fatality Statistics

2007 statistics

- 1.6 million fires
- 3430 civilian deaths
- 17,675 civilian injuries
- $14.6 billion in property loss

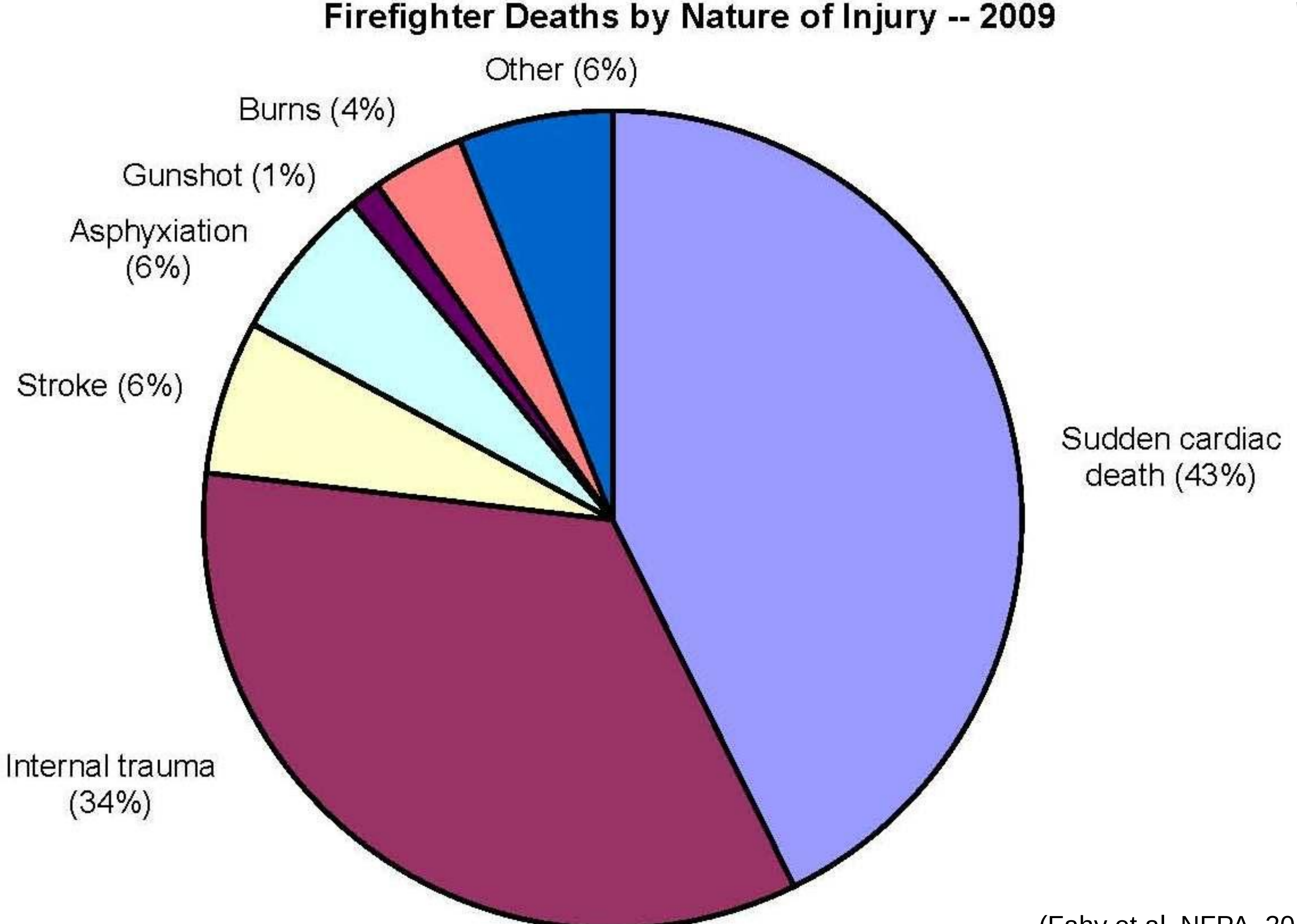
2008- 103 FF Fatalities

Firefighter Fatality Statistics



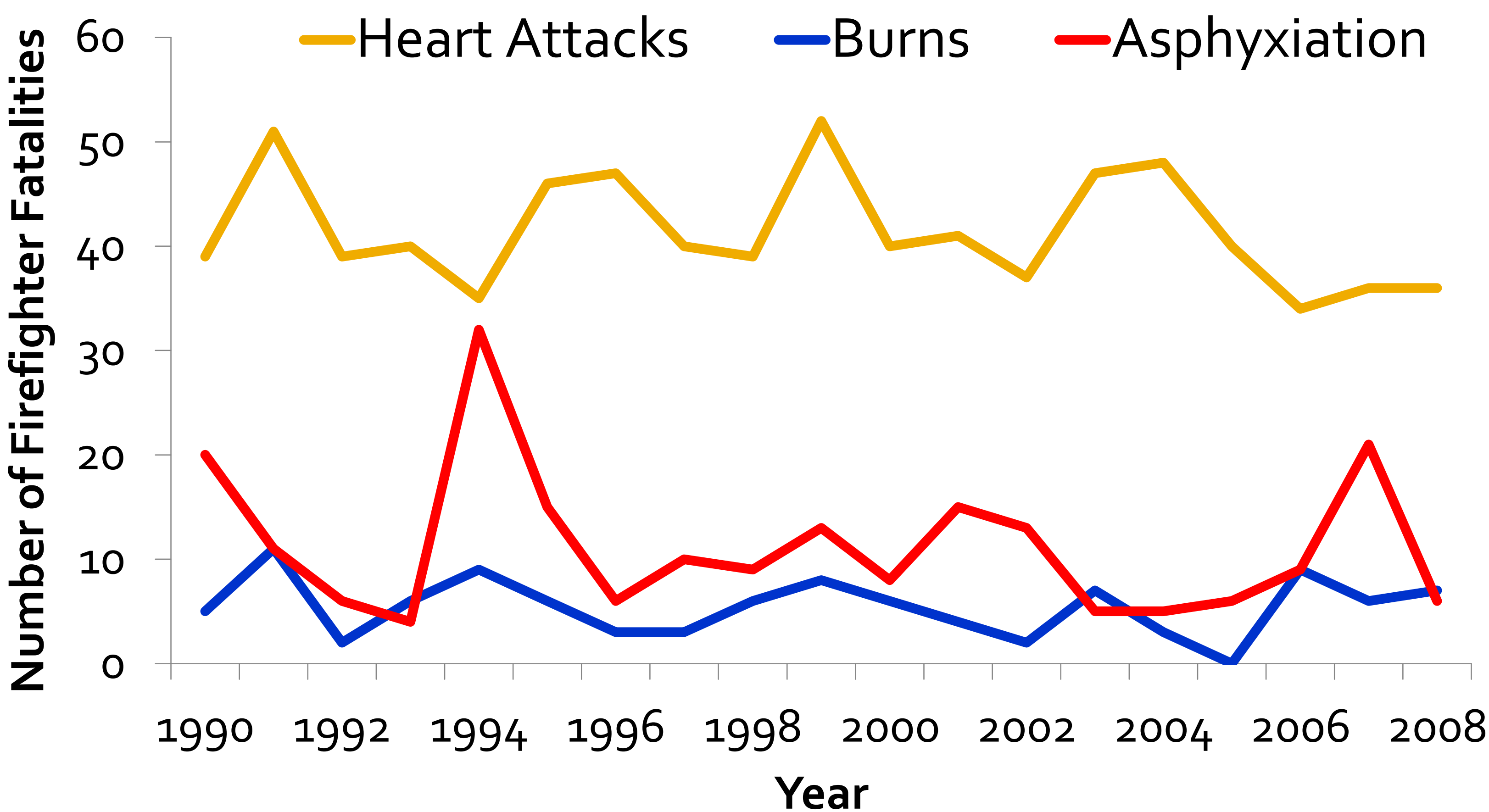
(Fahy et al, NFPA, 2010)

Firefighter Fatality Statistics



(Fahy et al, NFPA, 2010)

Firefighter Fatality Statistics

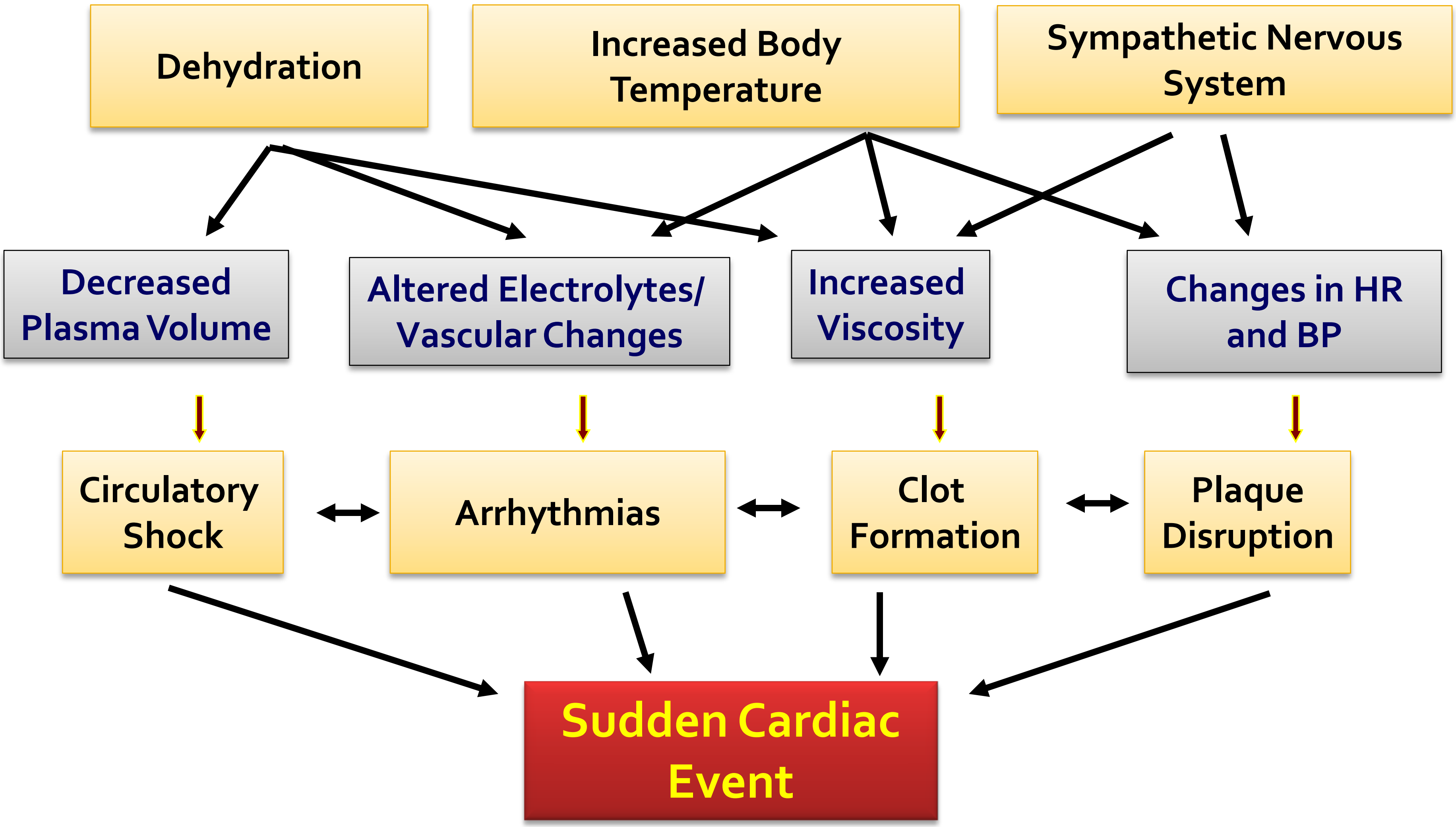


Section Two
Pathology of Sudden Cardiac Events

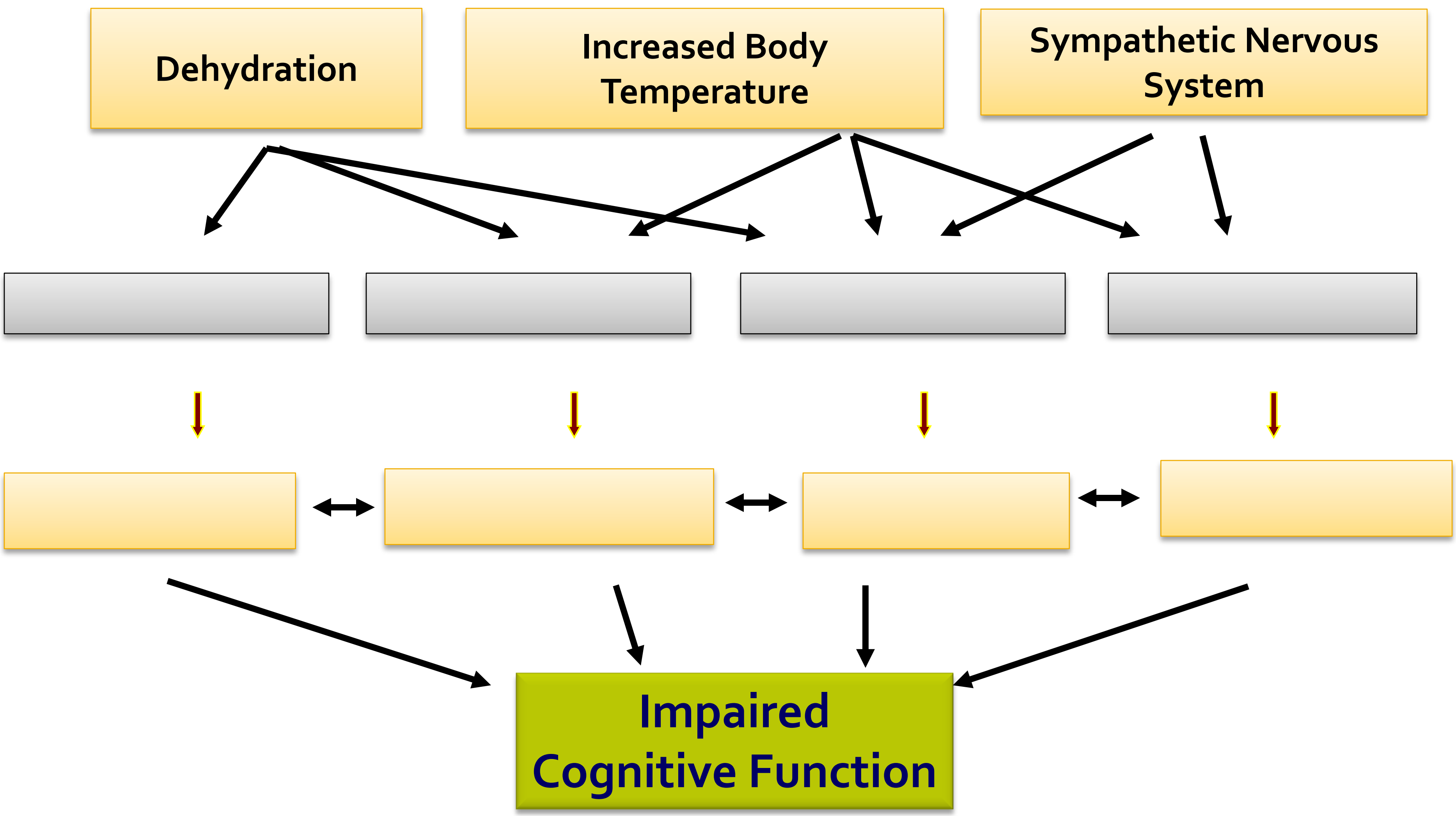
Theoretical Models

- Sudden Cardiac Events
- CV Disease Progression

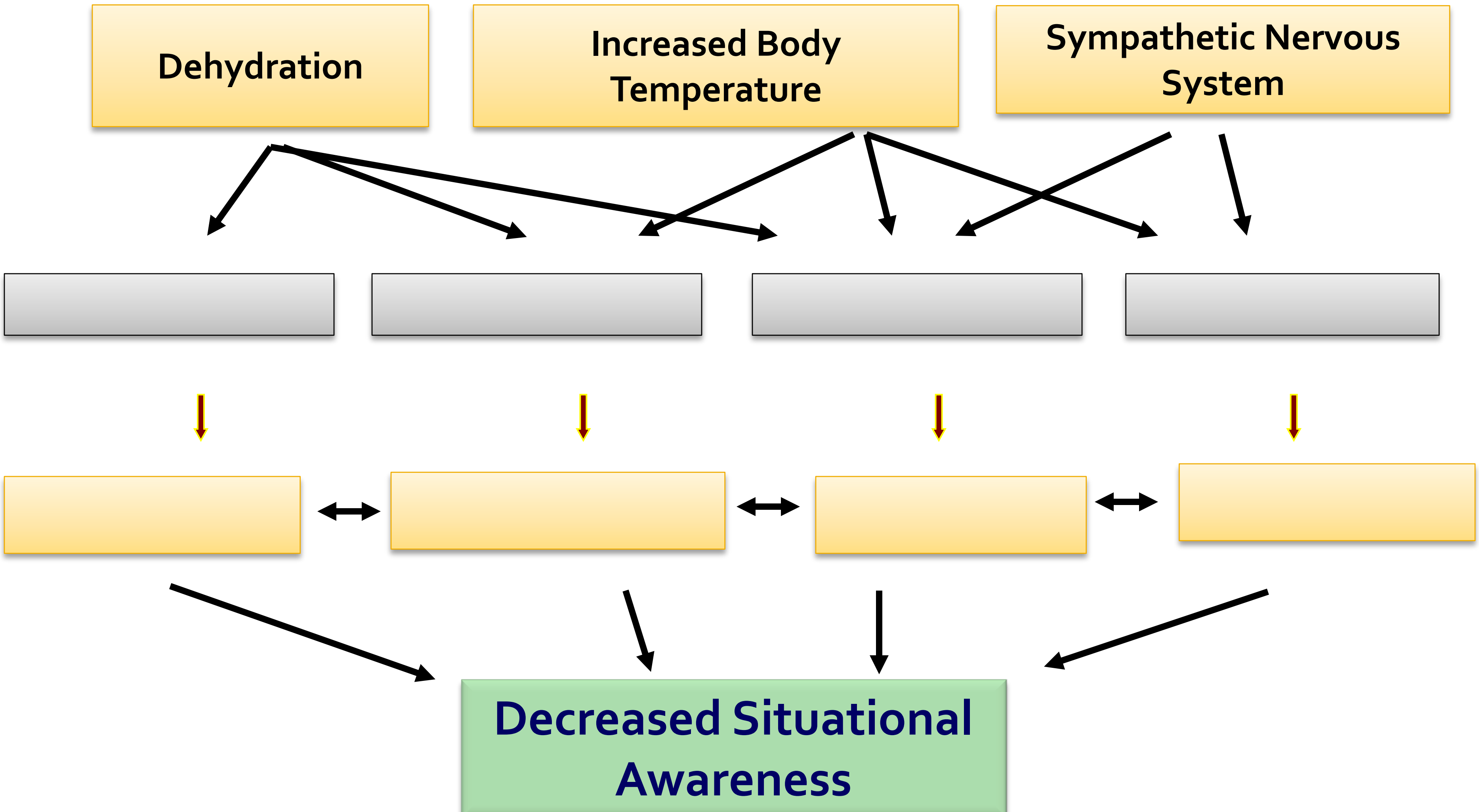
Mechanism of Sudden Cardiac Death



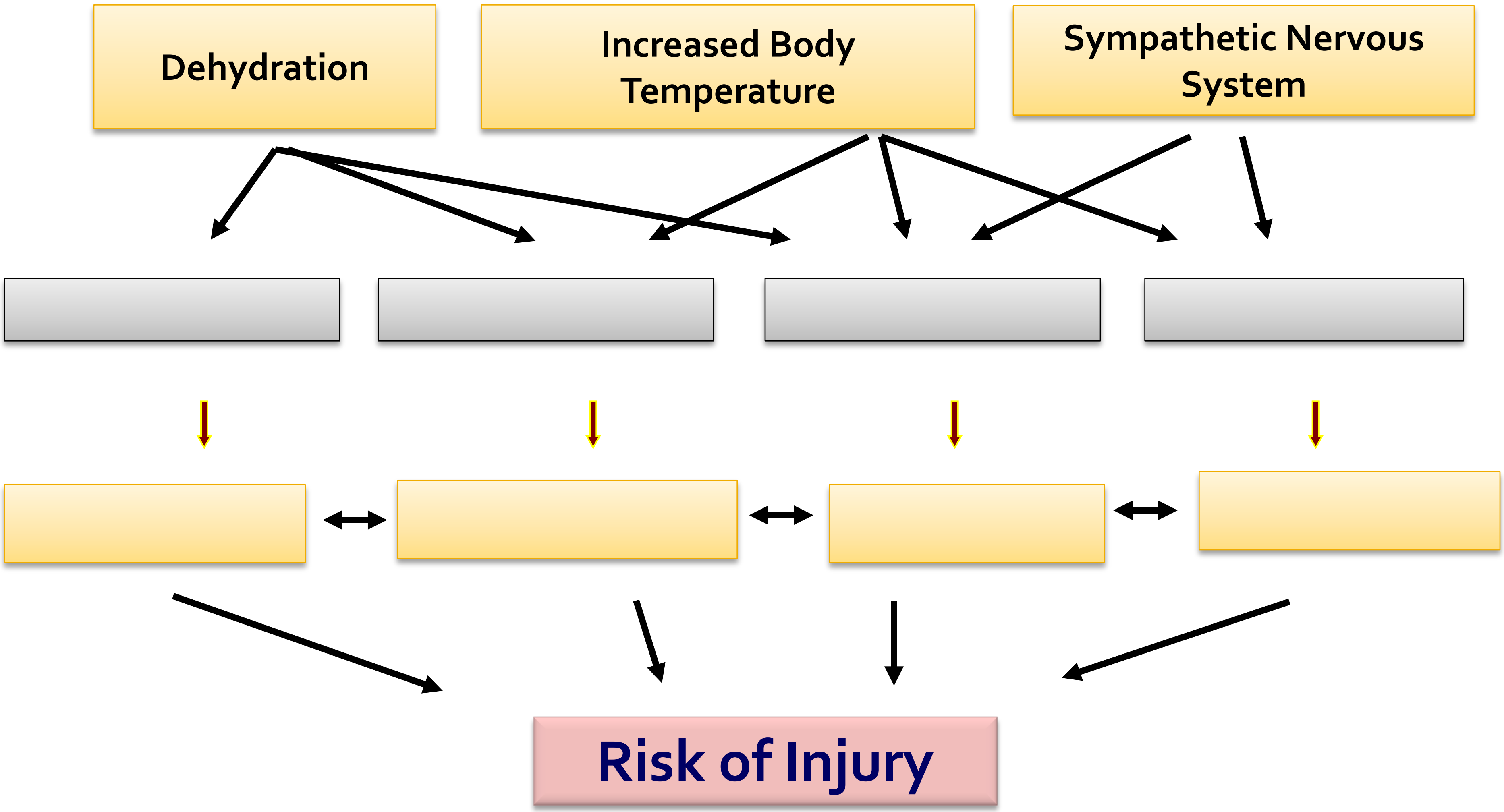
Mechanism of ……



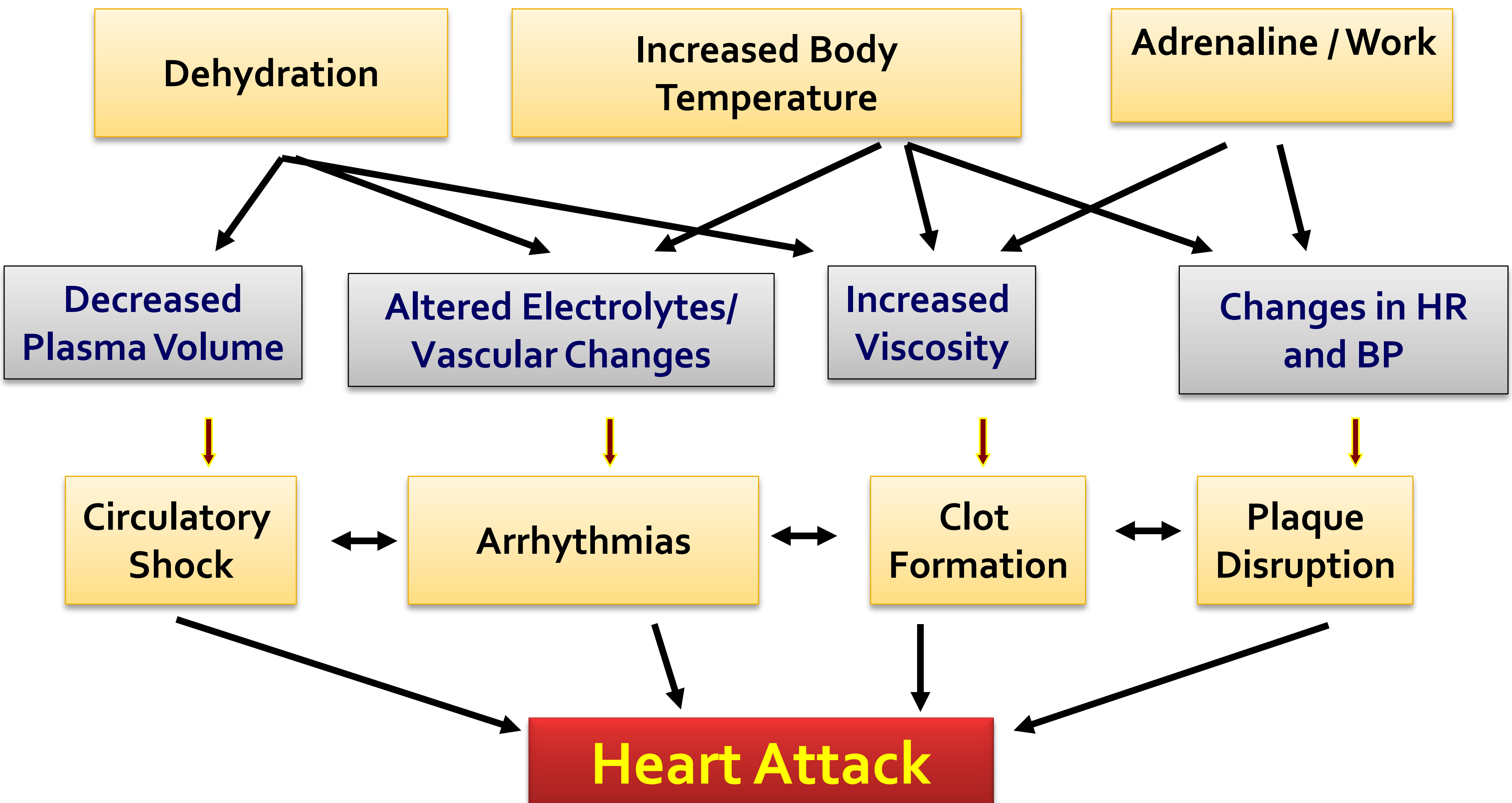
Mechanism of ......



Mechanism of ……



Mechanism of Sudden Cardiac Death



Myocardial Infarction

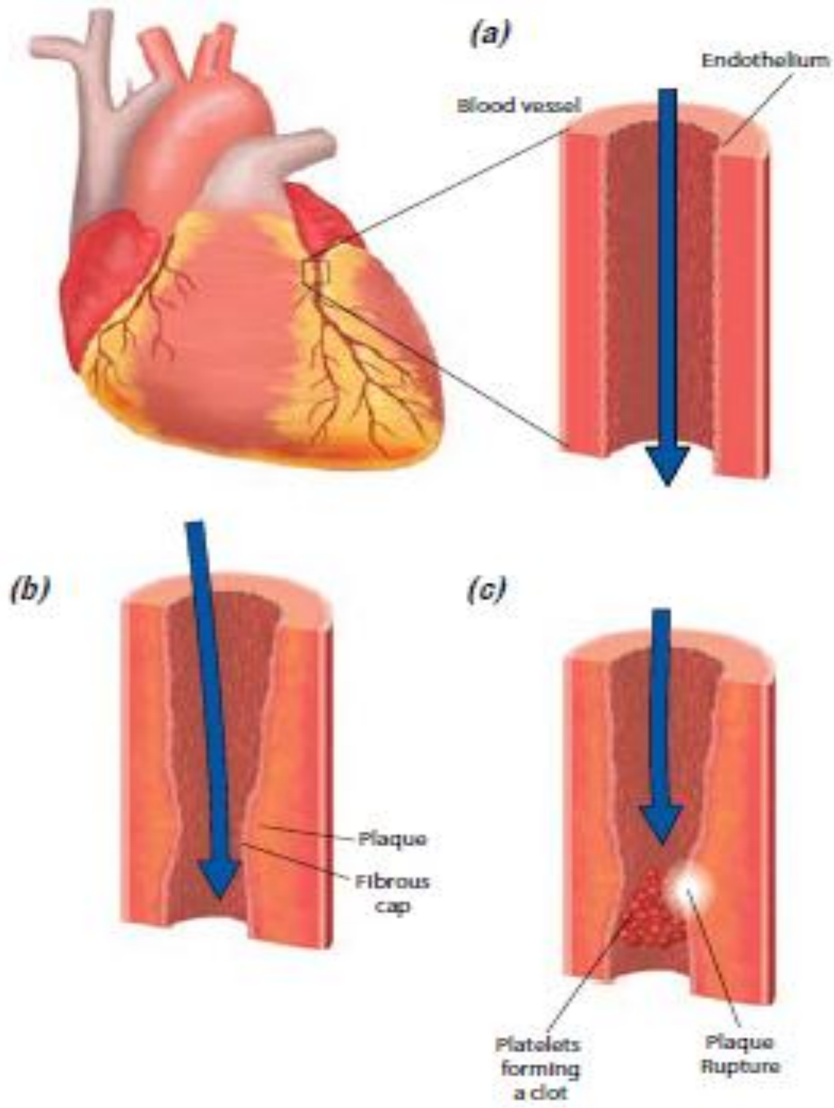
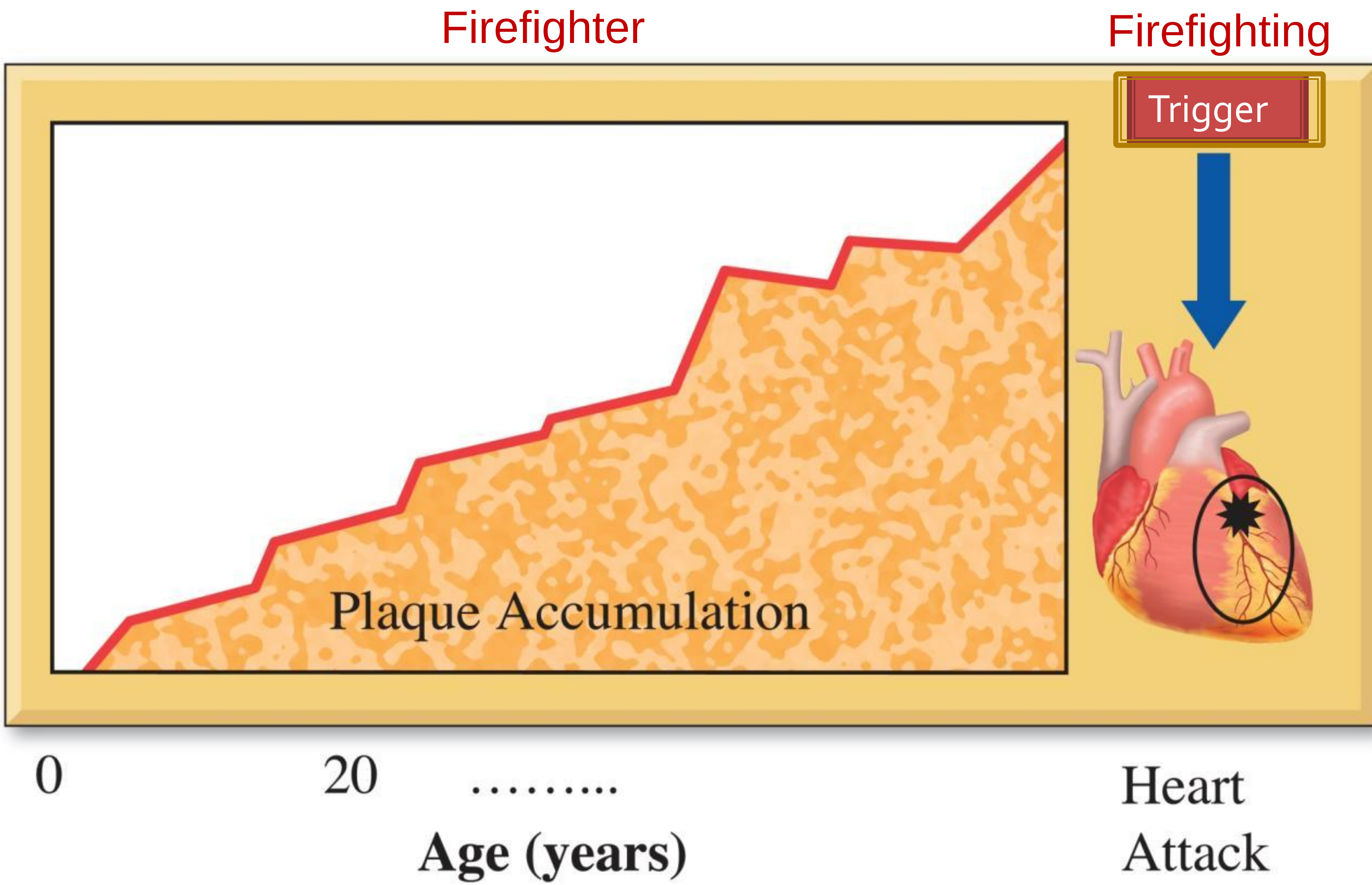


Figure 1.4. (a) Normal healthy artery; (b) plaque accumulation in an artery; (c) plaque rupture and clot formation.

Model of Sudden Cardiac Event



Section Three

Physiological Stress of Firefighting

Theoretical Model

Research Approaches

- Laboratory Studies
- Training Environment/Simulated
- Field Studies

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 100° C routinely

Chaotic

Low visibility

→ **Cardiovascular** (Increased HR and BP, Decreased Stroke Volume)

→ **Hematological** (Decreased Plasma Volume, Hemoconcentration)

→ **Thermoregulatory** (Elevated Core Temperature, Dehydration)

→ **Respiratory** (Increased Breathing Rate and Oxygen Consumption)

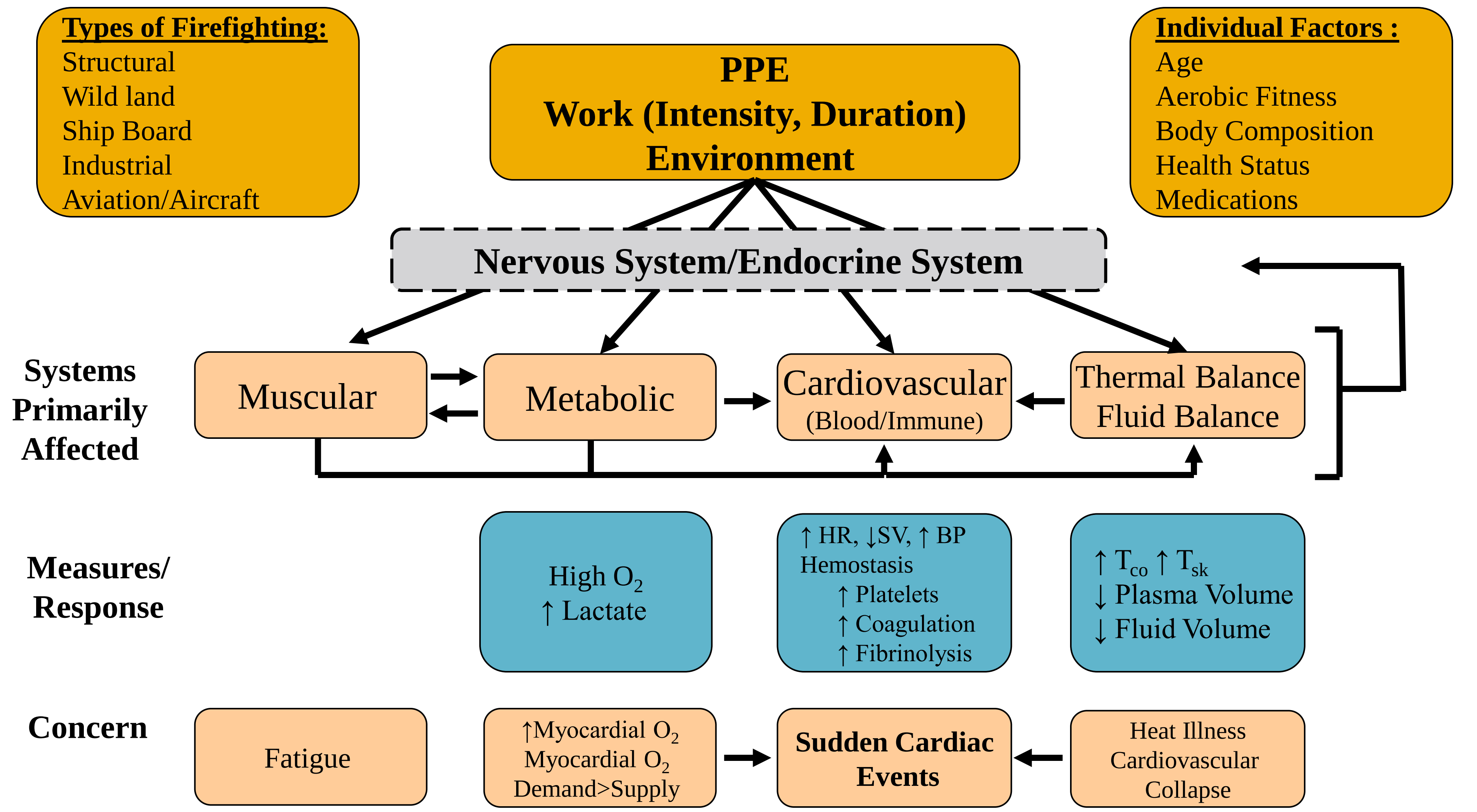
→ **Metabolic** (High Oxygen Cost, Increased Lactate, Fatigue)

→ **Immune/Endocrine** (Increased Leukocytes and Hormones)

→ **Nervous** (Sympathetic Surge and Increased Adrenaline)

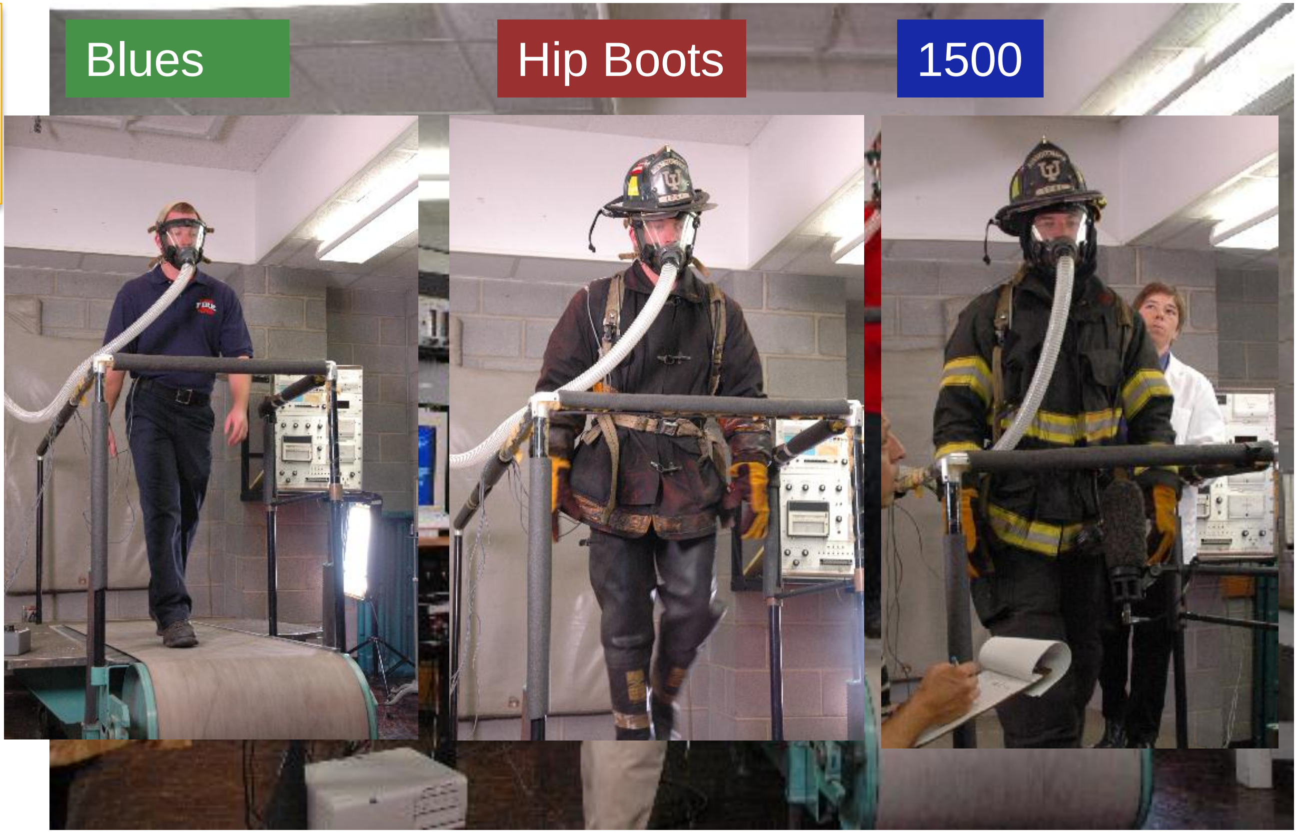
→ **Muscular** (Increased Oxygen Use and Heat Production)

Theoretical Model: Physiological Stress of Firefighting

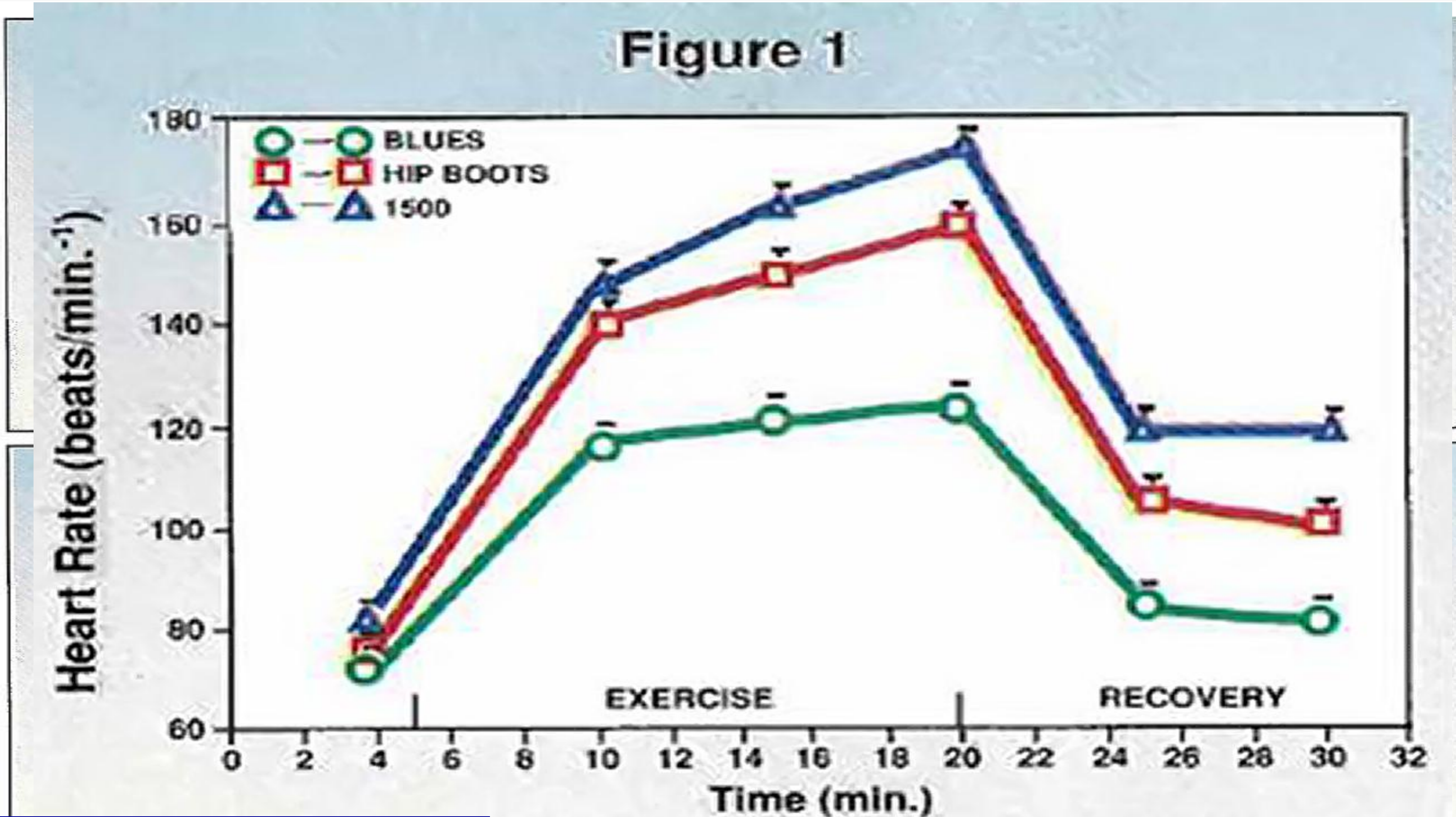


Laboratory Study-Effect of Gear

Laboratory-based study conducted at University of Illinois



Physiological Responses



Smith et al, 1995, *Ergonomics*

Recovery from Exercise in PPE

Purpose

Investigate physiological response to exercise in PPE and *recovery* from exercise-heat stress.

Motivation

Line of Duty Deaths - CHD related
N=449, 1994-2004

	Time Spent (%)	Fatalities (%)	Odds Ratio
Fire Suppression	1%	32.1%	136
Return from Alarm	7%	17.4%	10.5
Response to Alarm	4%	13.4%	14.1
Physical Training	8%	12.5%	6.6
Nonfire emergencies	15%	9.4%	2.6
Nonemergency duties	65%	15.4%	1.0

Kales, et al., NEJM, 2007

Recovery as a Vulnerable Period

Many cardiac fatalities occur AFTER fire suppression activities

	Time Spent (%)	Fatalities (%)
Fire Suppression	1%	32.1%
Return from Alarm	**7%**	**17.4%**
Response to Alarm	4%	13.4%
Physical Training	8%	12.5%
Non-Fire Emergencies	15%	9.4%
Non-emergency Duties	65%	15.4%

Kales, et al., NEJM, 2007

2007 33 NIOSH Fire Fighter Fatality Investigation and Prevention Program

Death in the line of duty...

A summary of a NIOSH fire fighter fatality investigation — *March 2009*

After Conducting Fire Suppression Duties at a Structure Fire, Captain Collapses in Incident Scene Rehabilitation - Kansas

SUMMARY

On August 13, 2007, a 44-year-old Captain reported for duty at 0700 hours. At 1819 hours his crew was dispatched to a multiunit apartment fire. At this time the air temperature was 97 degrees Fahrenheit (°F) with a relative humidity (RH) of 35%. Initial size-up reported heavy smoke from the two-story wood frame apartment building. The Captain, wearing turnout gear and his self contained breathing apparatus (SCBA), secured water supply to the first-in Engine with a 5-inch diameter hose. He was then assigned to assist with a primary search on the second floor of the apartment building. After being on-scene for about 10 minutes, the Captain was assigned to ... (CPR) and defibrillation, continued CPR in

NIOSH offers the following recommendations to reduce the risk of on-the-job heart attacks and sudden cardiac arrest among fire fighters at this and other fire departments across the country.

- Provide mandatory pre-placement and periodic medical evaluations to all fire fighters consistent with the National Fire Protection Association (NFPA) 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments.
- Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of firefighting, the personal protective equipment used by fire ...

at this, and other, fire departments across the

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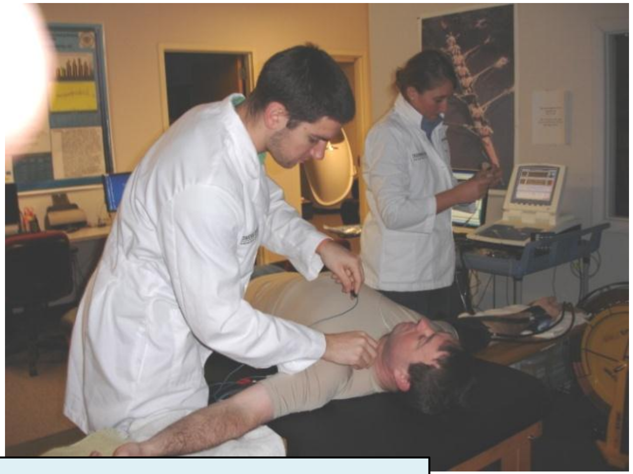
Methods

Subjects – 14 moderately trained FF

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

Protocol – 20 min exercise (TRD)
– 90 min RECOVERY



Measures
- Hemodynamics
- Vascular function
- Autonomic nervous balance

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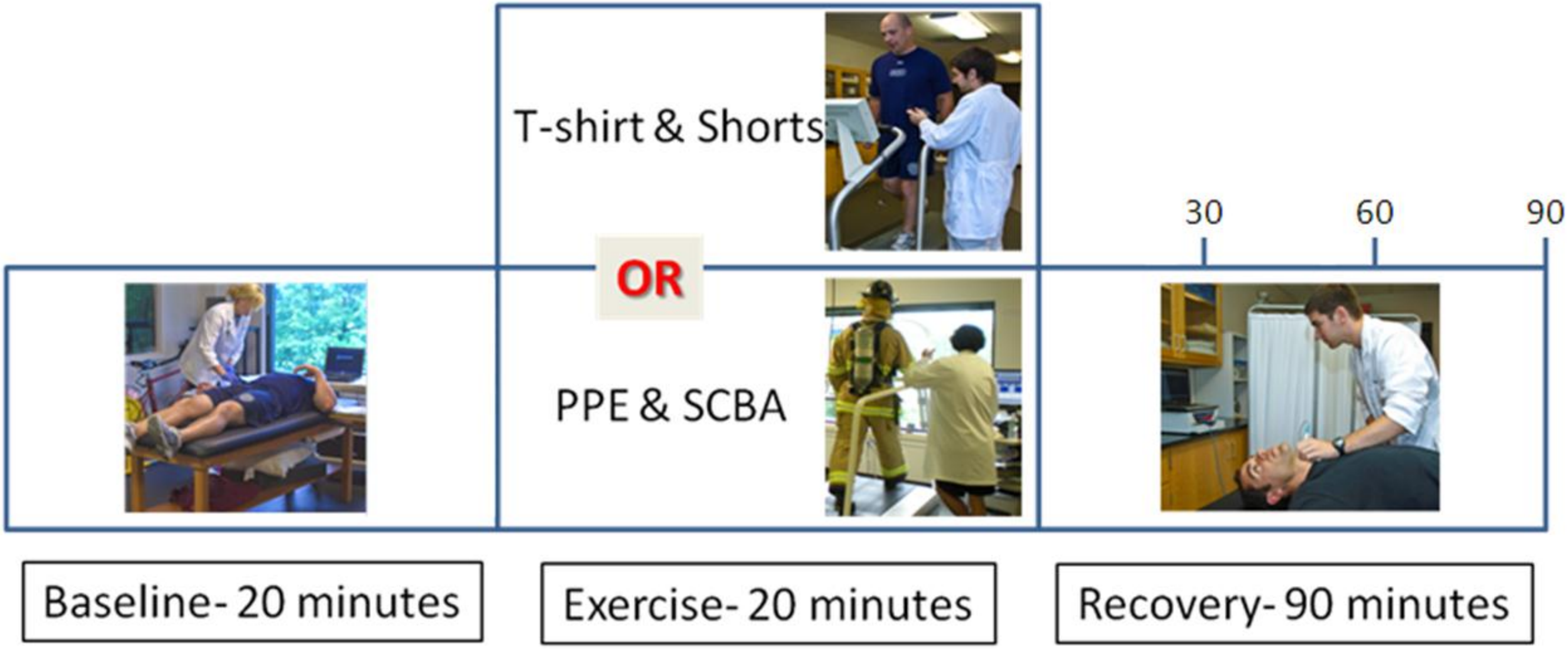
Methods

Protocol:



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Descriptive Measures

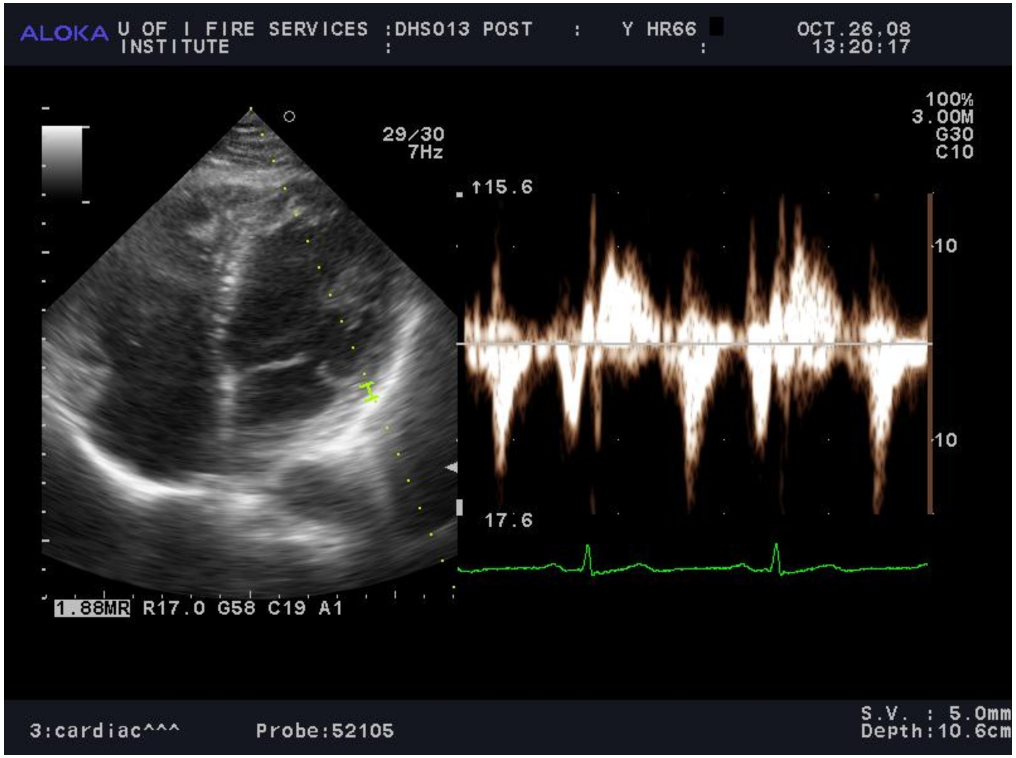
Age, height, weight

Dual-energy X-ray absorptiometery

Carotid intimal thickness

Cardiac Ultrasound

Cardiac Ultrasound



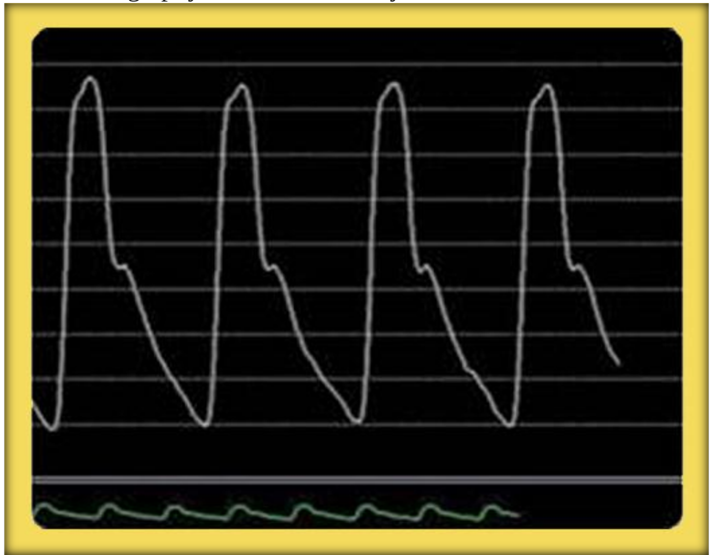
Recovery Measures

Endothelial Function
Resting and Reactive Hyperemia

Pulse Wave Analysis (PWA)
Pulse Wave Velocity (PWV)
- Vascular stiffness
- Myocardial oxygen supply (SEVR)

Autonomic Nervous System Balance

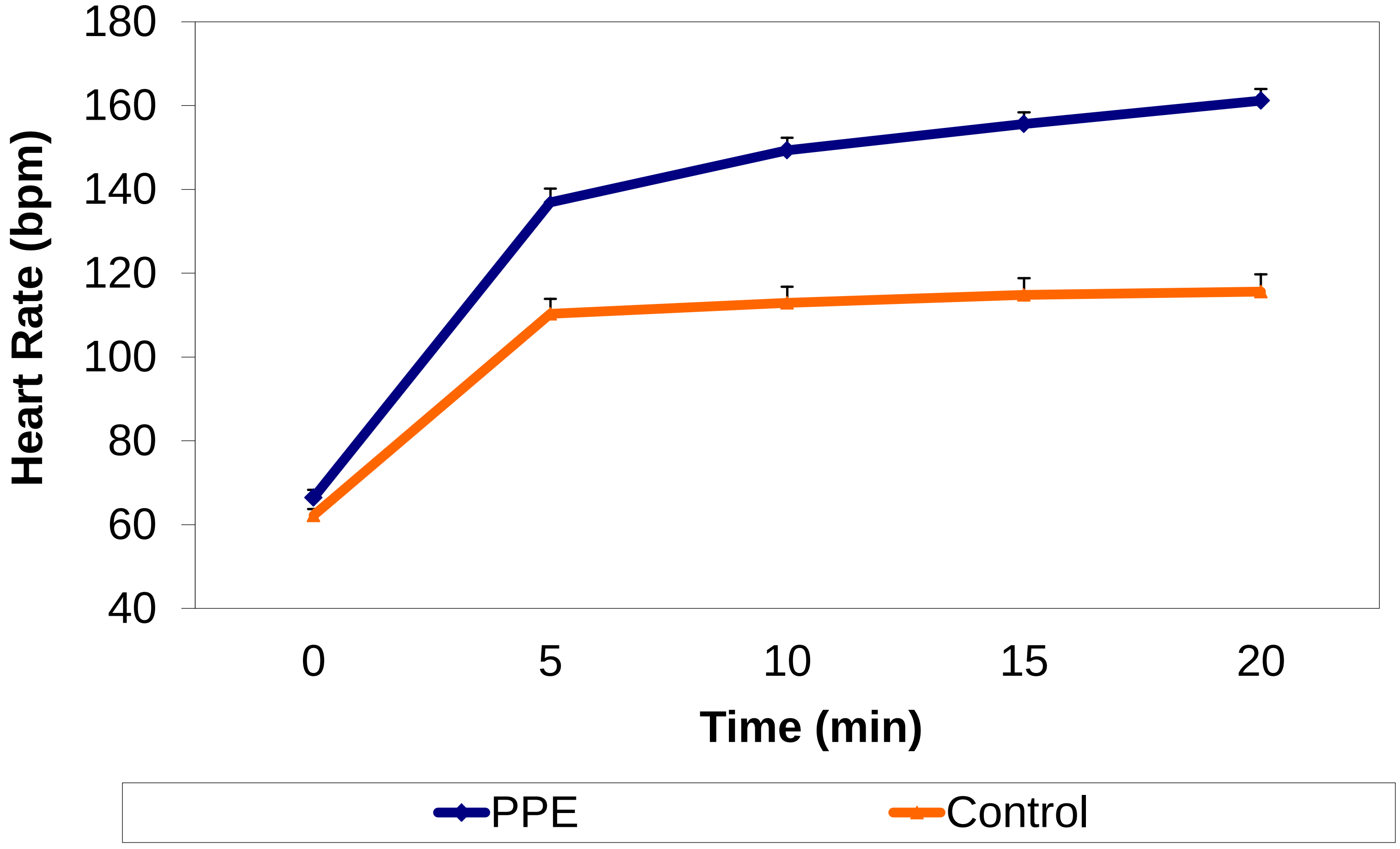
Applanation Tonography at the radial artery



Descriptive Measures

	Participants (n=14)
Resting Heart Rate (bpm)	63.0±6.3
Resting Blood Pressure (mm Hg)	
Systolic Blood Pressure	120.7±6.3
Diastolic Blood Pressure	72.7±8.7
Intimal Medial Thickness (mm)	0.49±0.09
Cardiac Ultrasound Measures	
Interventricular Septal Thickness; Diastole (mm)	9.43±1.95
Left Ventricular Posterior Wall Thickness; Diastole (mm)	10.43±1.70
Left Ventricular Mass (g)	234.50±55.05

Heart Rate during Exercise



N=14
Age= 37.9±8.1
BMI= 28.4±3.0

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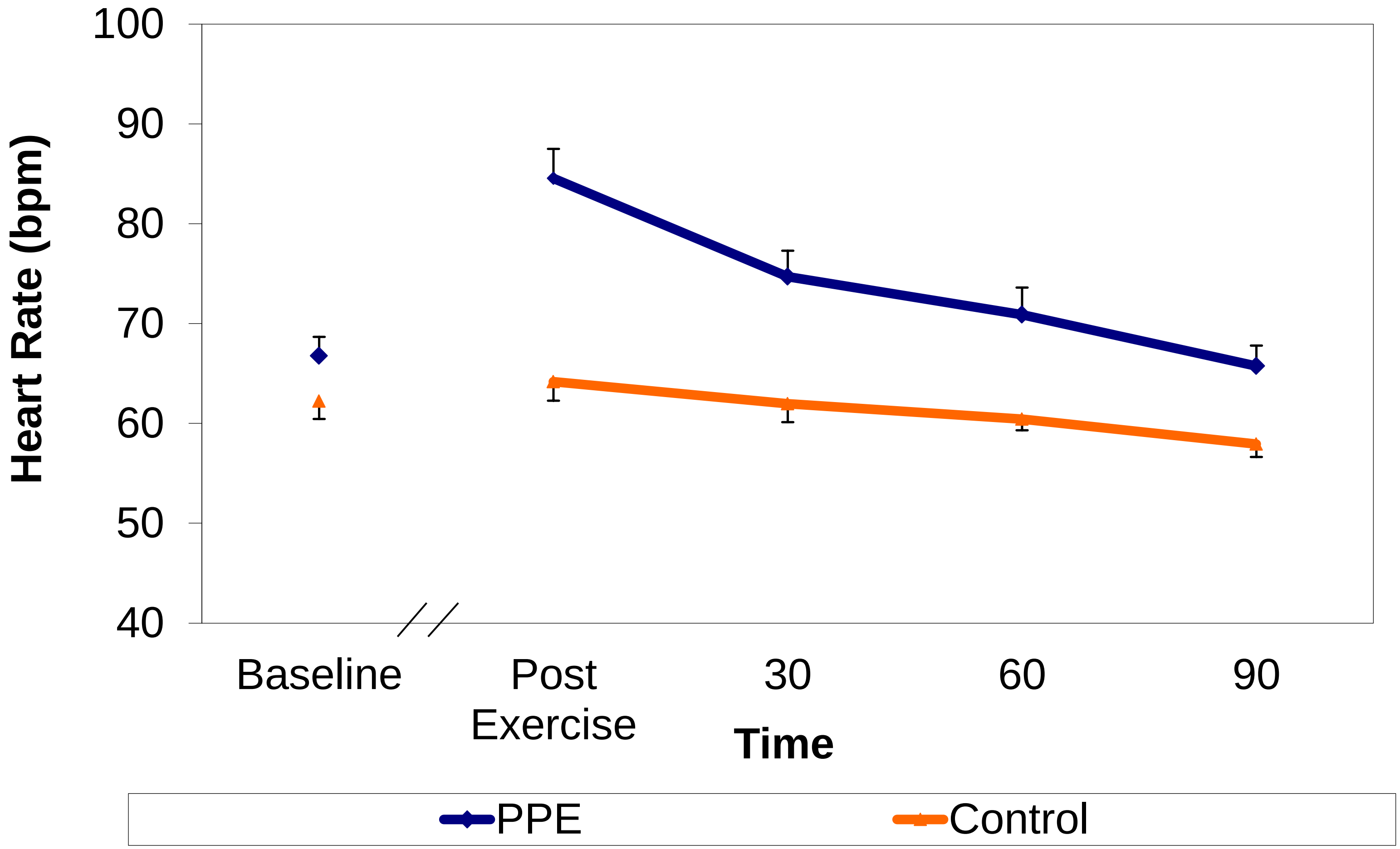
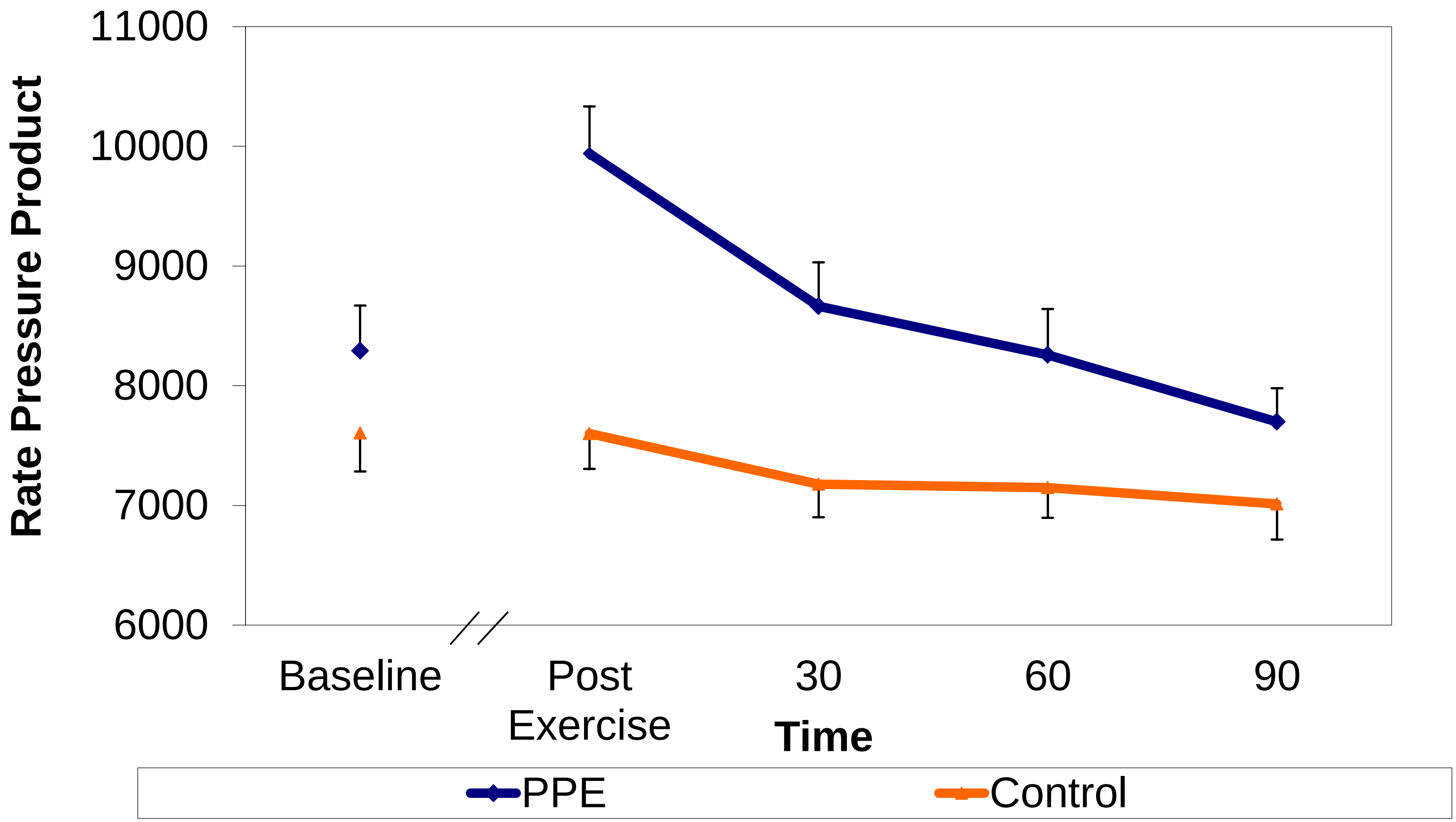
Heart Rate During Recovery



N=14
Age= 37.9±8.1
BMI= 28.4±3.0

DHS AFG EMW-2007-FP-02581

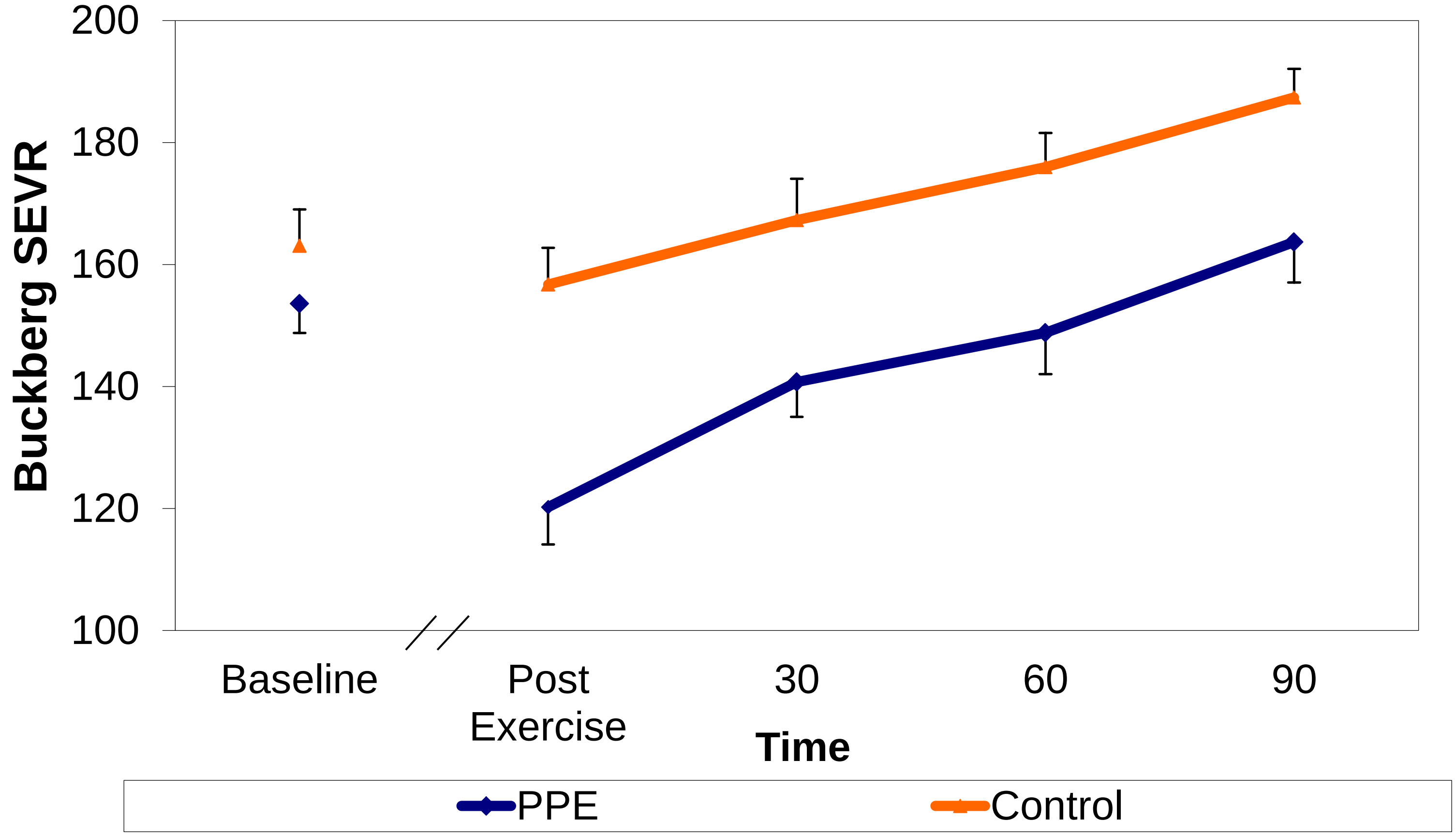
Rate Pressure Product During Recovery



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

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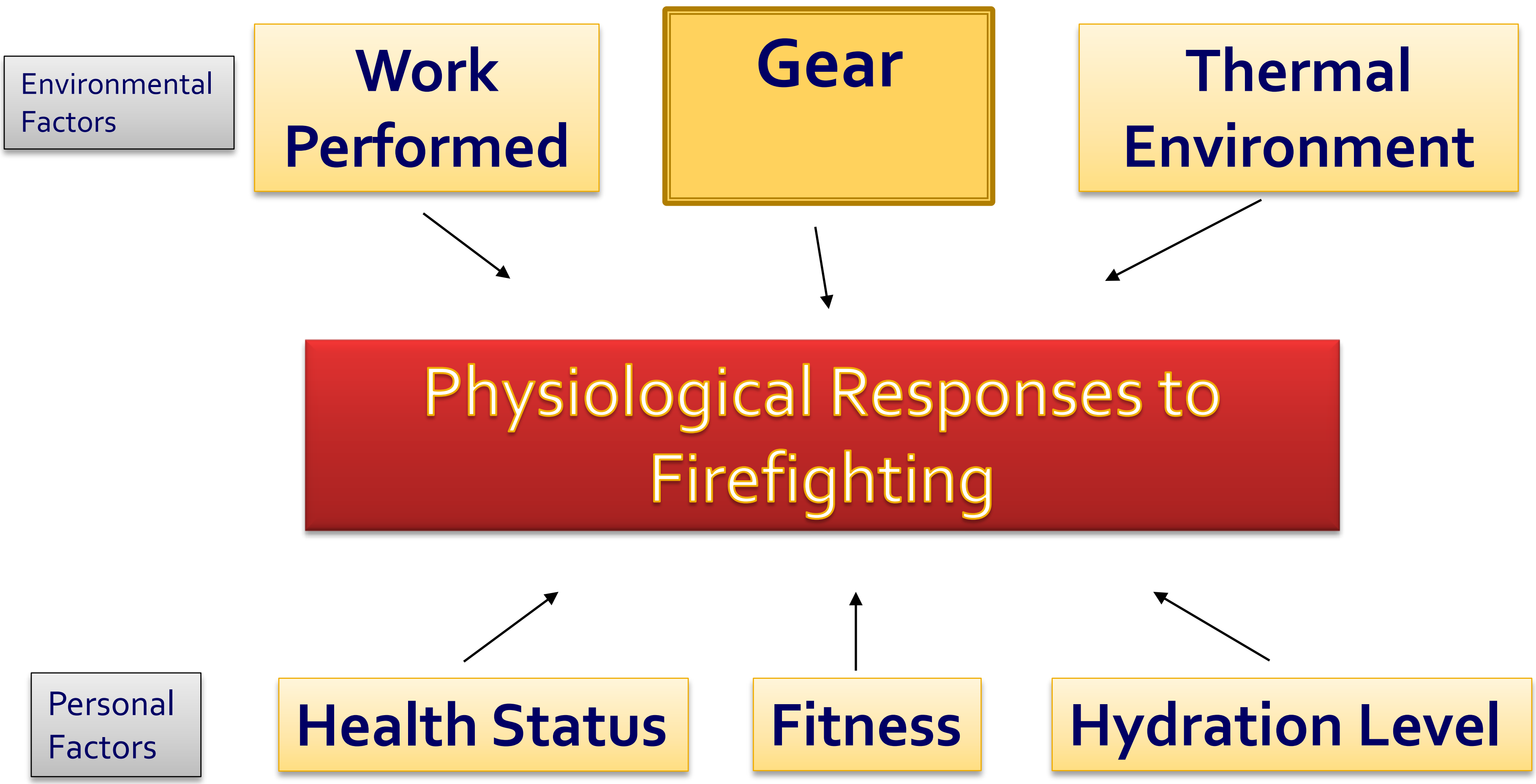
Simulated Firefighter Activities

Factors that Affect FF Responses

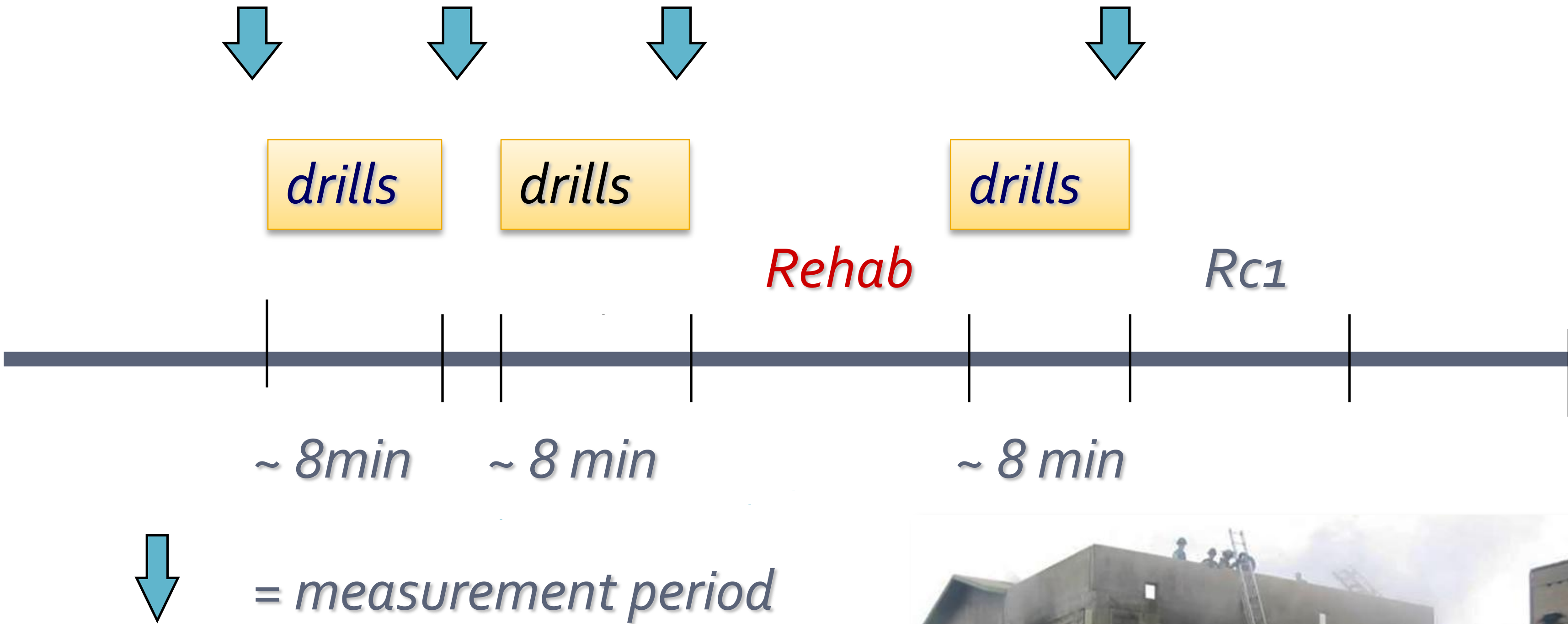


Characterizing Physiological Response

Physiological Responses to Firefighting

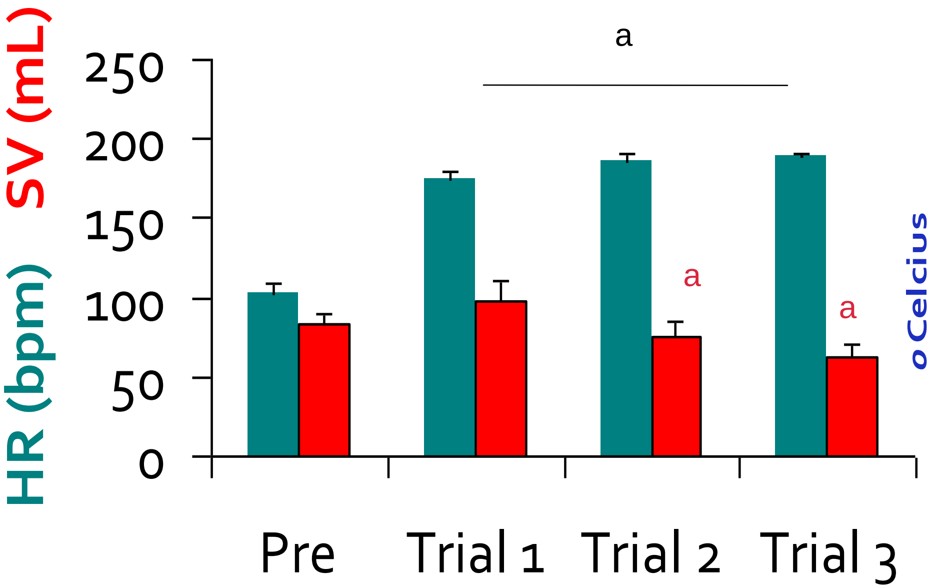
- HR, Temp
- Stroke Volume /Cardiac Output
- Blood Chemistry
- Hormones, Immune Function
- Blood Clotting

Changes during Firefighting



Heart Rate/Stroke Volume and Core Temp Responses to Live Burn Studies

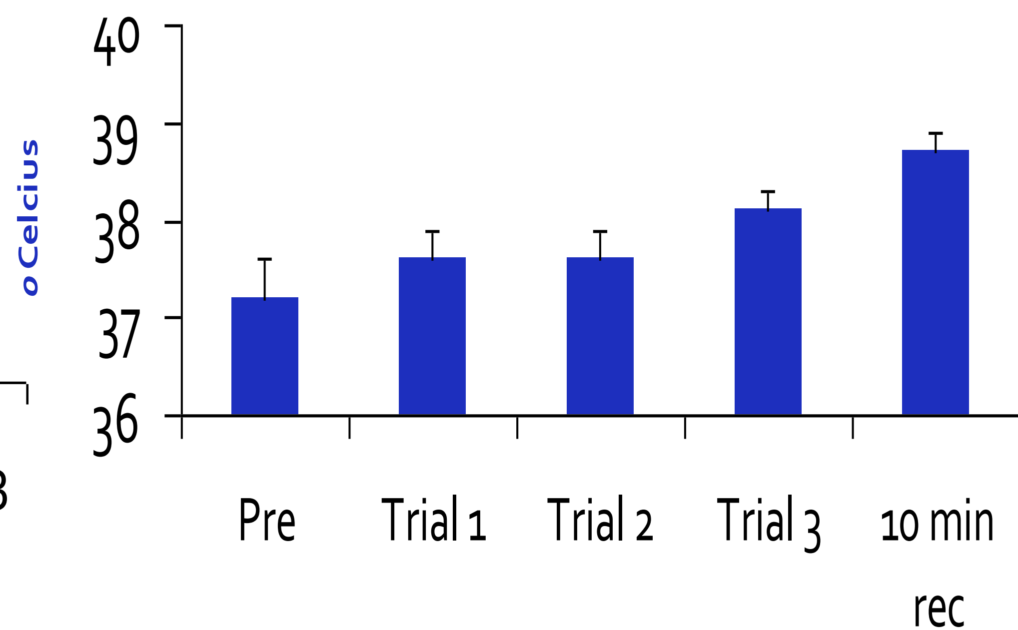
Heart Rate/ Stroke Volume



a p<0.05 vs Trial 1

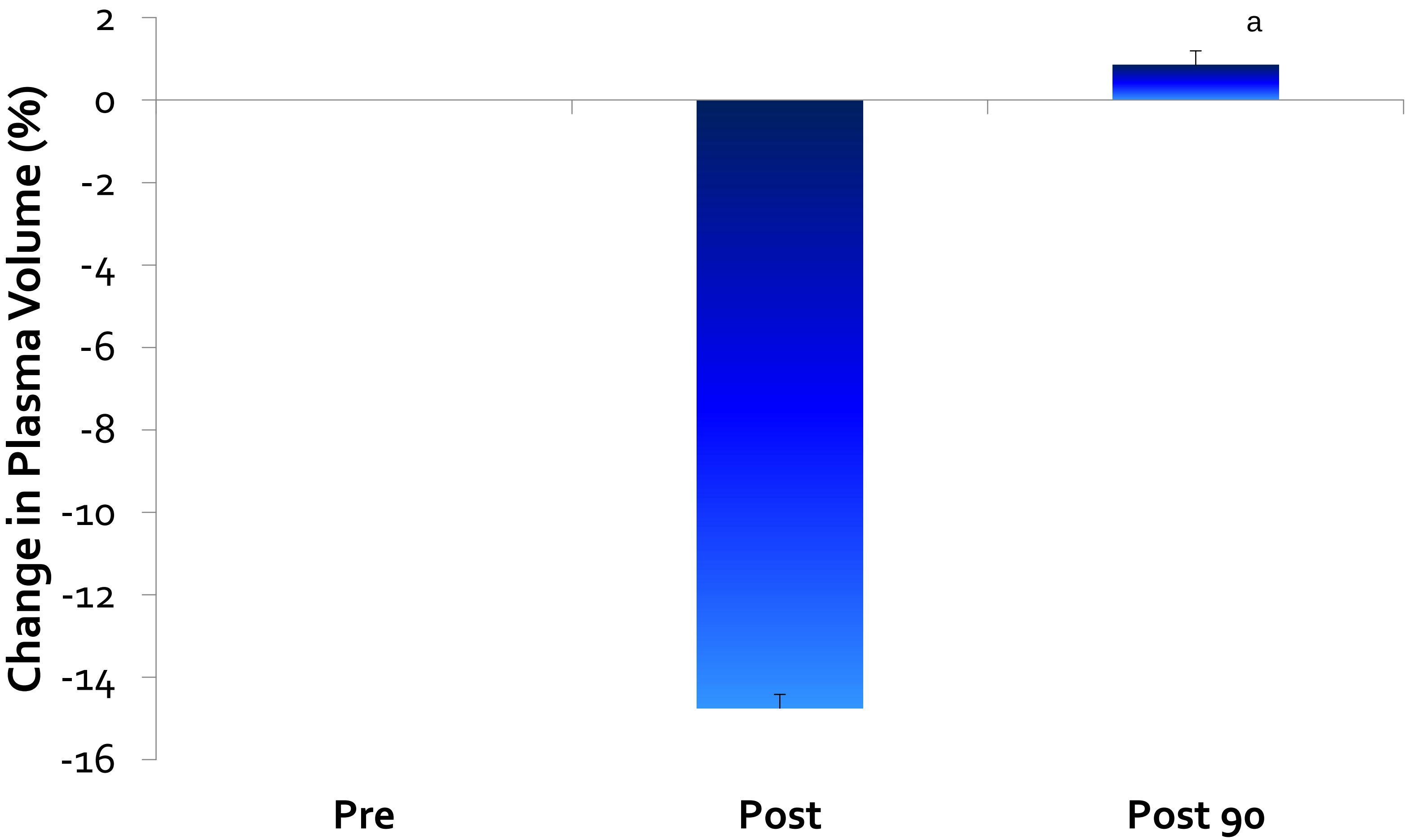
a p<0.05 vs Trial 1

Core Temperature



Smith, Petruzzello and Manning. 2001, *Ergonomics*.

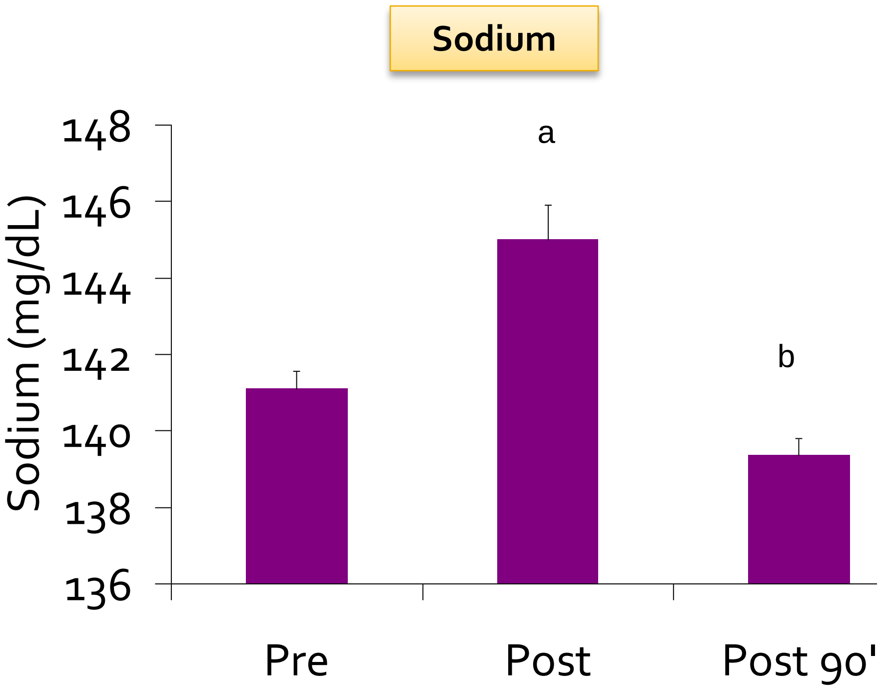
Dehydration



[a] Significantly different (p<0.05) than immediately post'

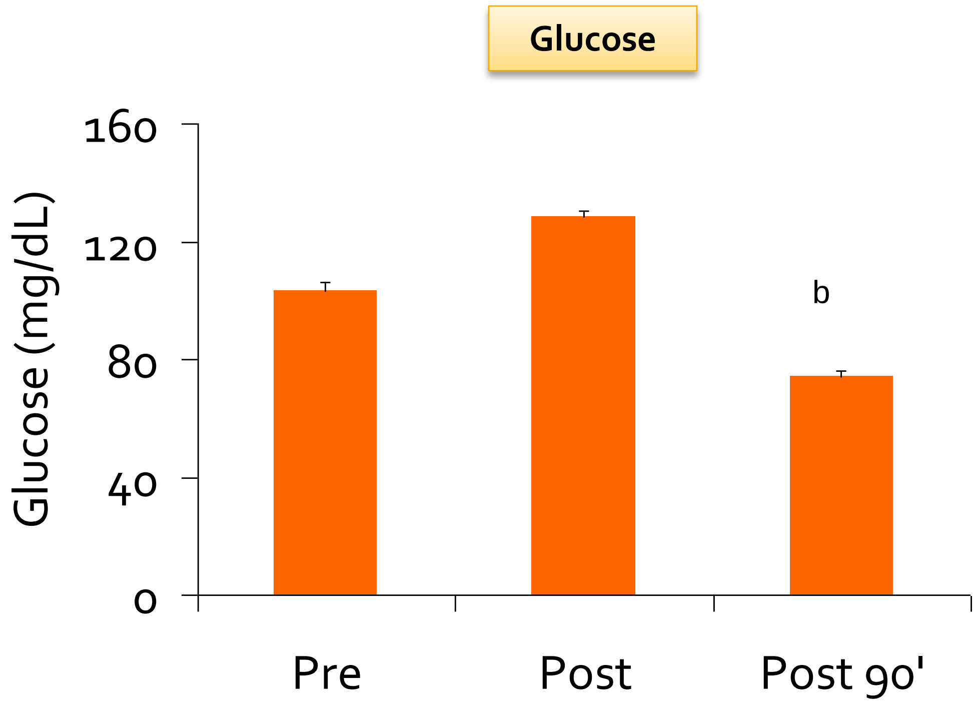
Smith et al. 2001, *Journal of Thermal Biology.*

Blood Chemistry Responses



a p<0.05 vs Pre and Post

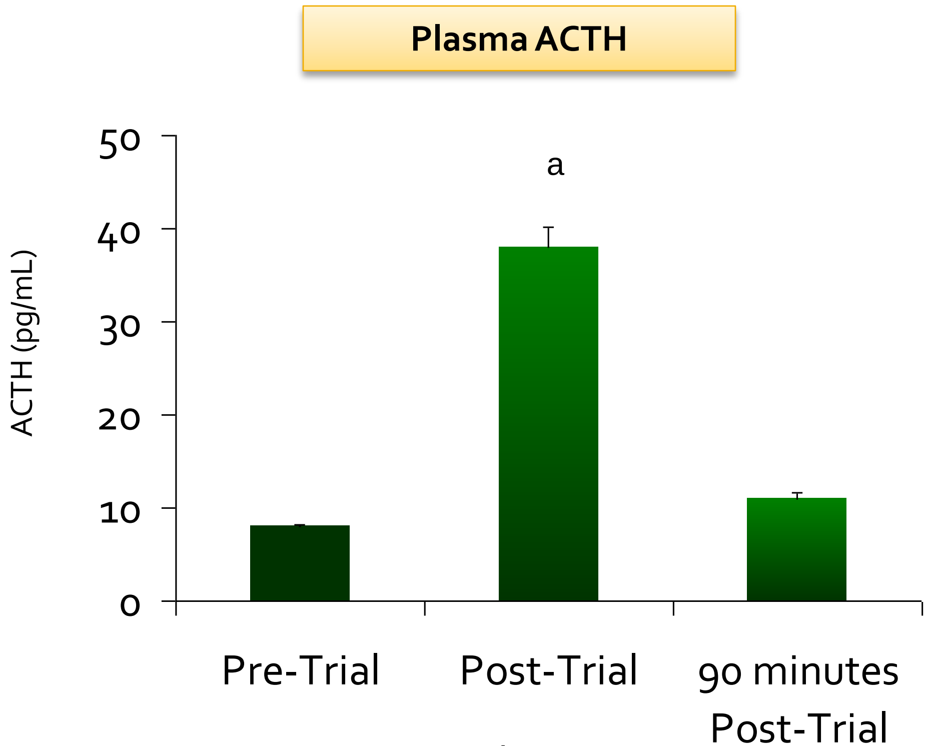
b p<0.05 vs Pre

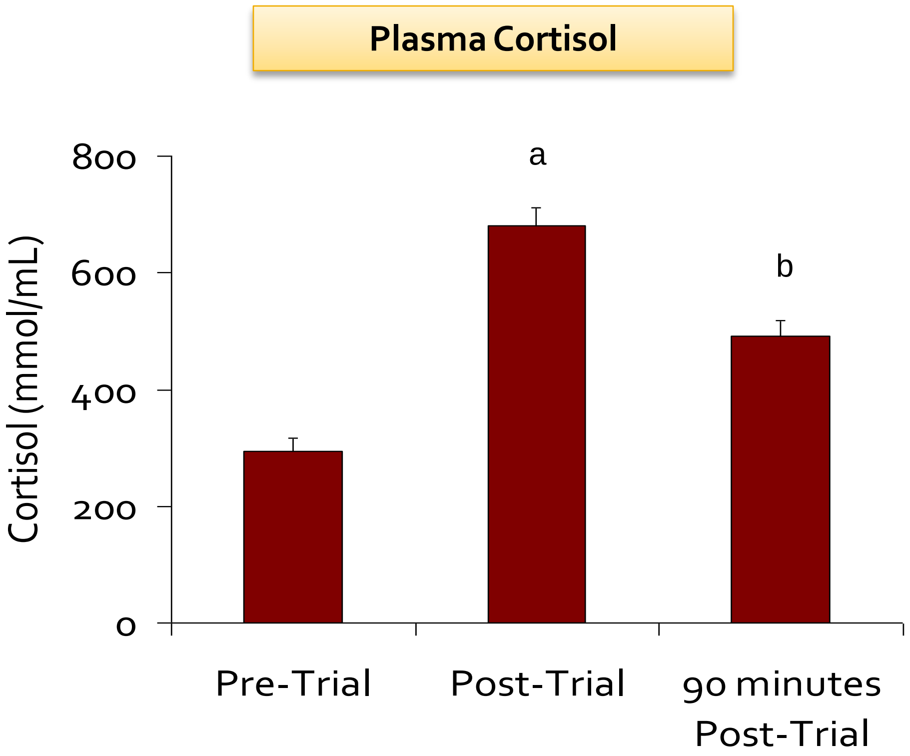


Mean Body Fat % = 18.1
Mean Age = 31.8 yrs
n=11

Smith et al., 2001. *Journal of Thermal Biology*.

Hormonal Responses to Firefighting Drills





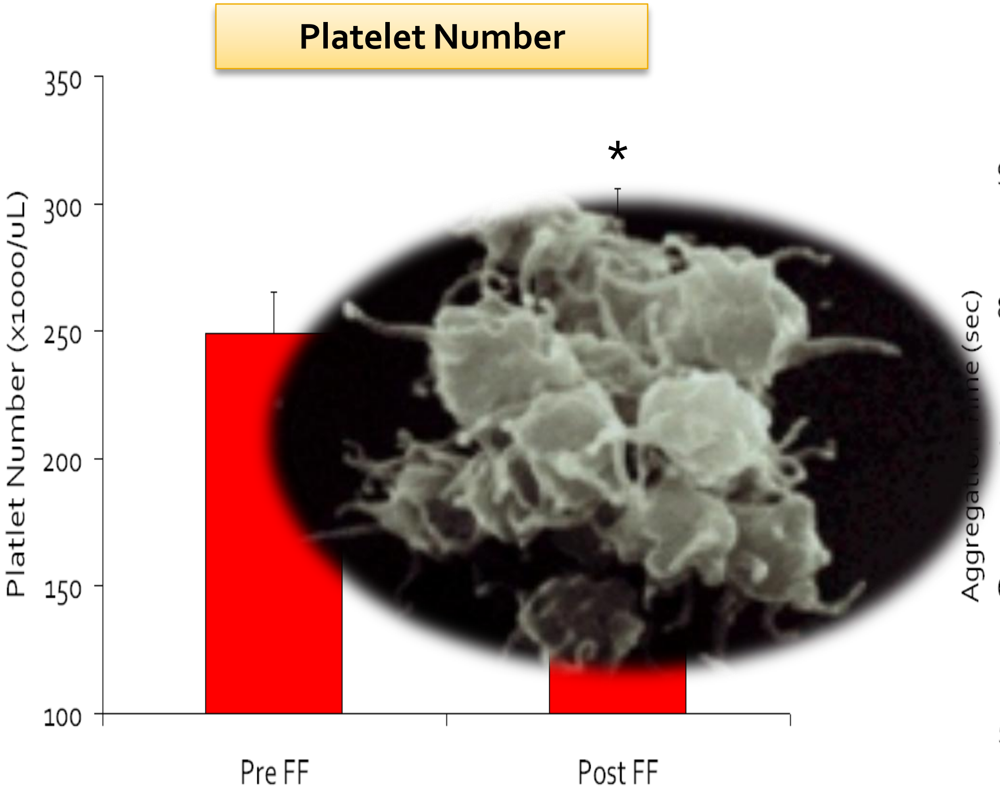
a $p<0.05$ vs Pre and Post

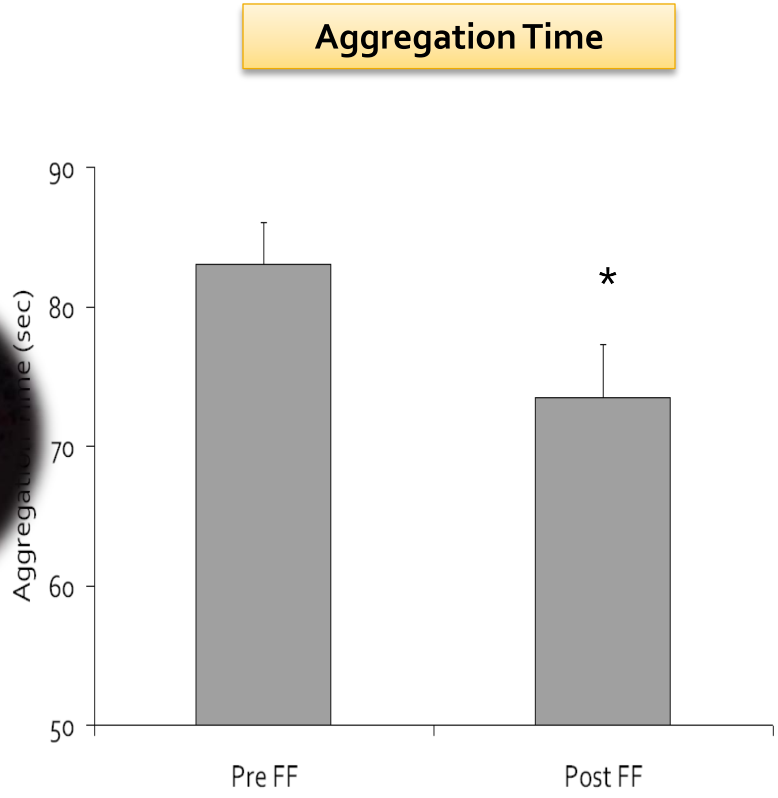
b $p<0.05$ vs Pre

Smith et al., 2005. *Ergonomics*.

Platelet Data

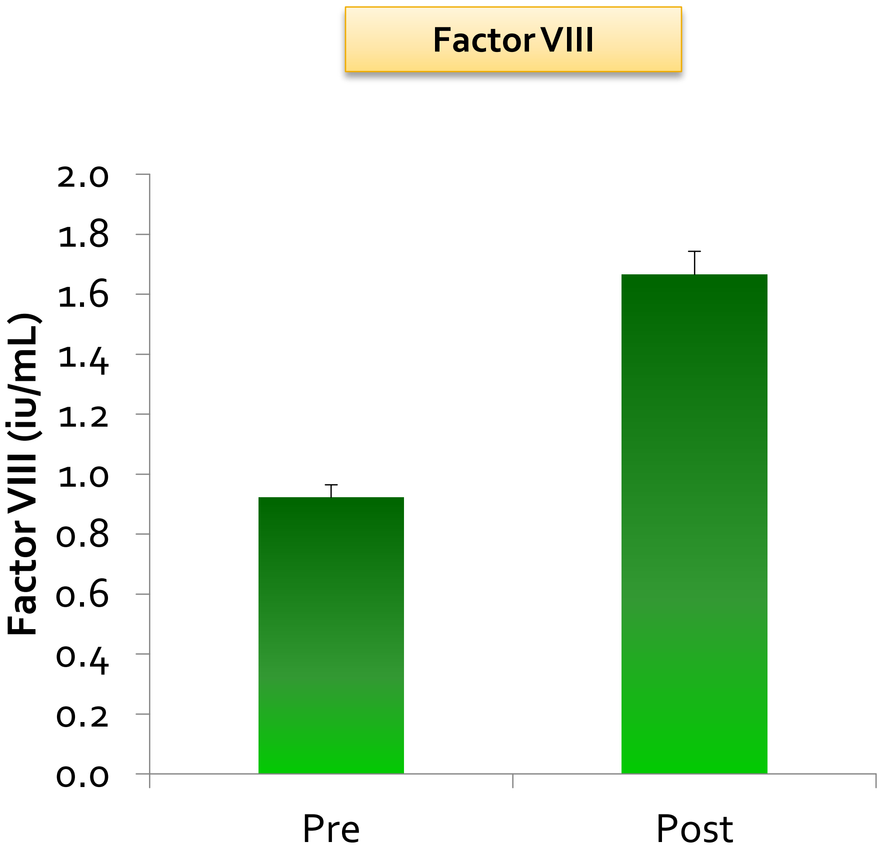
(n = 11)

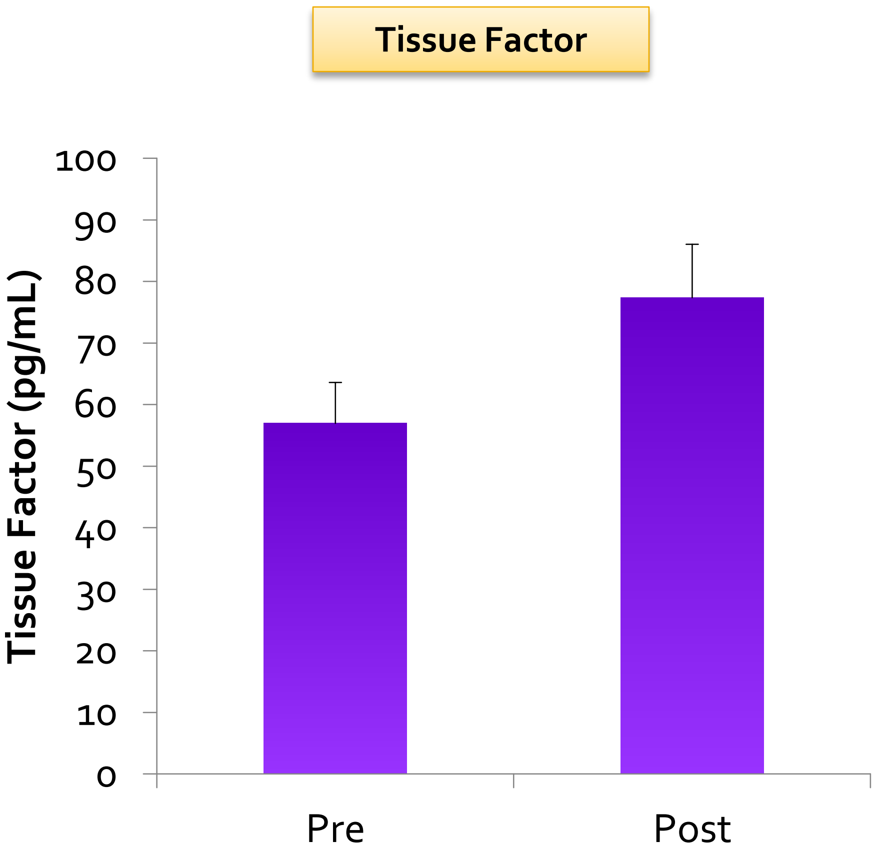




* $p < 0.05$

Coagulation





n=68
Age=29
BMI=27.56

Smith et al. 2007. UI Report, AFG Grant

Actual Firefighting Activities:
Alarm as a Vulnerable Period

Many cardiac fatalities occur shortly AFTER an Alarm

	Time Spent (%)	Fatalities (%)
Fire Suppression	1%	32.1%
Return from Alarm	7%	17.4%
Response to Alarm	**4%**	**13.4%**
Physical Training	8%	12.5%
Non-Fire Emergencies	15%	9.4%
Non-emergency Duties	65%	15.4%

Kales, et al., NEJM, 2007

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NIOSH Fire Fighter Fatality Investigation and Prevention Program

Death in the line of duty...

A summary of a NIOSH fire fighter fatality investigation — September 1, 1998

Fire Fighter Dies of a Heart Attack while Responding to a Residential Oil Heater Fire - Delaware

SUMMARY

On January 6, 1998, a 58-year-old male career fire fighter with a 28-year service record with the employing fire department collapsed while responding to a residential oil heater fire. The ladder truck to which the fire fighter was assigned was the first piece of equipment to arrive at the fire scene and approached the dwelling from the street in front. After parking the vehicle, the fire fighter and three other fire fighters exited the truck wearing full protective gear and headed toward the front door of the dwelling. The homeowner stated that the fire was from an oil heater in the basement. Ground-level access to the basement was in the rear of the building. The fire fighter and his partner hurried to the back of the building, while the other two fire fighters began placing ladders to access the roof of the structure. When the fire fighter and his partner reached the basement access, he stopped, said, "Hold on, I'm tired," and placed his hands on his knees. When his partner asked if he was okay, the fire fighter did not respond. The fire fighter then fell face-first to the pavement. His partner turned him onto his back, and

Purpose

To use a physiological monitoring system to document cardiac responses during a 24-hour shift

DHS AFG EMW-2007-FP-02581

Protocol

Oxnard and Boston Fire Department
24 hours of monitoring for 3 – 4 months
Logged CV strain/Autonomic function

- **Alarm response**
- During FF activities
- Recovery

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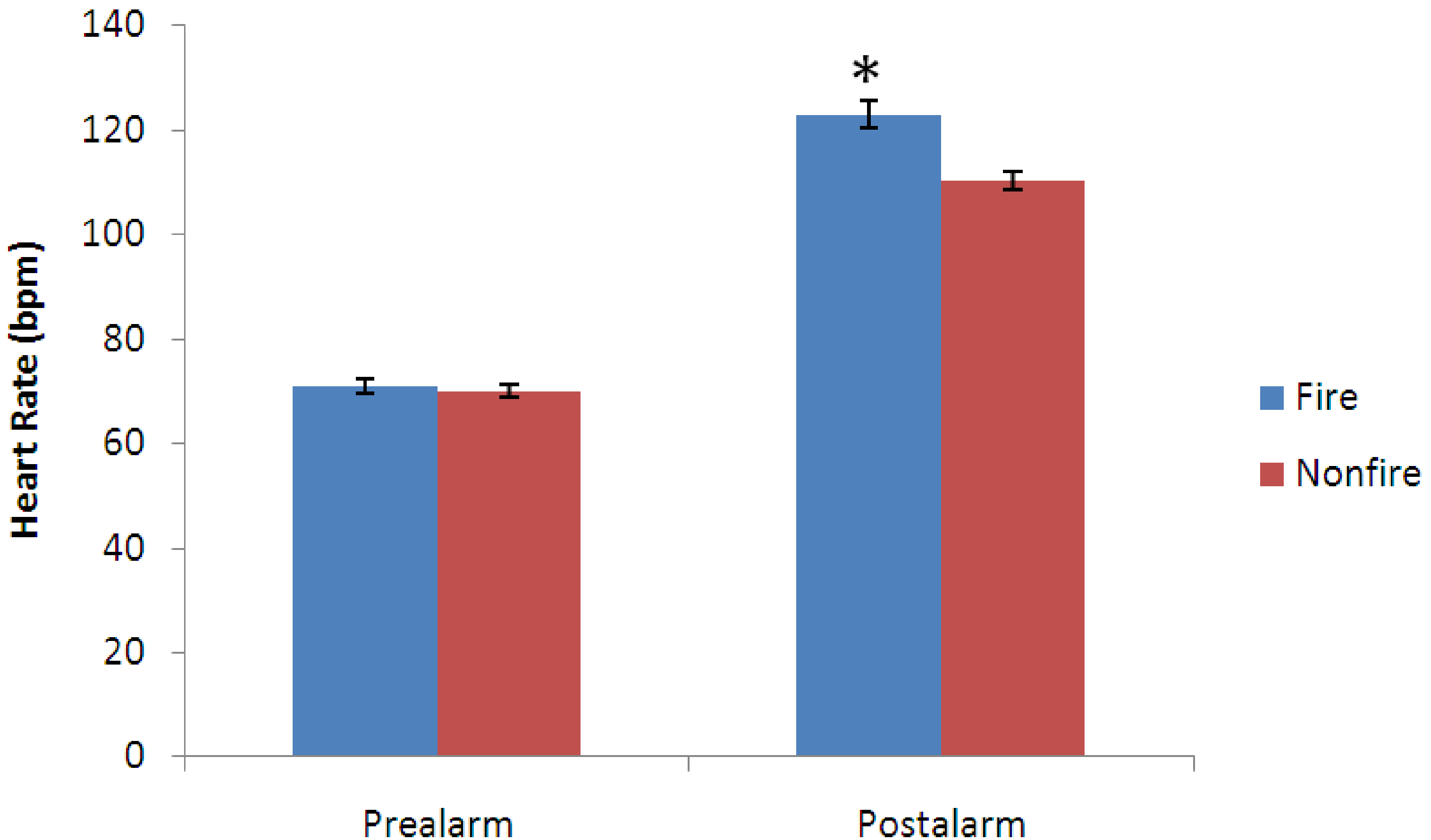
Heart Rate Response to Alarms



n=50
Age= 39.0 ± 11.4
BMI= 27.7 ± 3.5
Yrs of Service= 9.2 ± 9.8

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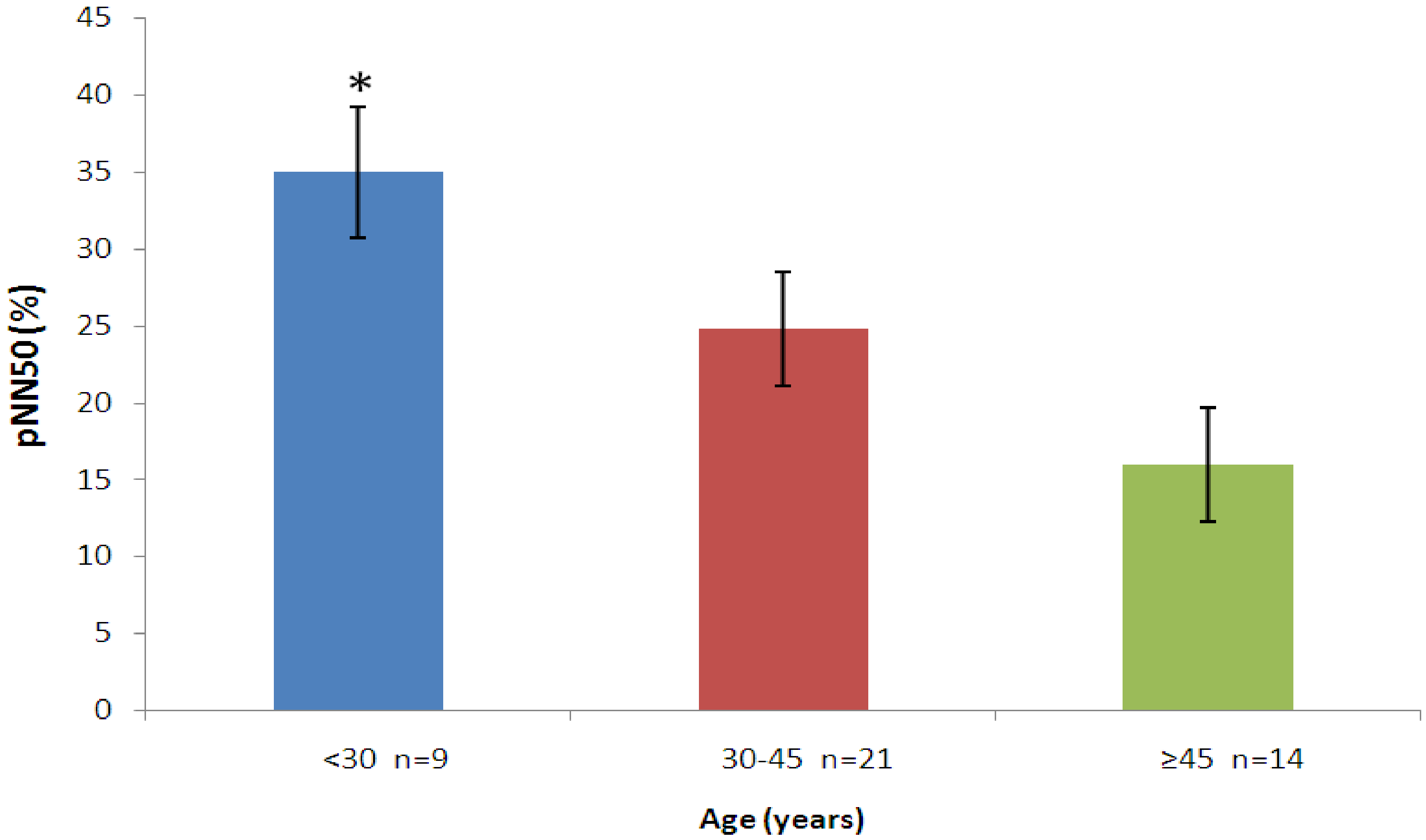
Heart Rate Variability



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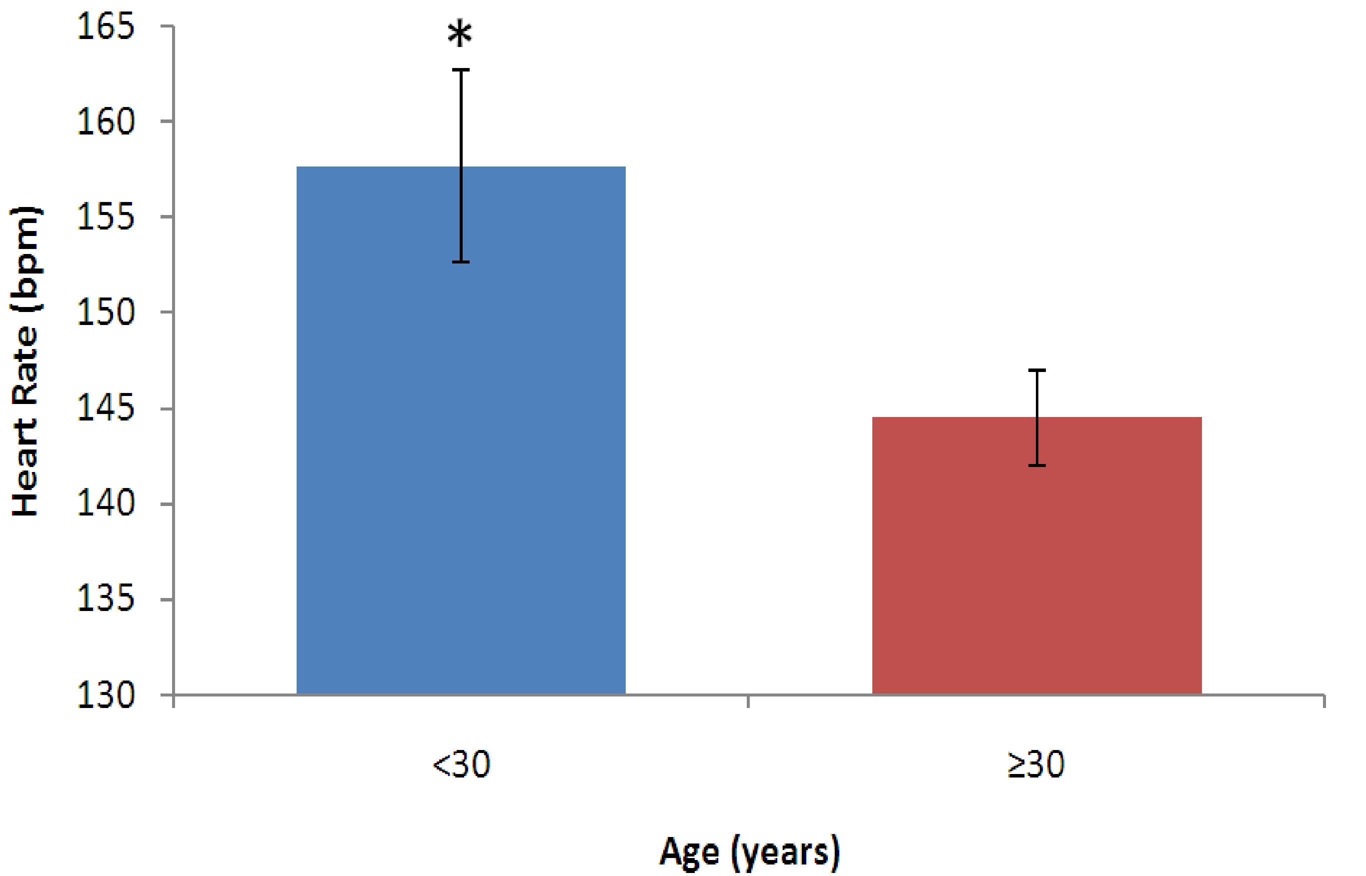
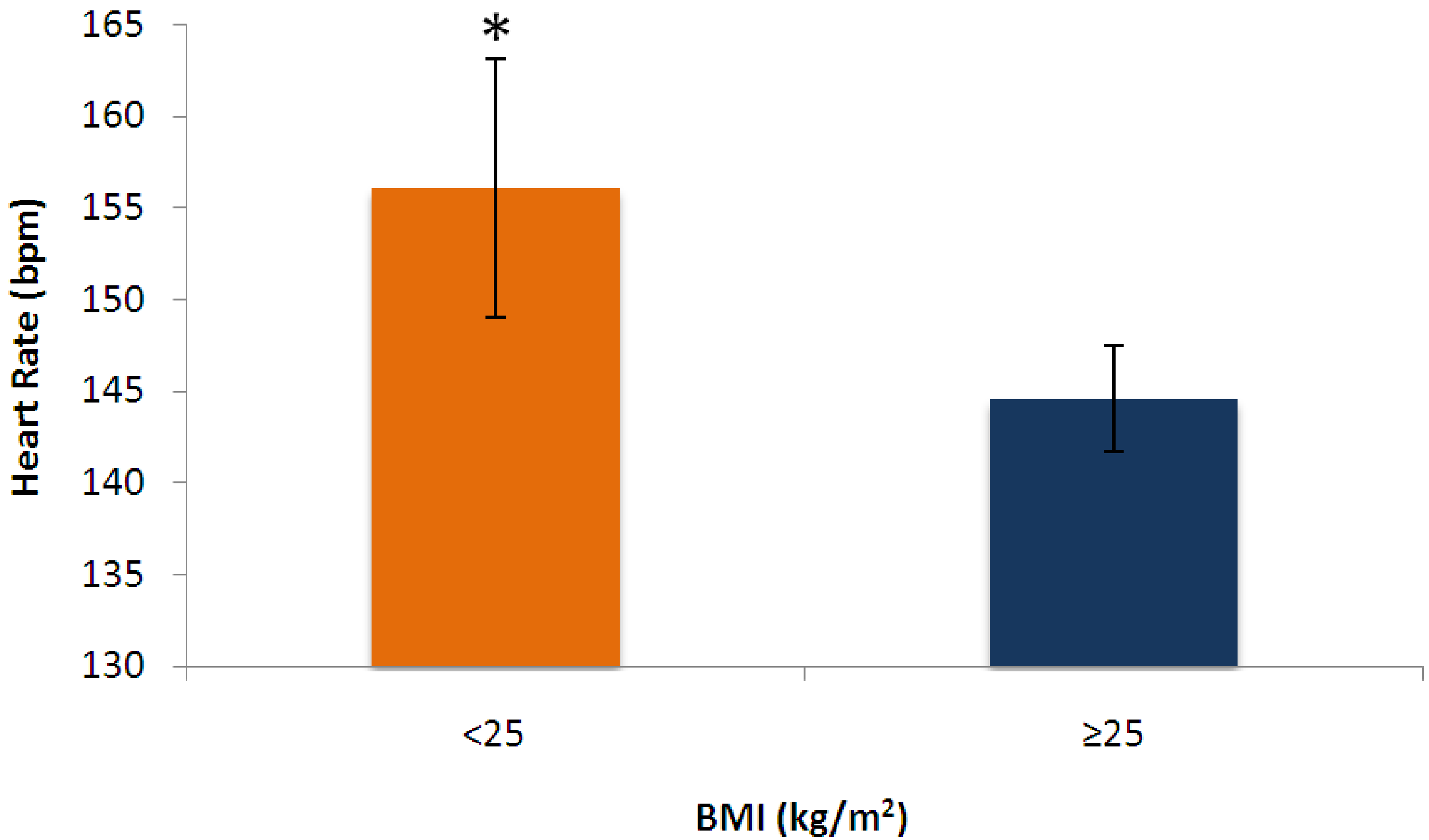
Heart Rate Response to Strenuous Working Fires



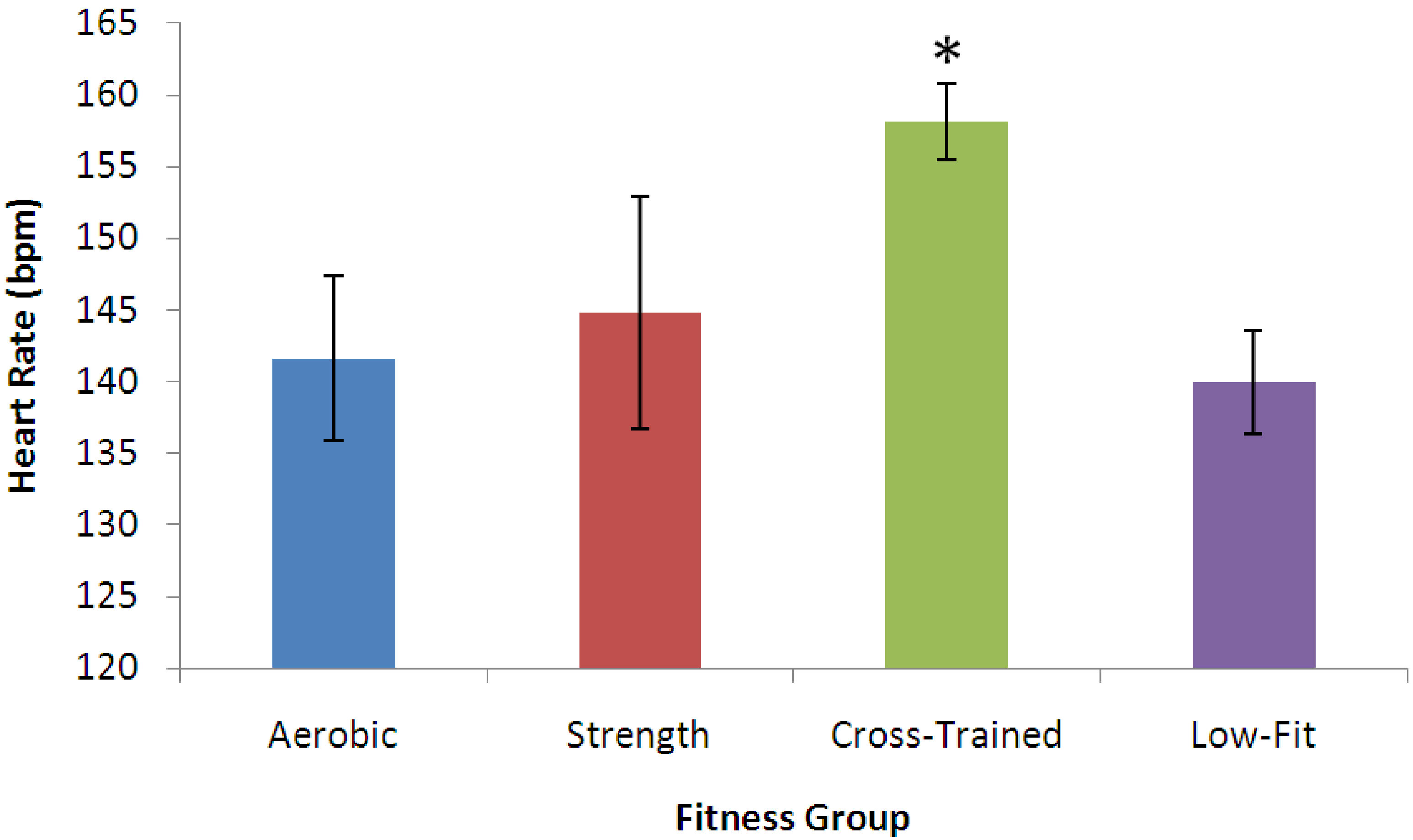
DHS AFG EMW-2007-FP-02581

Heart Rate Response to Strenuous Working Fires



DHS AFG EMW-2007-FP-02581

Heart Rate Response to Strenuous Working Fires



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Section Four

Minimizing Sudden Cardiac Death in the Fire Service

Compelling evidence that cardiovascular strain is a problem in Fire Service, based on:

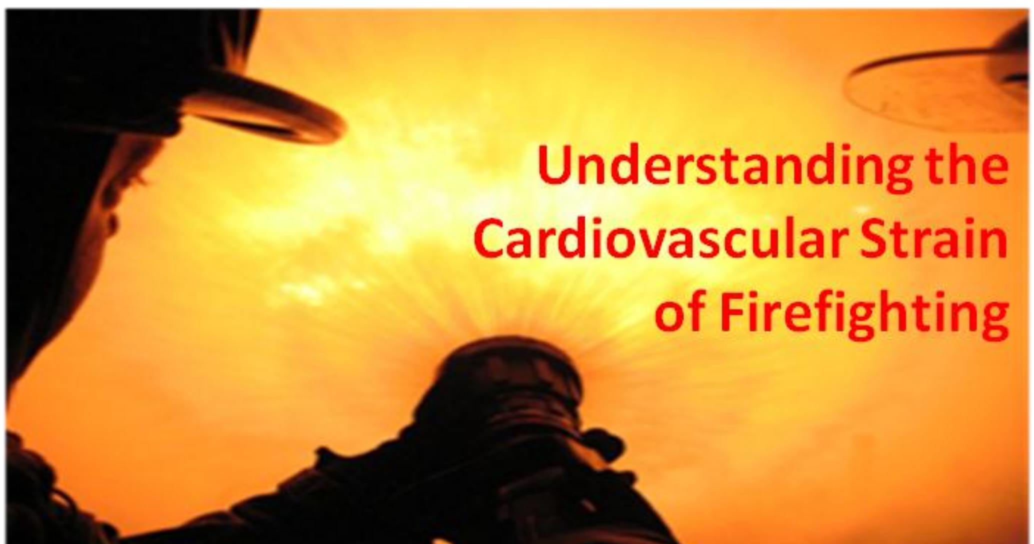
- Theoretical knowledge
- Anecdotal evidence
- Statistical results
- Research findings

<u>Preparation</u>

- Lessen Risk Factors
- Medical Clearance
- Signs & Symptoms
- Physical Fitness

<u>Recovery</u>

- Incident Rehabilitation



Pre-Event

Medical Readiness

- Medical conditions (cardiovascular function, kidney function, fluid and electrolyte balance, thermoregulation, fever, immune function, skin) affect response
- Medications (antihistamines, antidepressants, stimulants, diuretics, b-blockers)
- **All firefighters should have a medical evaluation – compliant with NFPA 1582**

Pre-Event

Hydration

- Prehydration
- **Dehydration**

Pre-Event

Aerobic Fitness:

- ↑Thermal Tolerance
- ↑ Plasma Volume
- ↑ Cardiac Efficiency
- ↑ Work Capacity
- Improve Clotting Profile

Appropriate Body Size:

- ↑Thermal Tolerance
- ↓Thermal Strain
- ↑ Cardiac Efficiency
- ↑ Work Efficiency
- Improve Clotting Profile

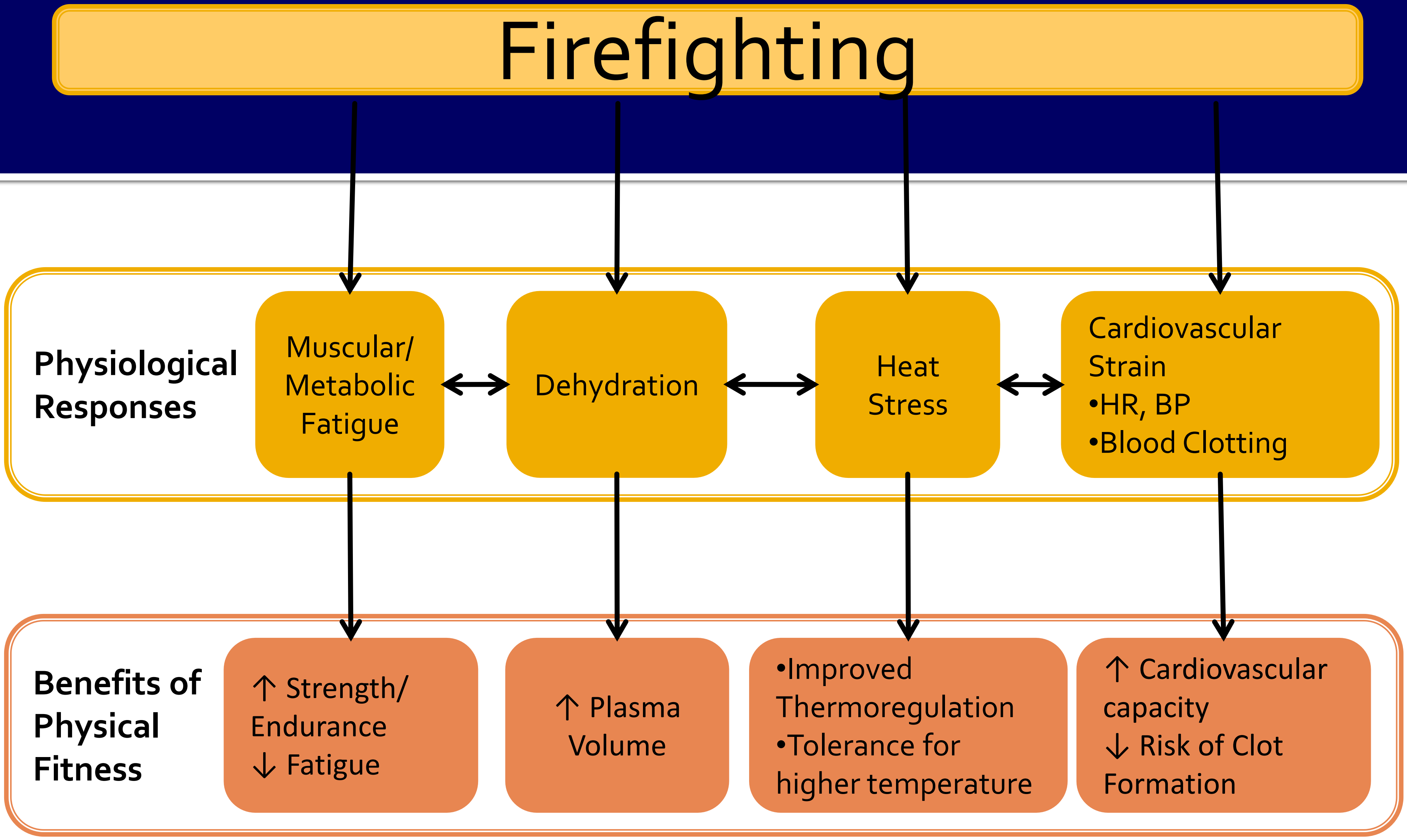
Effect of Body Size on CV

Variable	Body Mass Index (kg/m^2)		
	<25.9 (Group 1)	25.9-29.5 (Group 2)	≥29.5 (Group 3)
Intima-media thickness	0.44 (0.01)	0.46 (0.01)	0.52(0.01)*†
Aortic pulse wave velocity	5.9(0.1)	6.4(0.2)*	6.8(0.1)*
Peak Reactive Hyperemia	28.57(1.29)	32.19(1.36)	29.67(1.34)
β Stiffness	4.6(0.2)	5.1(0.2)	6.2(0.4)

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

N=110 firefighters
Age= 29.7±8.0 years

Fahs et al., 2009, Am J Cardiol.

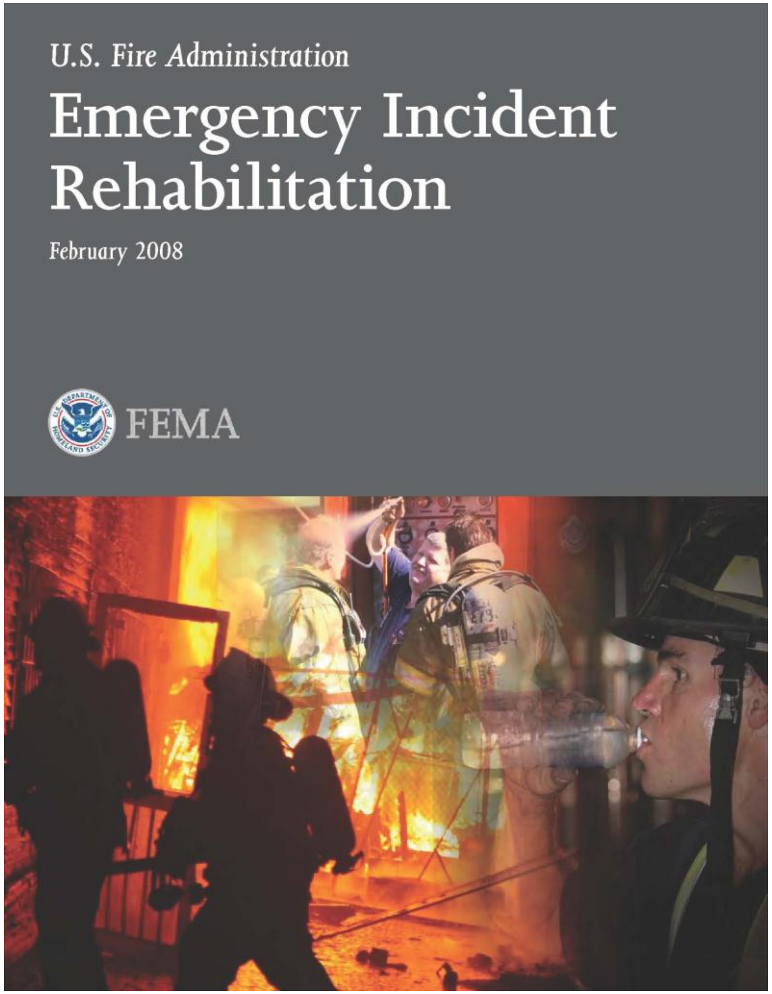


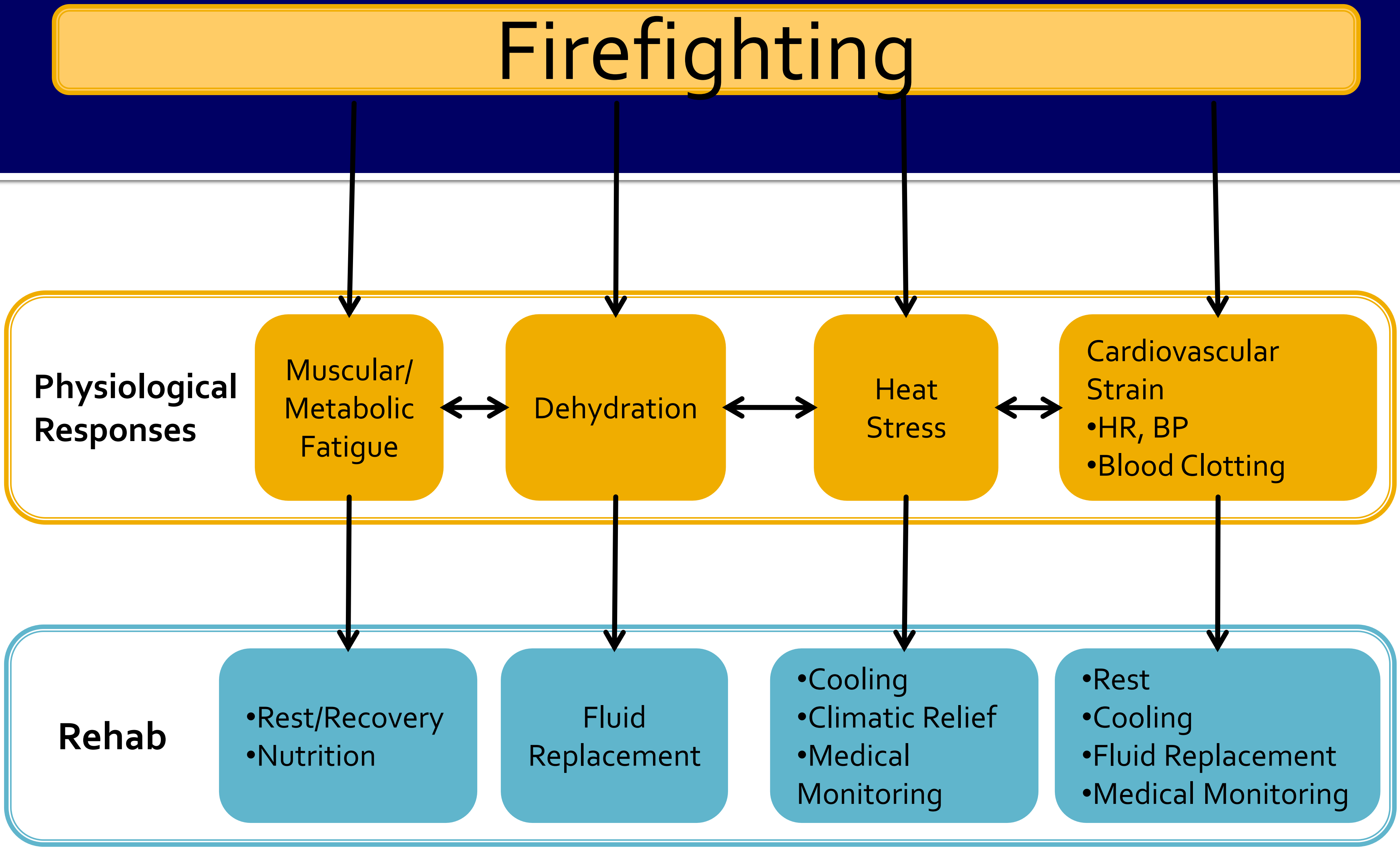
Firefighting
Physiological Responses
Muscular/ Metabolic Fatigue
Dehydration
Heat Stress
Cardiovascular Strain
•HR, BP
•Blood Clotting
Benefits of Physical Fitness
↑ Strength/ Endurance
↓ Fatigue
↑ Plasma Volume
•Improved Thermoregulation
•Tolerance for higher temperature
↑ Cardiovascular capacity
↓ Risk of Clot Formation

Incident – On Scene

Adopt Aggressive Incident Rehabilitation Policies

1. Cool- "Aggressively"
2. Rehydrate
3. Provide rest and recovery
4. Medical Monitoring




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

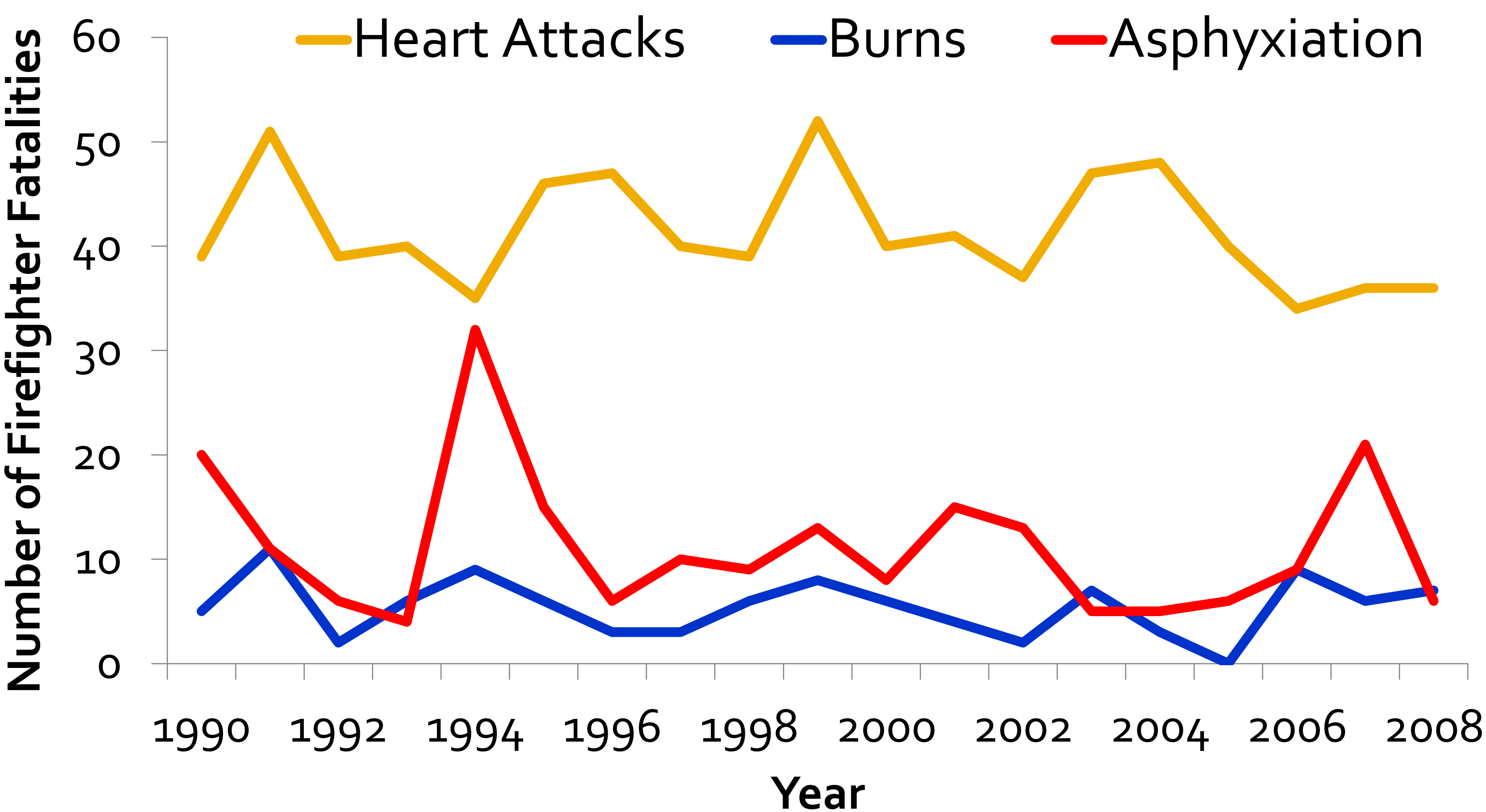
Section Four

Minimizing Sudden Cardiac Death in the Fire Service

Use of Technology

What is the potential role of physiological monitoring to improve the health and safety of firefighters?

Firefighter Fatality Statistics



PHASER

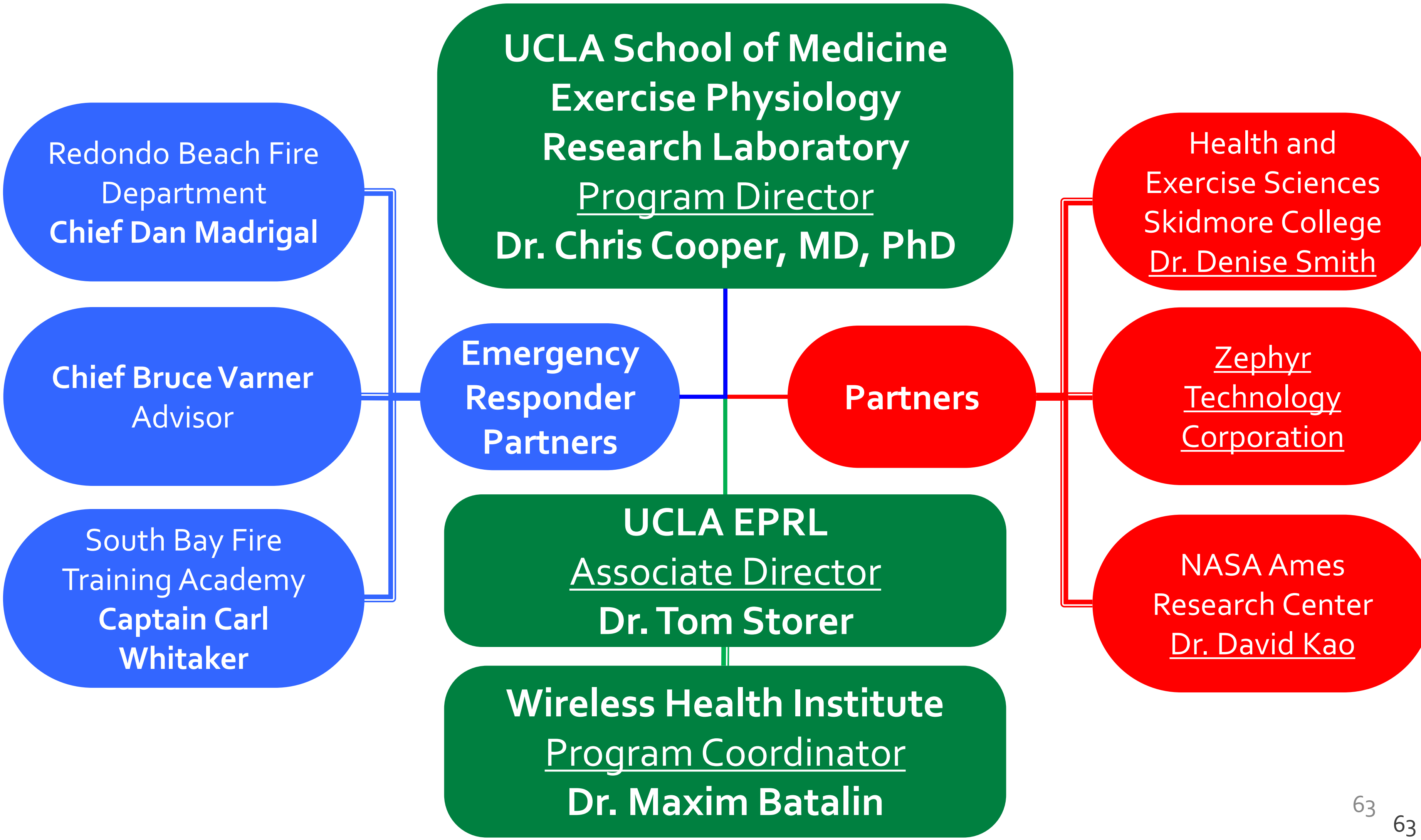
Physiological Health Assessment System for Emergency Responders (PHASER)

First Responder Safety and Protection Program

Homeland Security

Science and Technology

Program organizational chart



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PHASER: Technological challenges

- Physiology/Medical
  - What can be measured? What should be measured?
  - Which parameters are necessary, sufficient?
  - Baselining
    - How? How many? What conditions?
- Sensors
  - Which ones?
  - Size, Power, Form, Weight, Power?
  - Vest, wrist band, headband, within PPE, Tricorder?
  - Real time decision aid? What kind of alarms?
- Detection vs. Prediction?
  - Replace the MD?
- What is good enough and is that good enough!?
  - 30%, 40%, …, 90%, …, ????
- What can be leveraged: Gov Agencies, Industry, Academia, international. How can we work together to solve common problems?

Star Trek Medical Tricorder

PHASER specific aims

PHASER

- Risk Identification, Prioritization
- Sensor Selection, Prioritization
- Physiology Experiments
- Field Monitoring
- Networked Solution (NetFit)

PHASER

UCLA

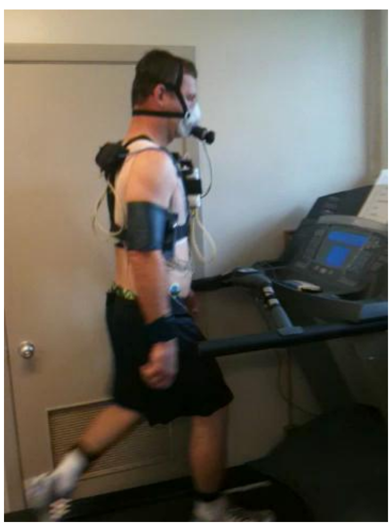
Zephyr

PHASER-NET: Networked Solutions for Emergency Responders

PHASER Net

Net-Fit

Fitness Assessment,
Guidance and Monitoring



Net-Safe

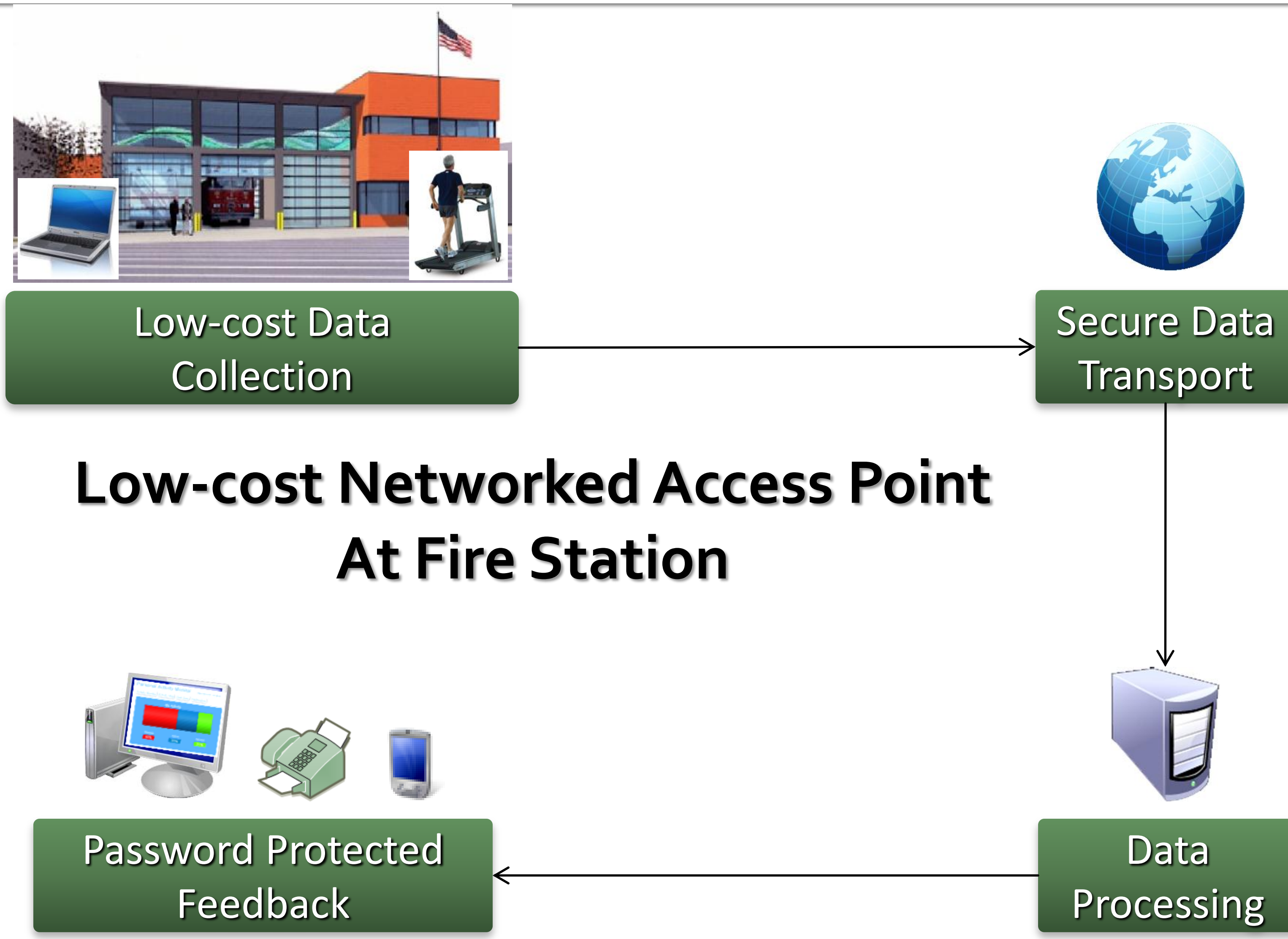
On-Scene Monitoring
Rehab Monitoring

Net-Select

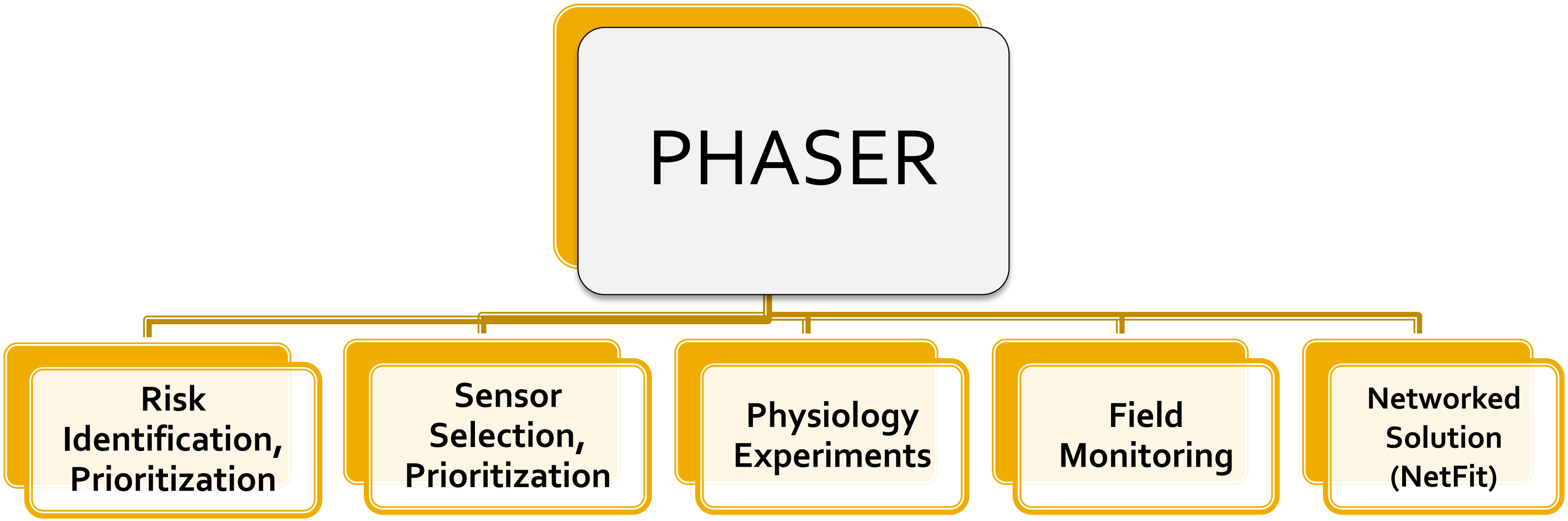
Sensor Selection and Validation

NetFit Mobile: Setup

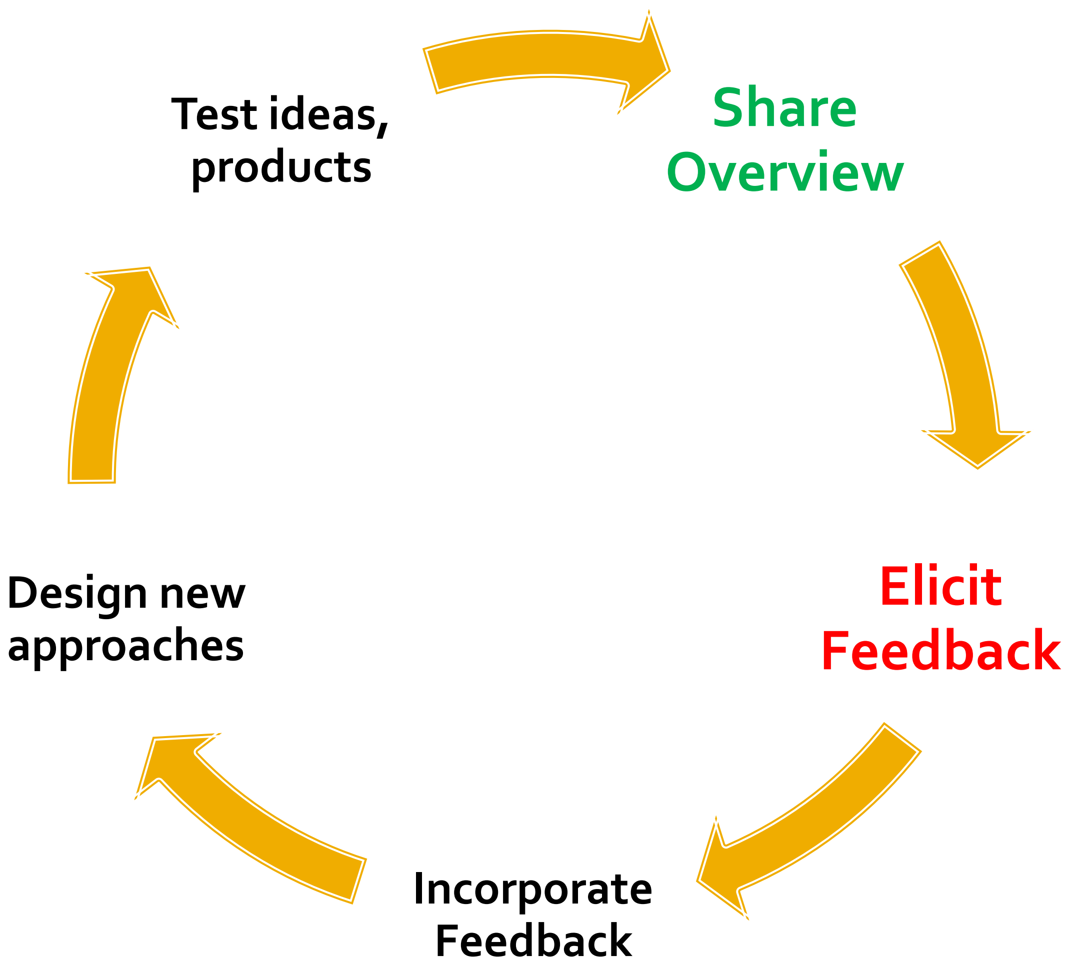
Baseline assessment: NetFit Access Point



Overview of Activites



Fire Service Involvement is Critical



Discussion

- How do you see physiological monitoring helping the fire service?
- What challenges might this technology face in the fire service?
- What advantages do you see to on-scene/real time physiological monitoring
- How do you envision an IC and EMS utilizing this information?
- Where are your concerns or desires with this technology.

Further Feedback/Questions

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Thank You

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