FRI 2008

Denver, Colorado

August 14-16, 2008

#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?

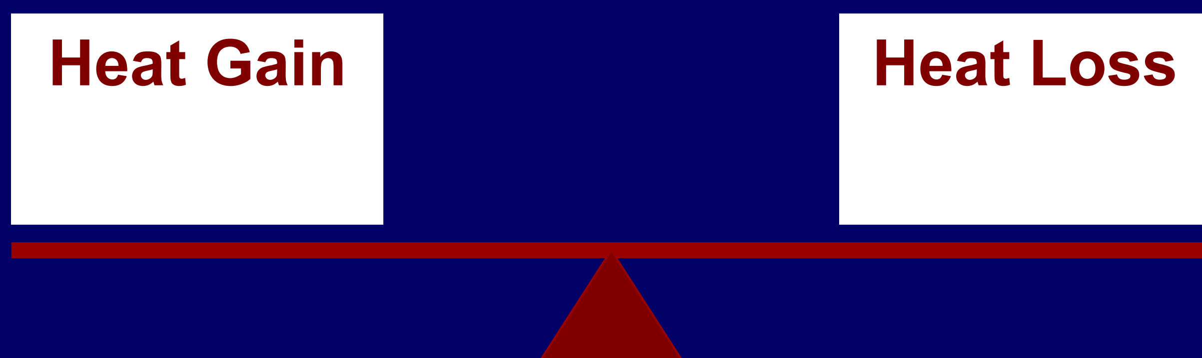
Heat Stress - The various physical work and environmental components that combine to create the heat load under which an individual works.

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



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?

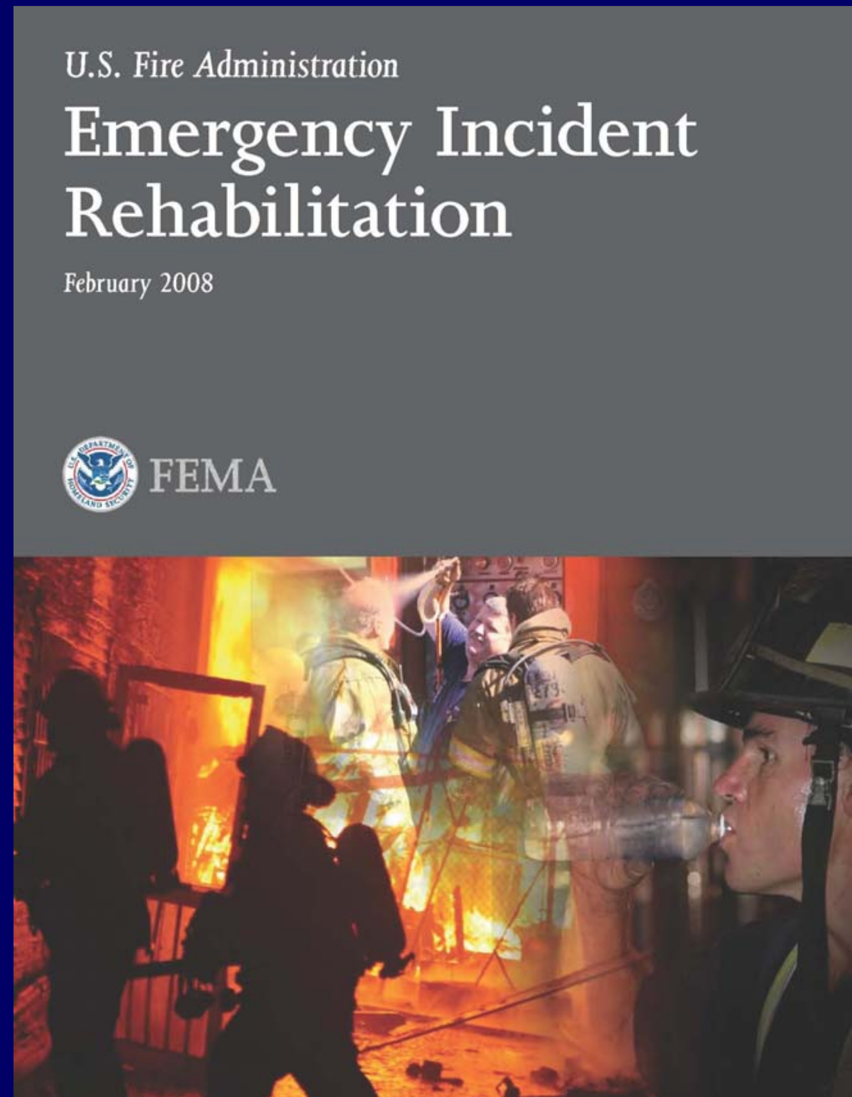
1. Classic Heat Illness
   – usually seen during longer duration activity
2. Dehydration, Fatigue, Impaired Cognitive Function
   – worsens as activity continues
3. Increased Cardiovascular Strain – linked to sudden cardiac events???
4. Fatigue leading to increased slips, trips and falls???

Exertional Heat Illness

- Heat cramps
- Syncope
- Heat exhaustion
- Heat stroke

Heat Stroke

- Case Studies



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

Theoretical Background

"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."

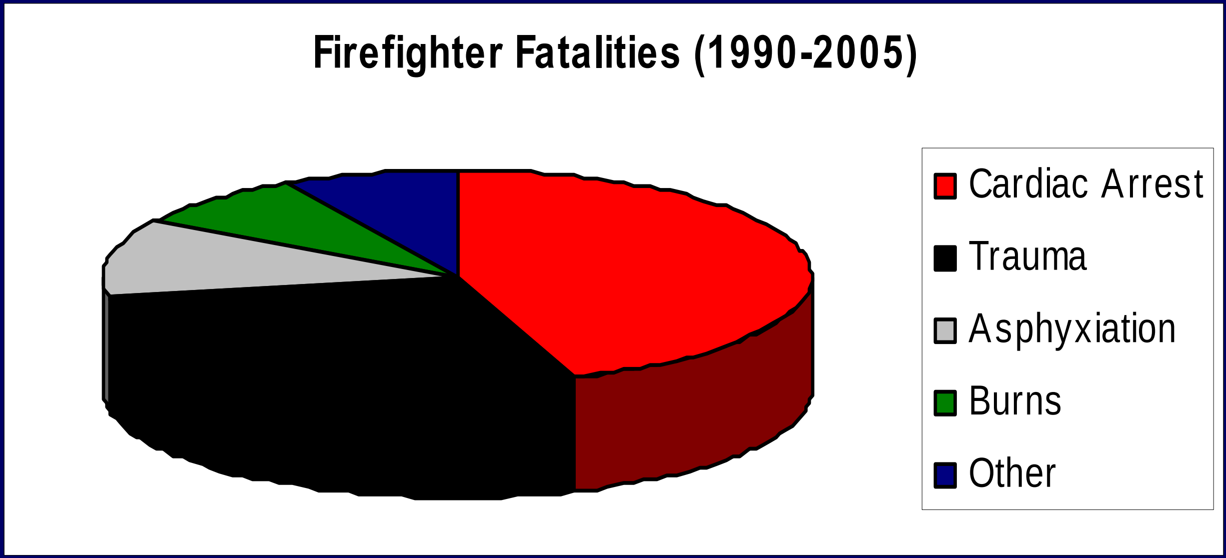
L.Rowell, 1993. In *Human Cardiovascular Physiology*, Oxford Press.

Fire Service Statistics

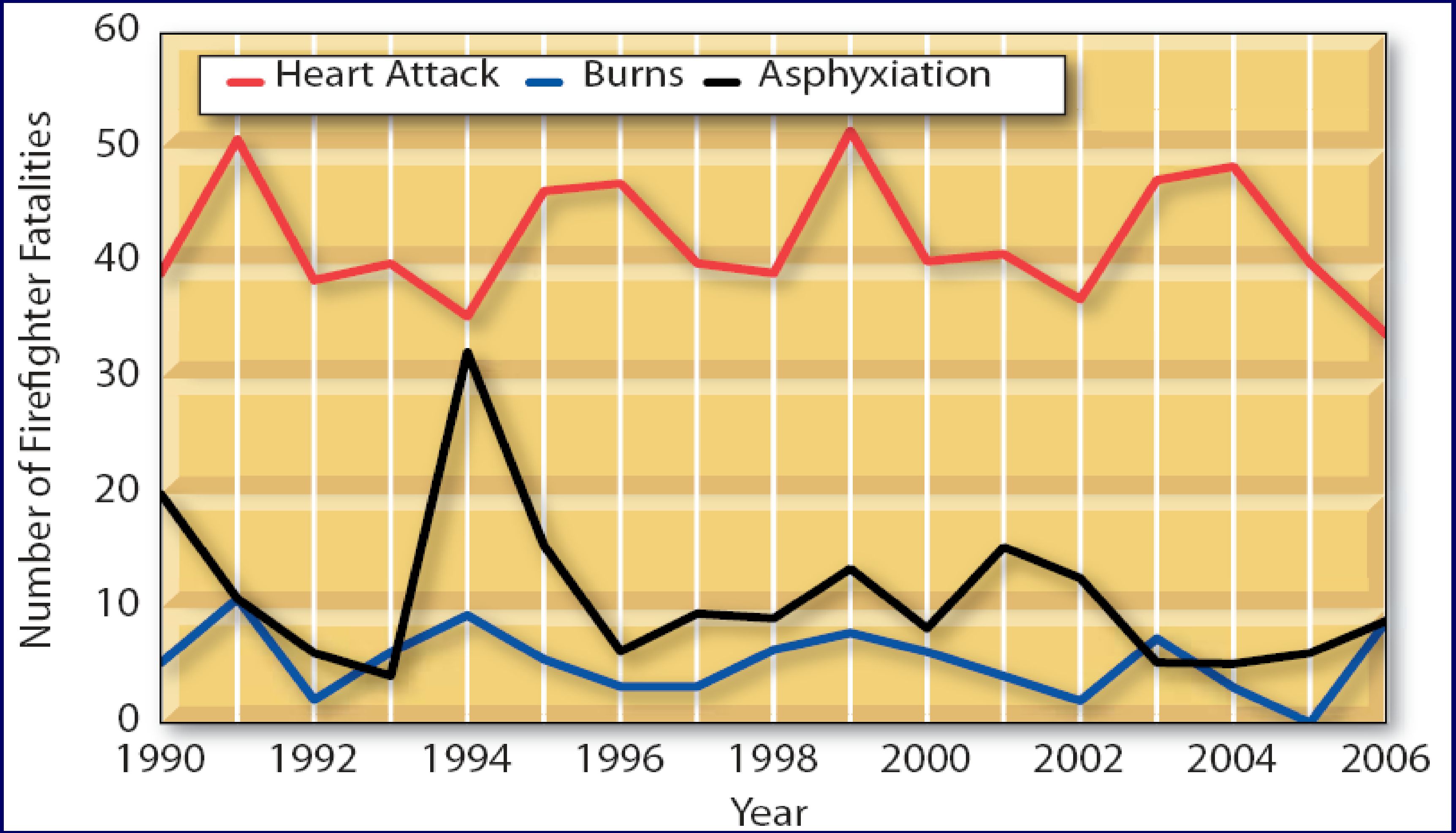
- **Firefighting is a dangerous occupation**
  - Injuries – approx. 60-80,000 per year reported
  - Fatalities – approx. 100 per year
  - Highest occupational death rate for sudden cardiac events

Fatality Statistics I

- **Firefighter fatalities 1990-2005**
  - **44% Cardiac Arrest/MI**
  - **27% Trauma**
  - **11% Asphyxiation**
  - **8% Burns**
  - **10% Other**



Fatality Statistics II



Heart Deaths by Occupation

	% of On-Duty Deaths caused by CVD
Firefighters	**45%**
Police	22%
Overall*	15%
Construction	11.5%
EMS	11%

*Average % of all Occupational Fatalities, all Industries

Risk of CHD Death

Type of Duty	RR of CHD death
Fire suppression – OR** (95% CI)	53 (40-72)
Physical training – OR** (95%CI)	5.2 (3.6-7.5)
Alarm response – OR** (95% CI)	7.4 (5.1-11)
Alarm return –OR (95% CI)	5.8 (4.1-8.1)
EMS and other non-fire emerg. OR** (95% CI)	1.3 (0.9-2.0)
Firehouse and other non-emergency activities – OR** (95% CI)	1.0

Kales et al 2007

Cardiovascular Strain of FF

Physical Work

Sympathetic Nerve Stimulation (Adrenaline)

Heat Stress

Cardiovascular Strain of FF

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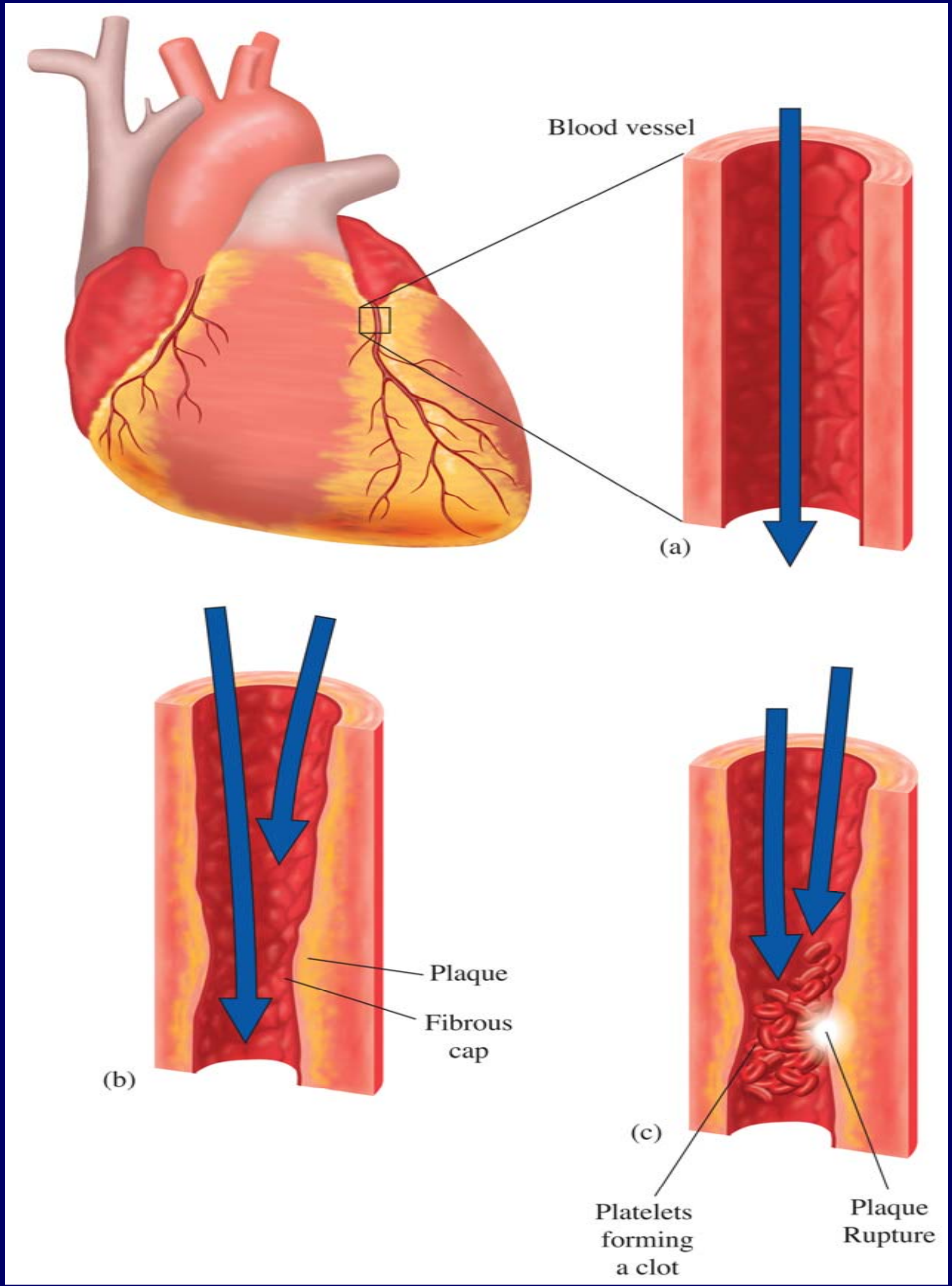
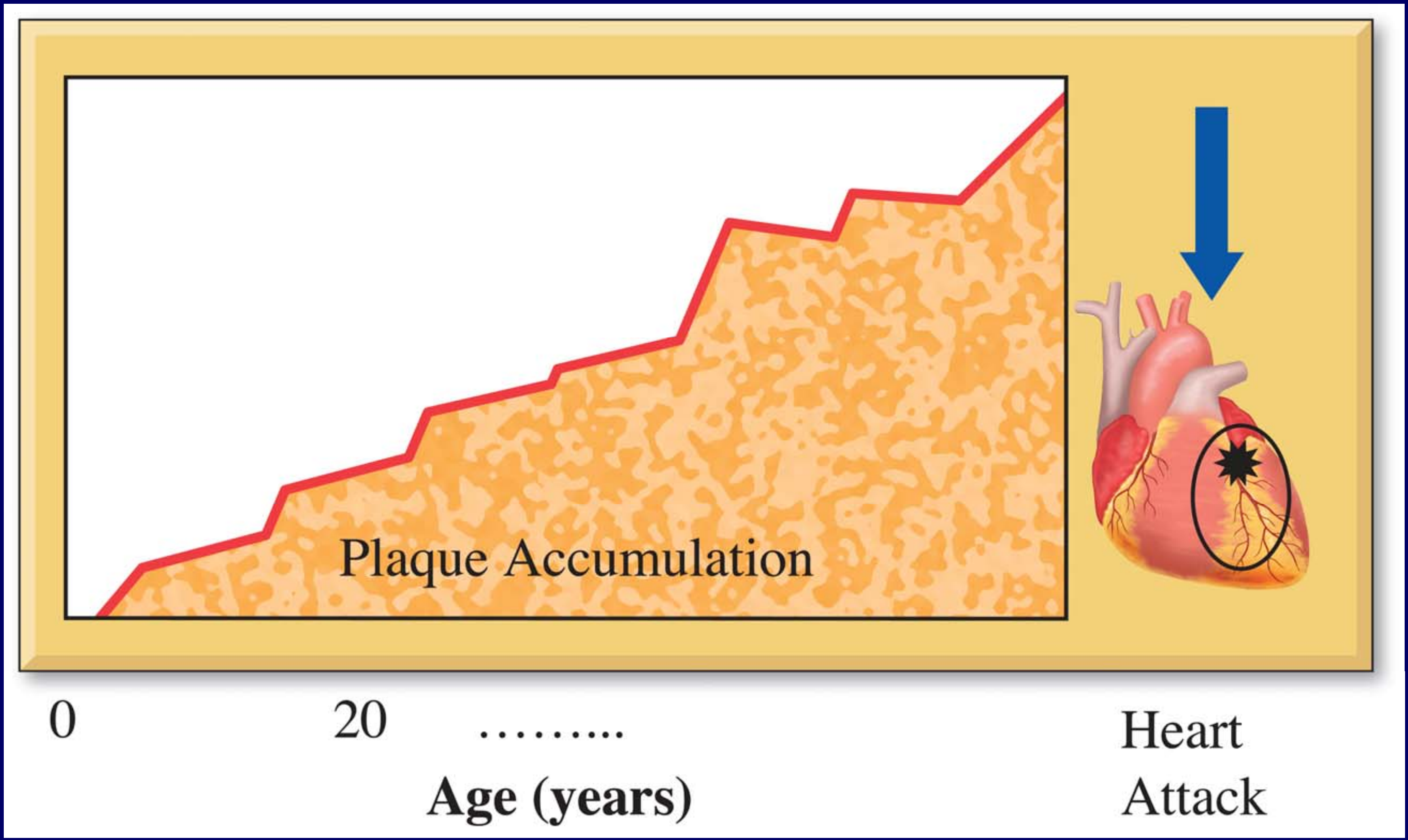
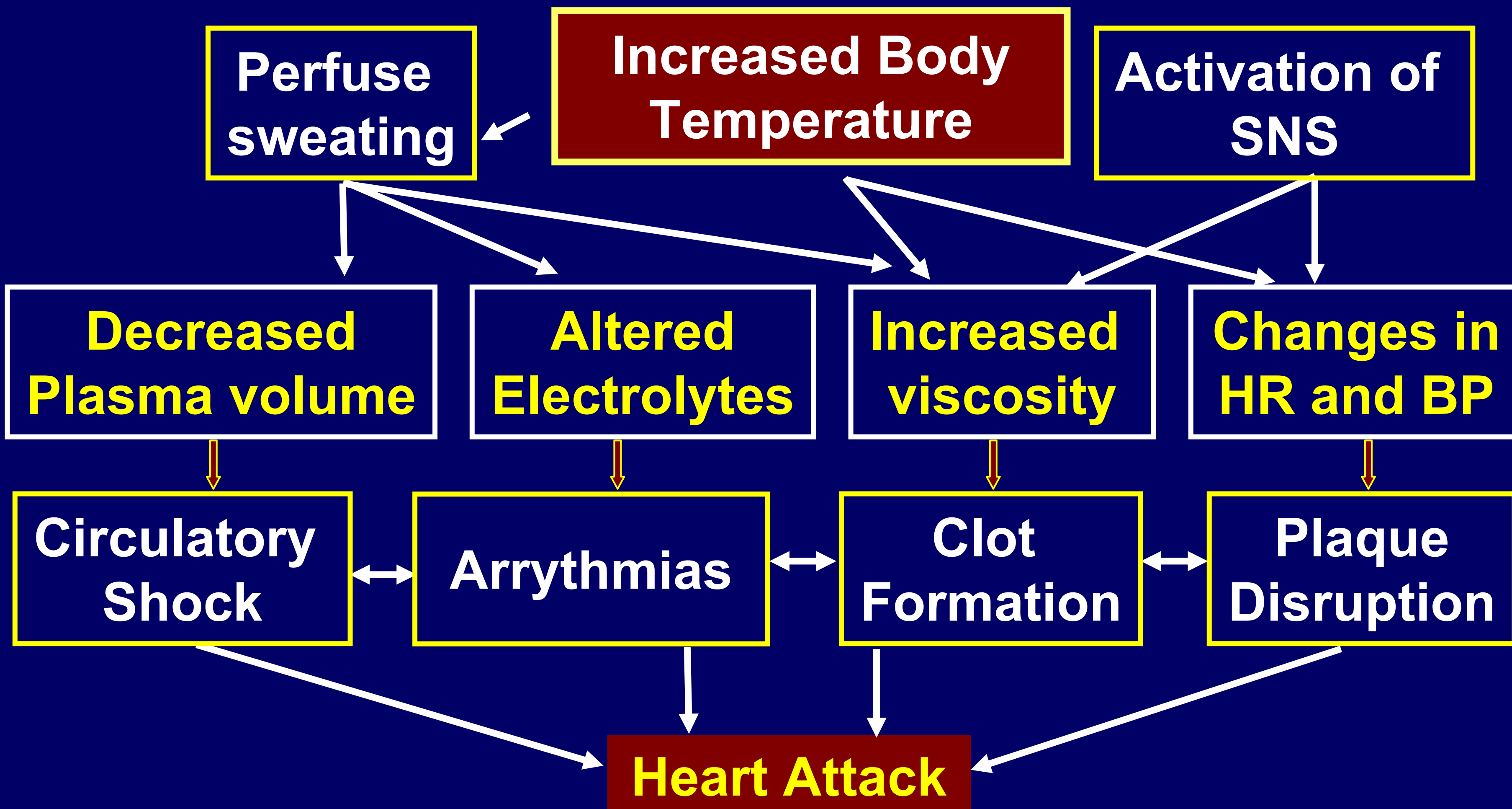


Blood vessel
(a)
Plaque
Fibrous cap
(b)
(c)
Platelets forming a clot
Plaque Rupture

Model of Sudden Cardiac Event



Simplified Schematic of Heat Stress



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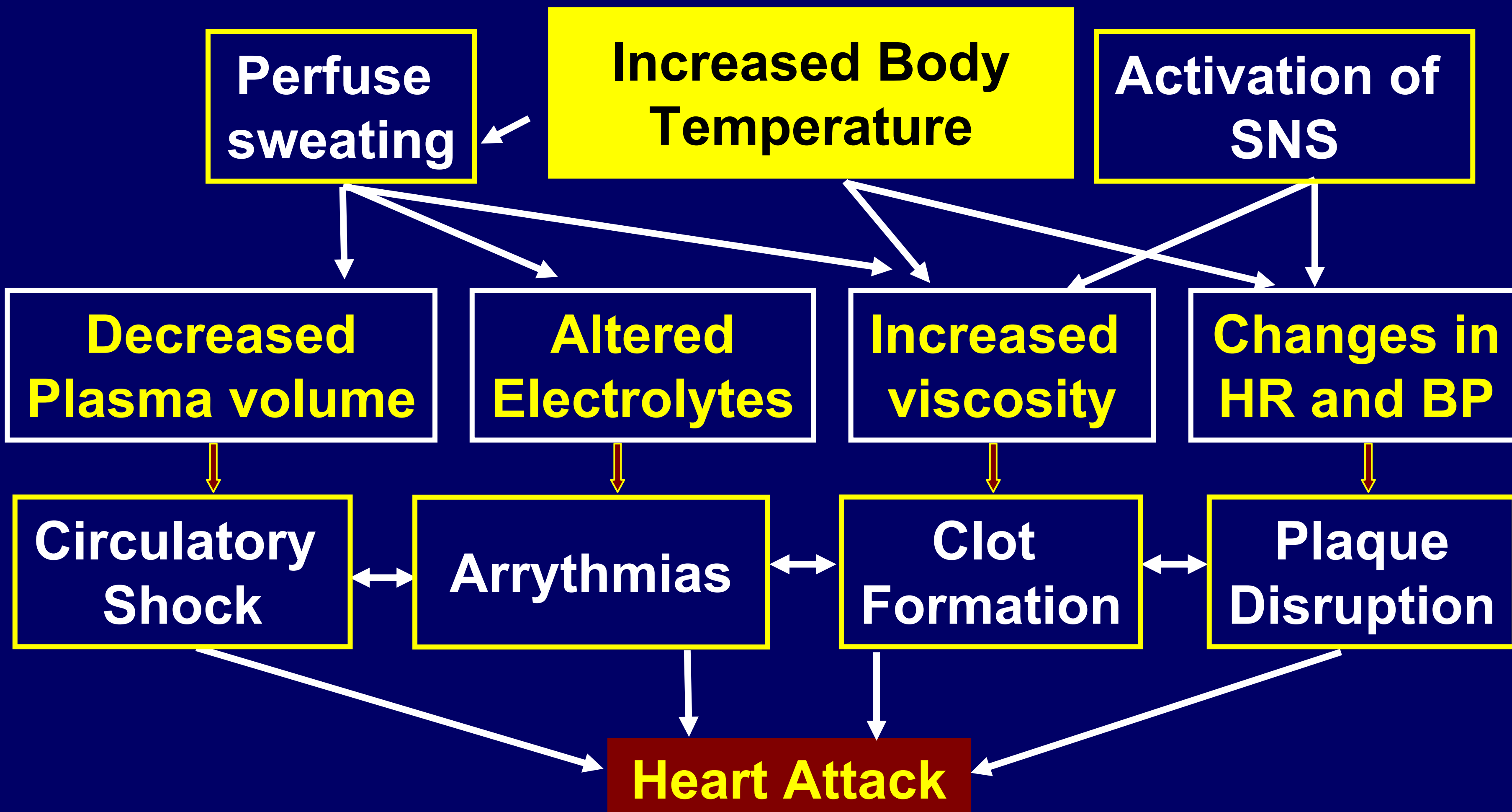

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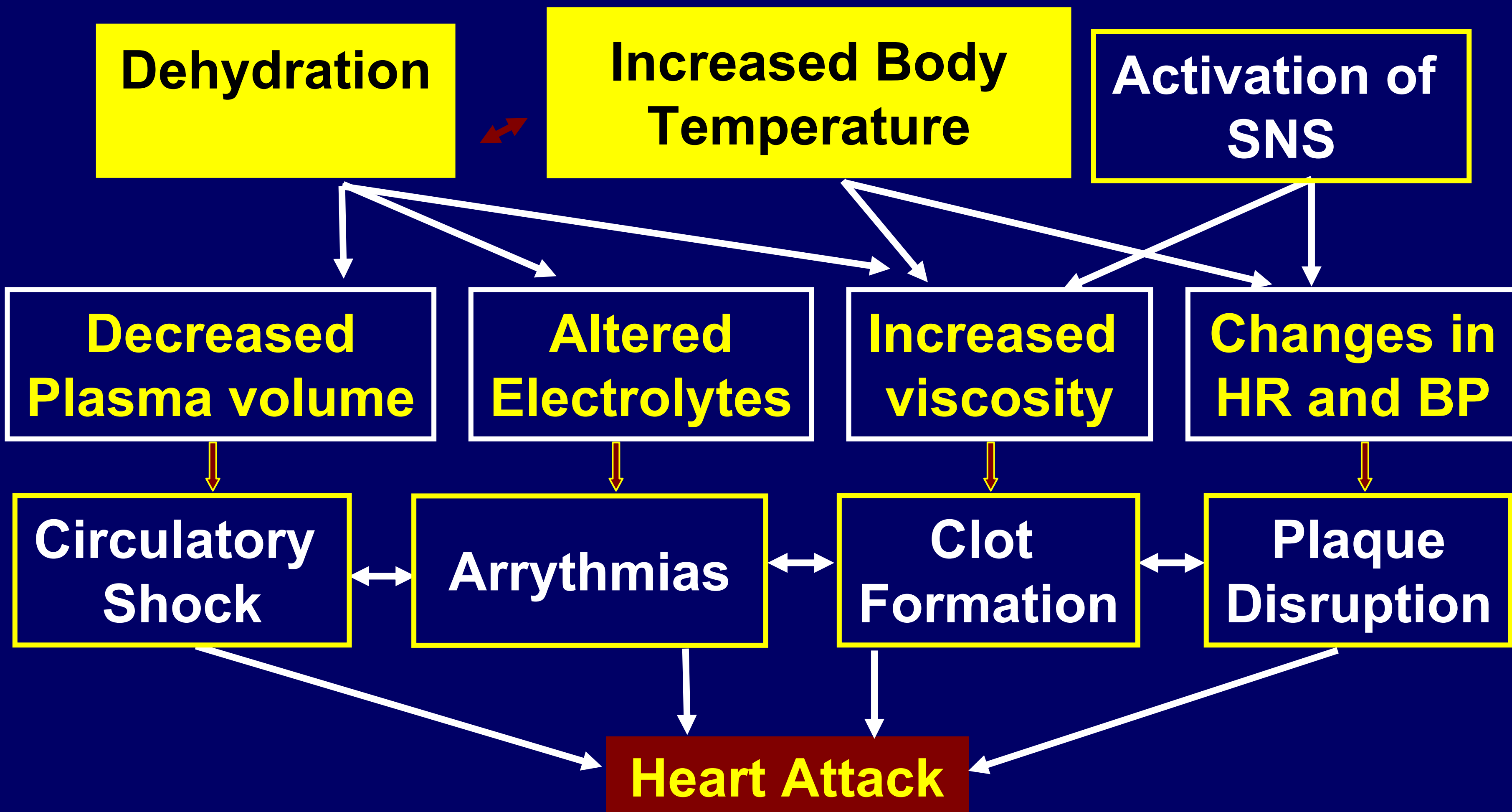
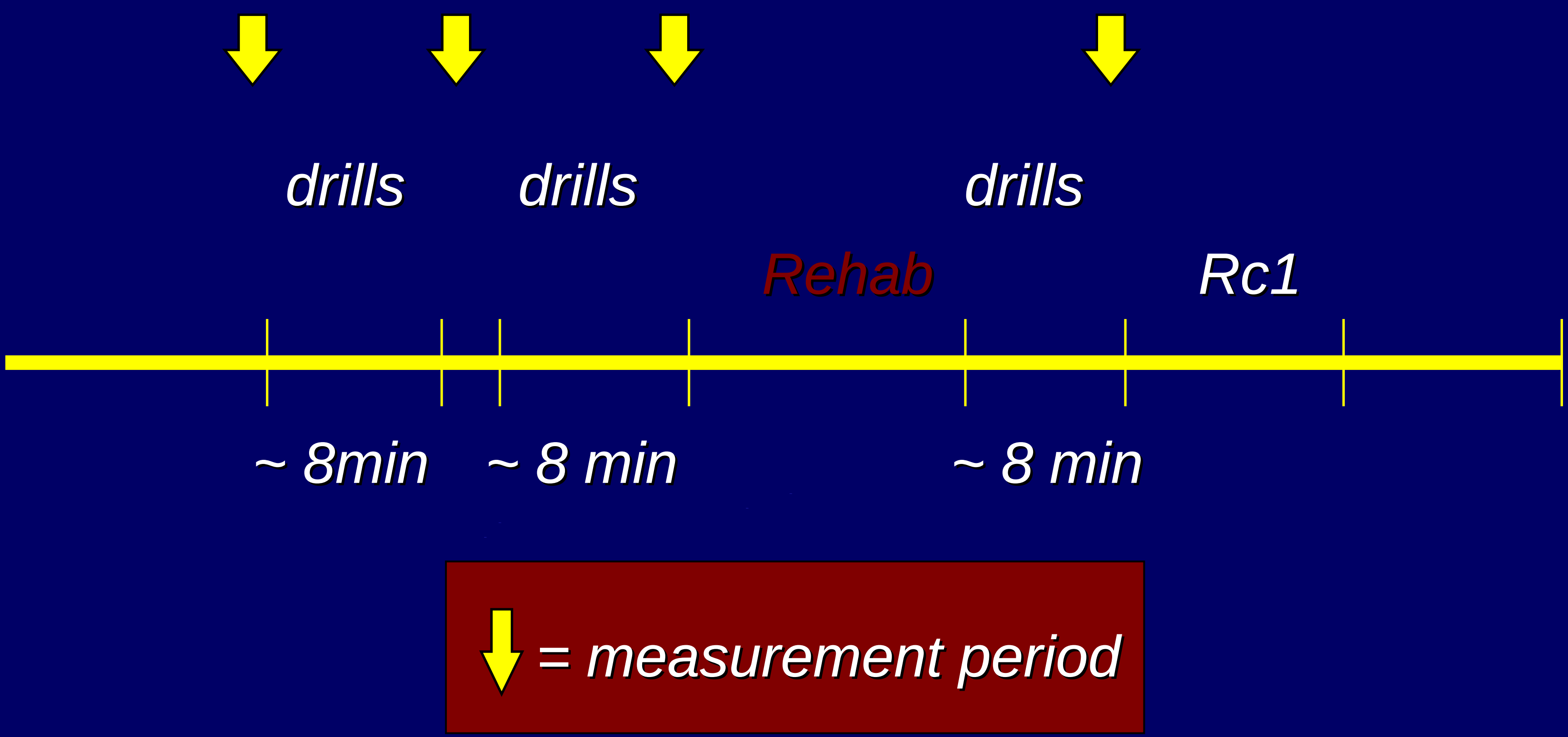
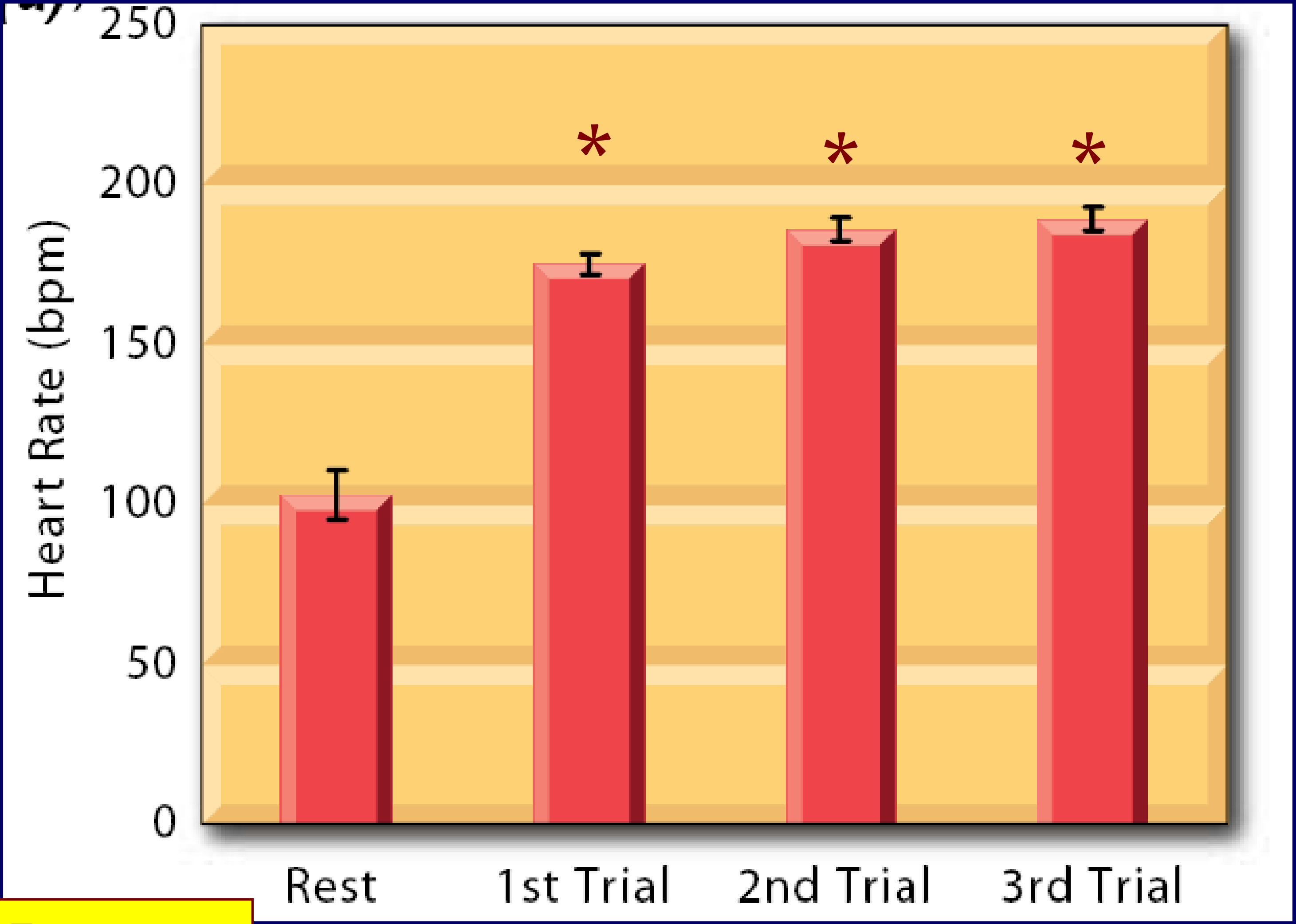


Field-based Research to Document the Stress of Firefighting

Changes During Firefighting

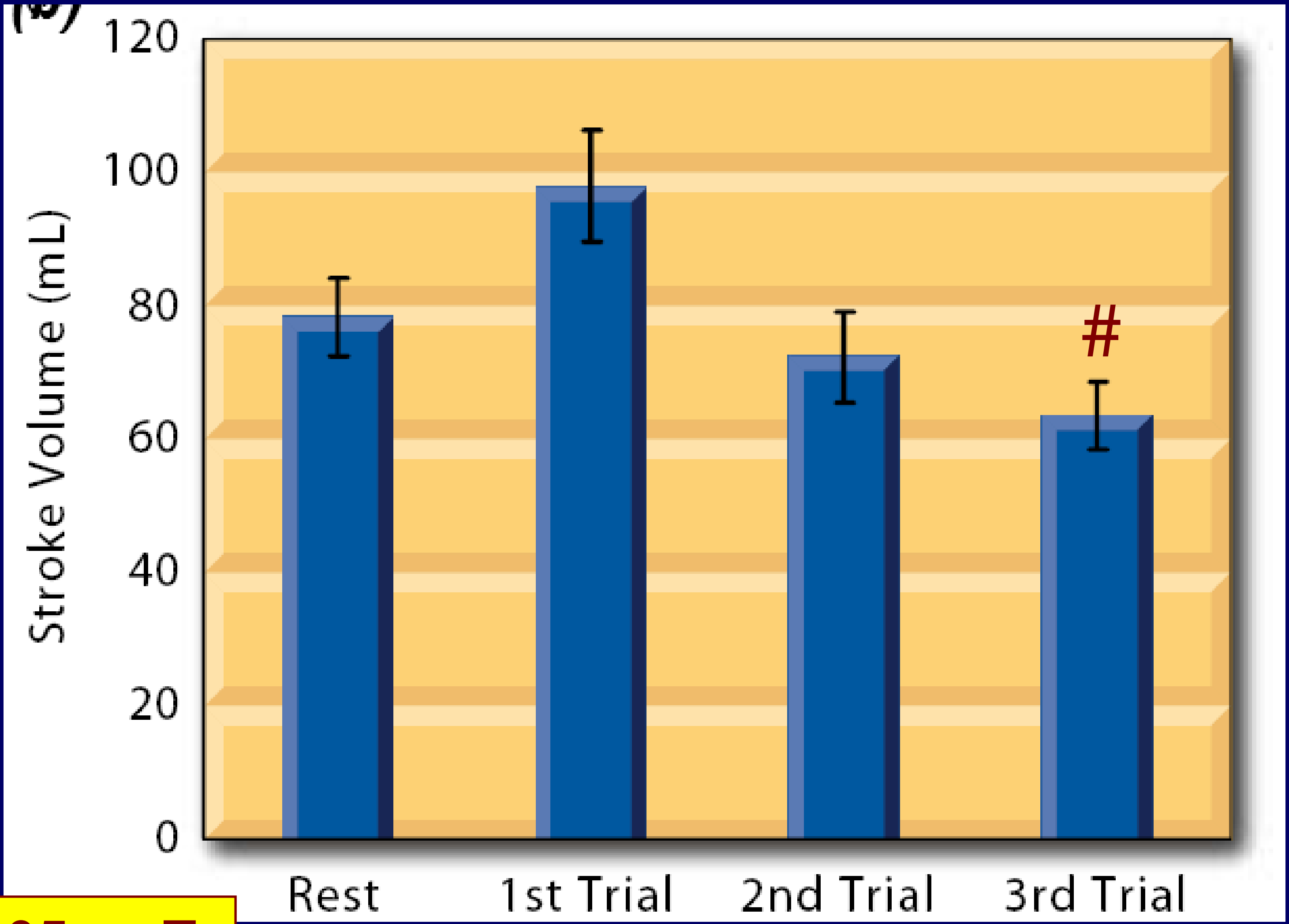


Heart Rate Response



*** p<0.05 vs rest**

Stroke Volume Response



# $p<0.05$ vs T_1

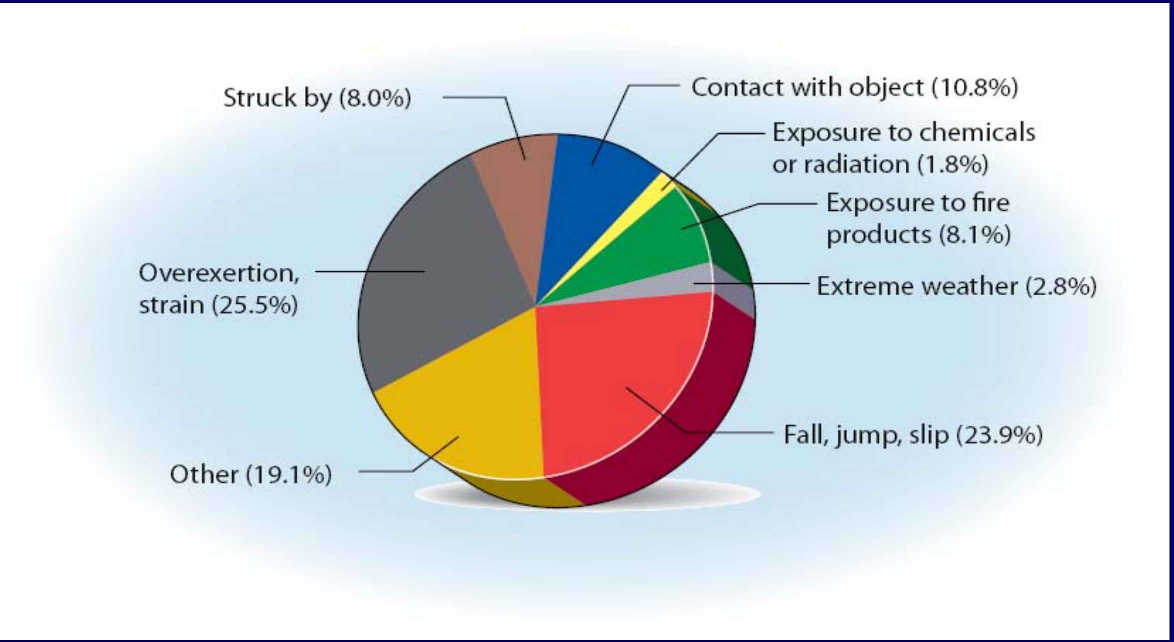
Effect of Firefighting on Coagulation Factors (N=10; Mean ± SD)

Variable	Pre	Post
Platelets ($x10^3$/uL)	236.6 (48.2)	316.2 (83.4) *
Prothrombin Time (s)	10.18 (0.6)	10.13 (0.6)
Fibrinogen (mg/dL)	254.5 (17.2)	265.6 (21.5) *

* $p<0.001$

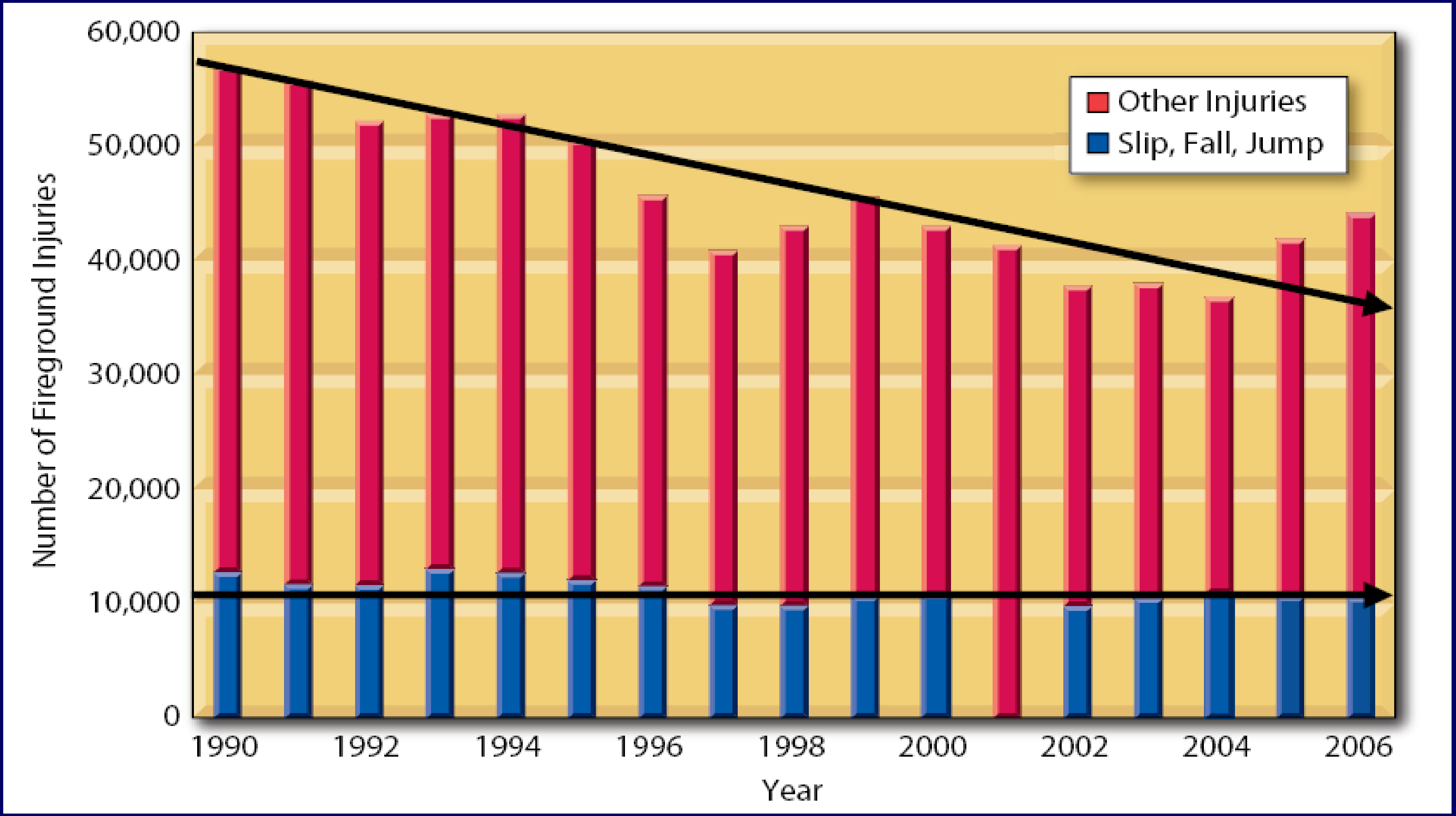
Fireground Injuries

- 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

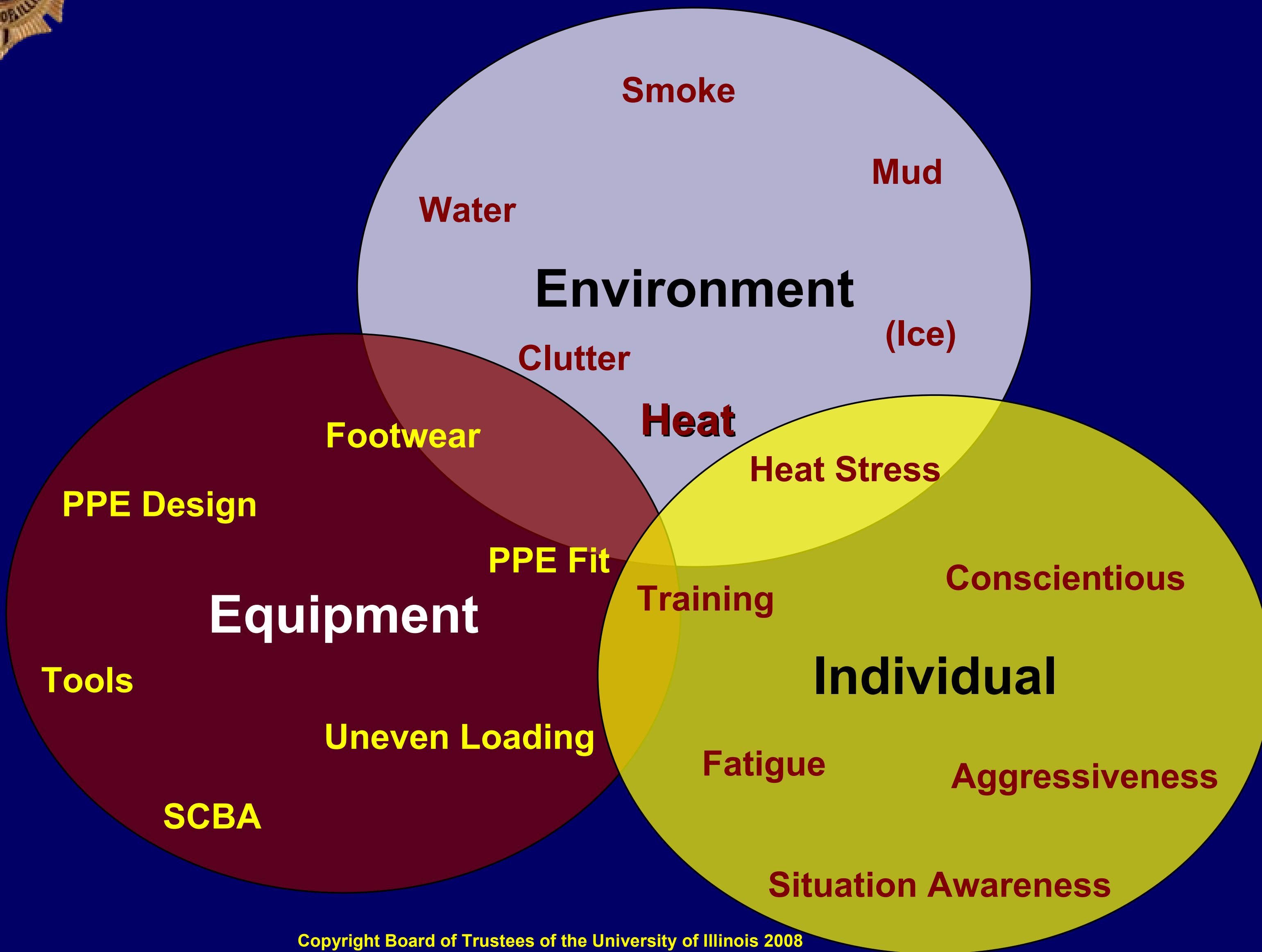
Fireground Injuries



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



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

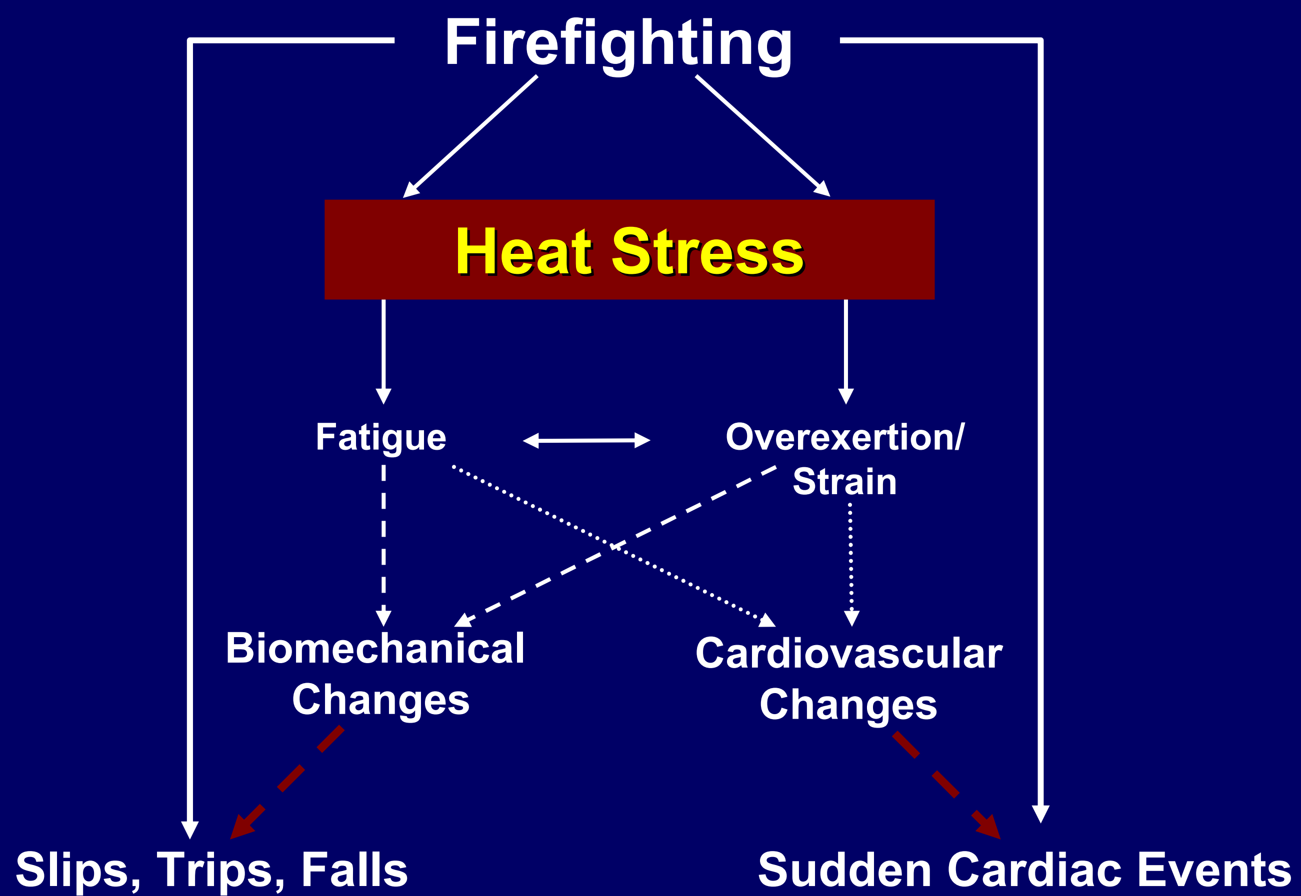
What we know about FF Biomechanics

- 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

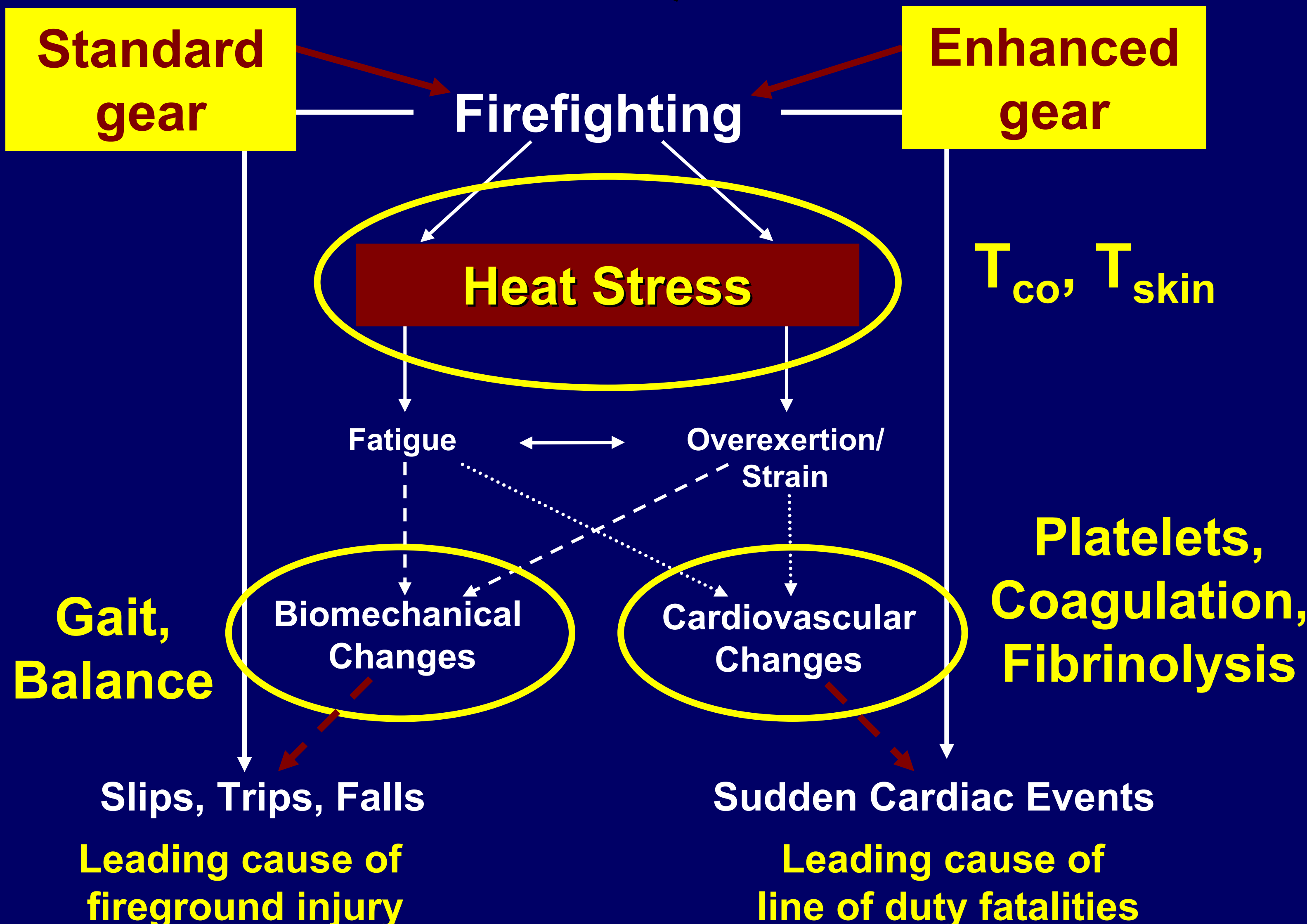
Research Question



Leading cause of fireground injury

Leading cause of line of duty fatalities

Research Question



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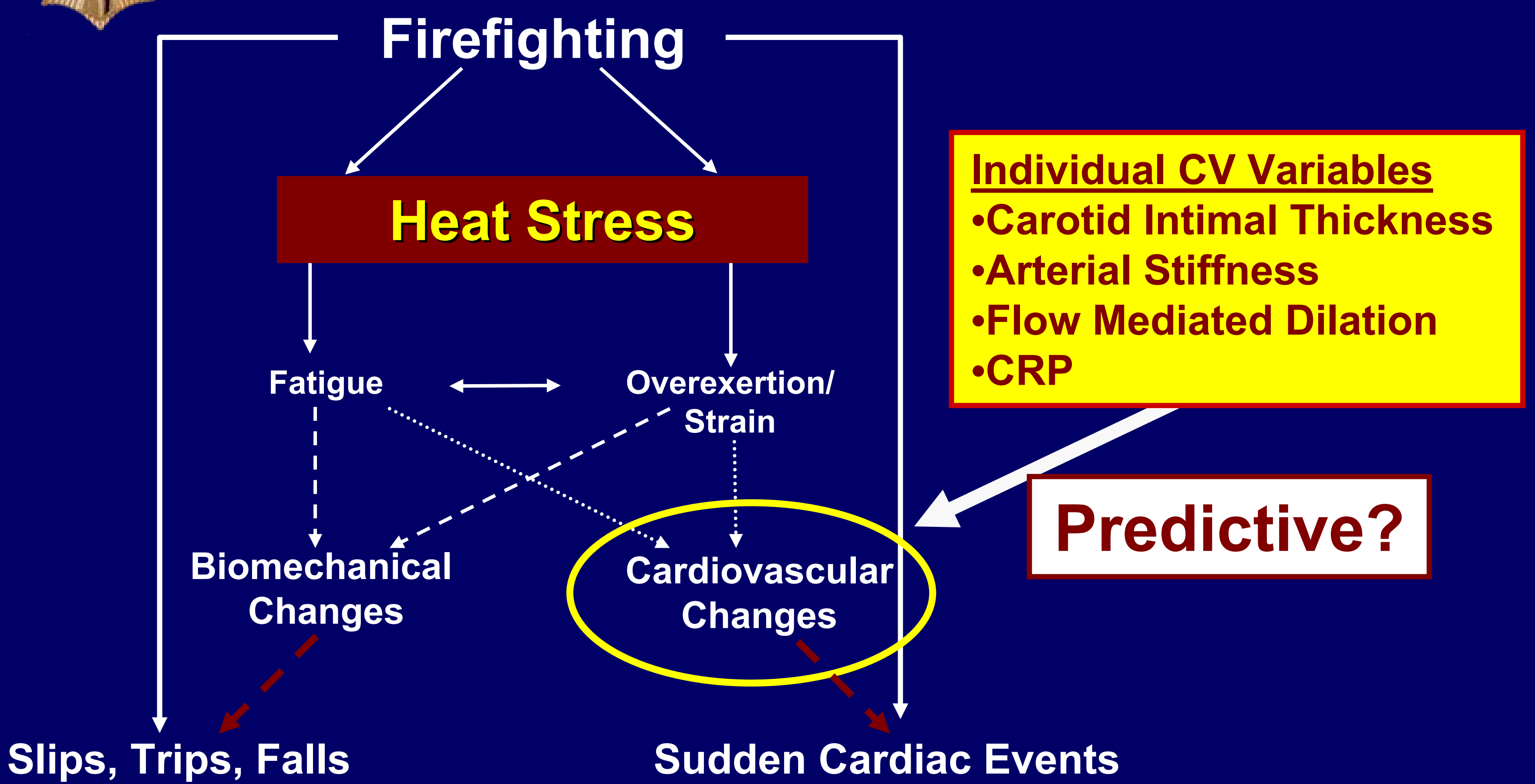
Role of Individual Health Factors



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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

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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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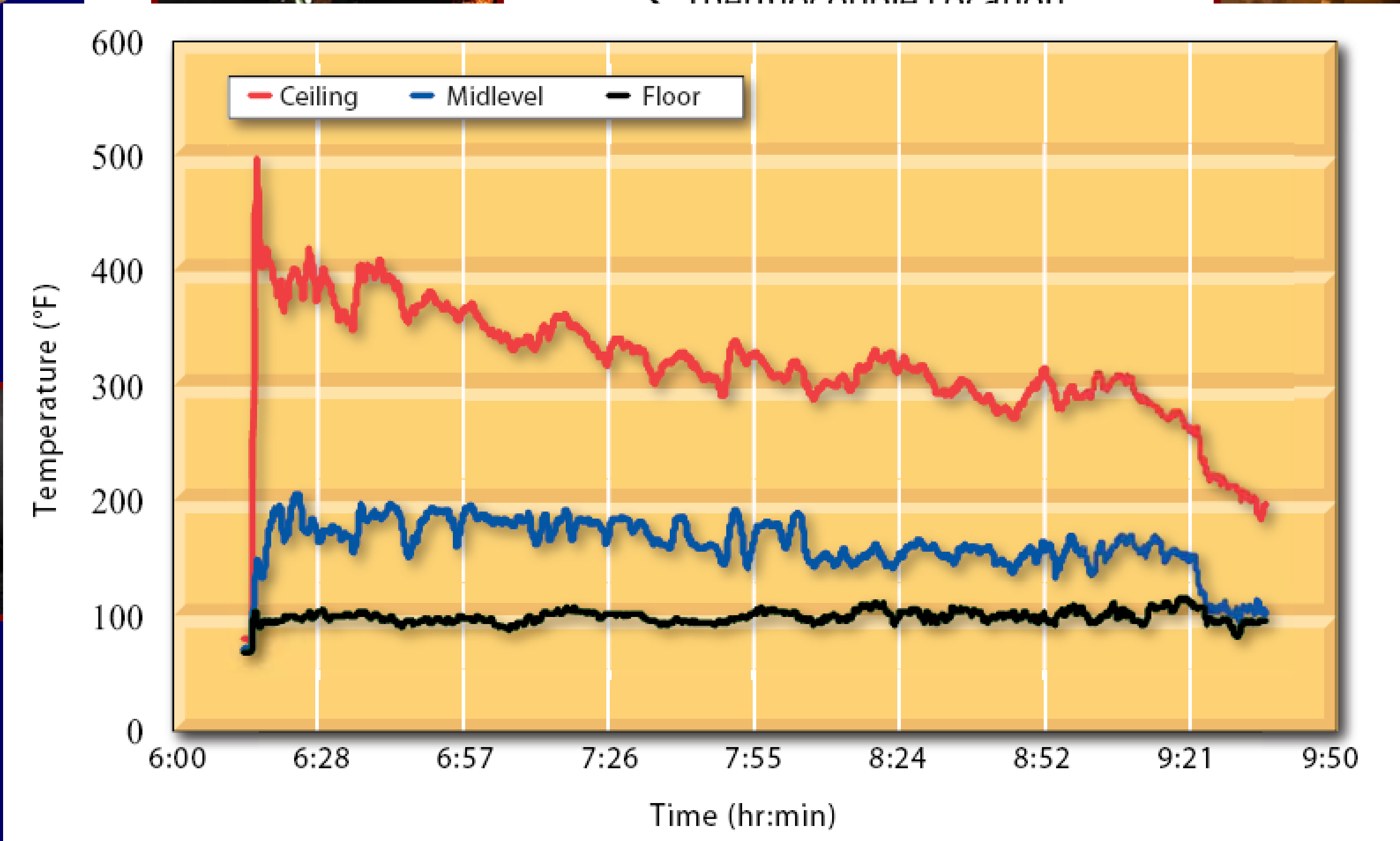
Protocol

Thermocouple Location



2 to 3

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Results

Descriptive Characteristics (n=110)

Variable	Standard (n=54)	Enhanced (n=56)
Age (yrs.)	29.5 (3.4)	29.9 (5.4)
Ht. (m)	1.8 (0.07)	1.8 (0.08)
Wt. (kg)	86.0 (15.3)	89.8 (13.9)
BMI	27.6 (3.8)	28.6 (3.5)

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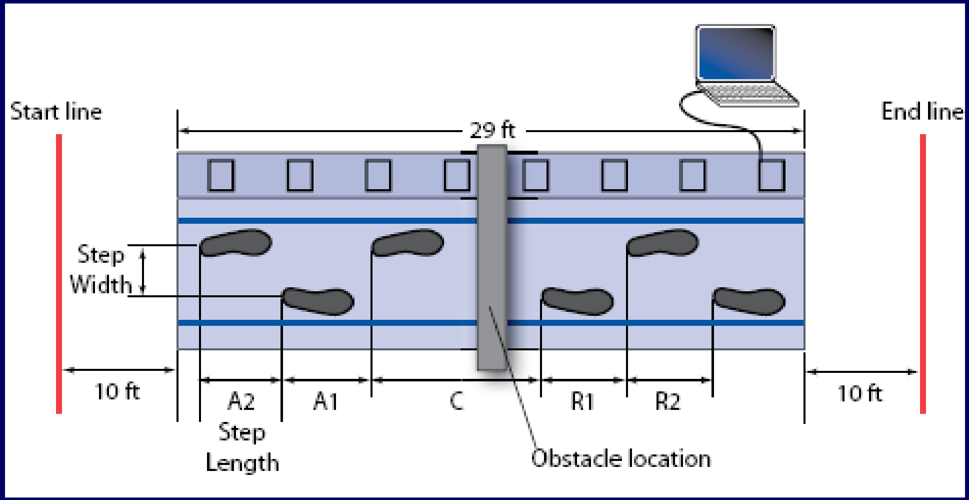
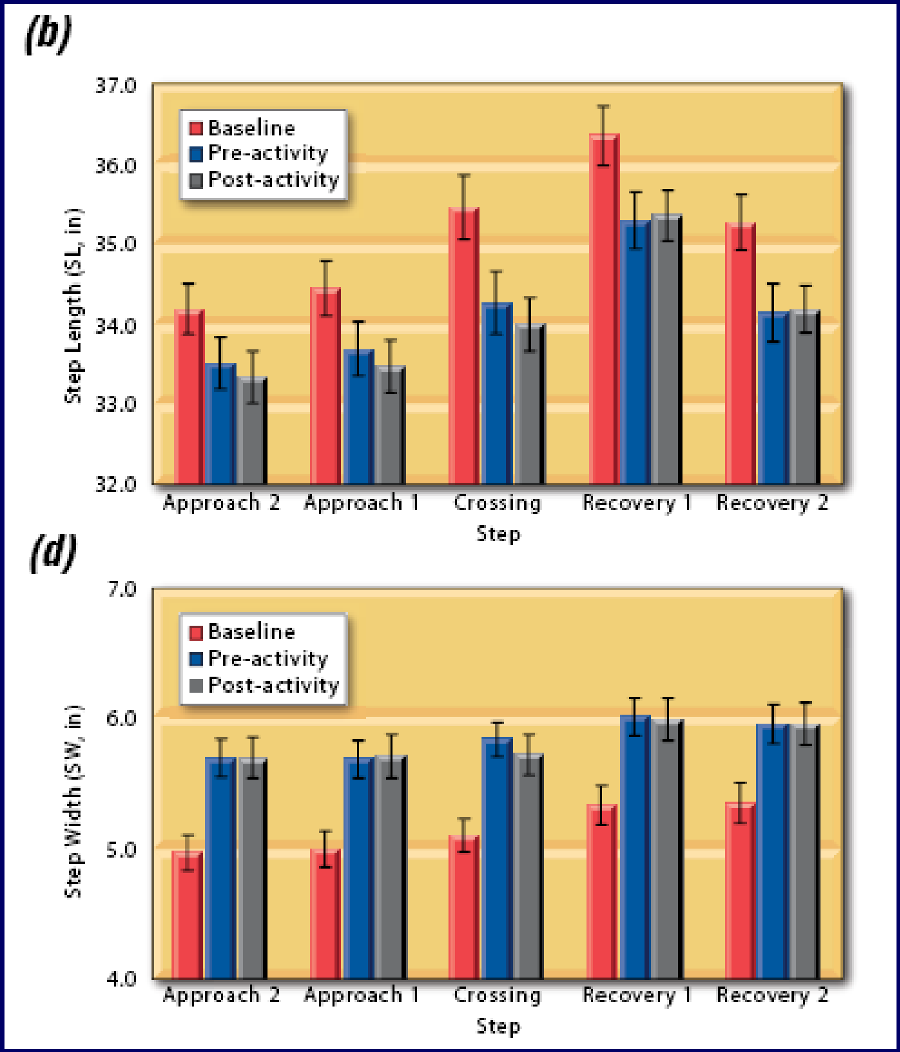
Gait Data





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Gait Data

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

* 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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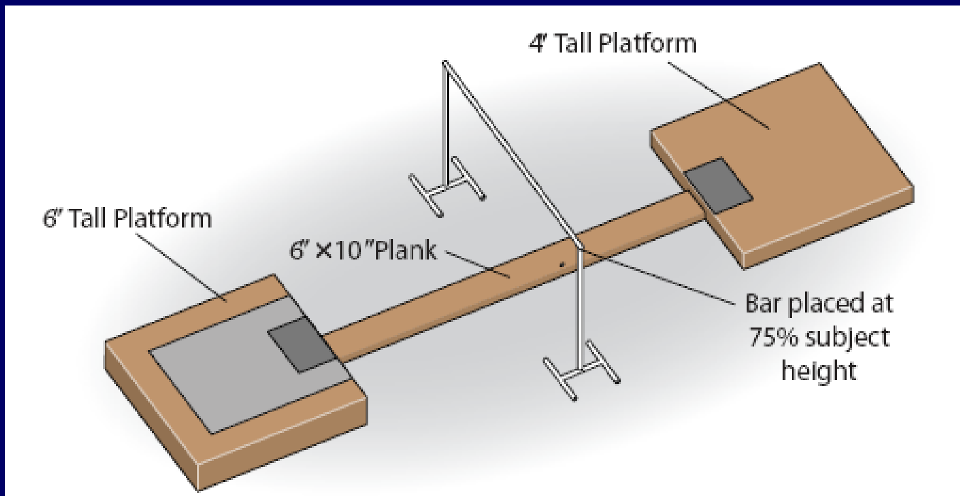
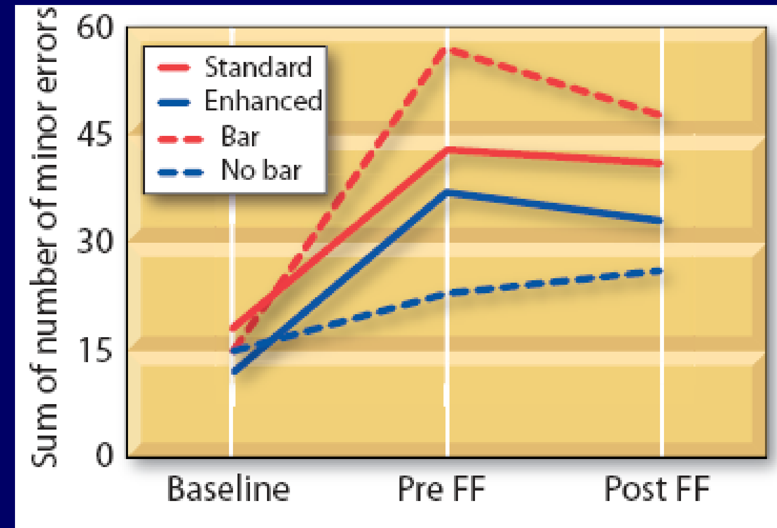
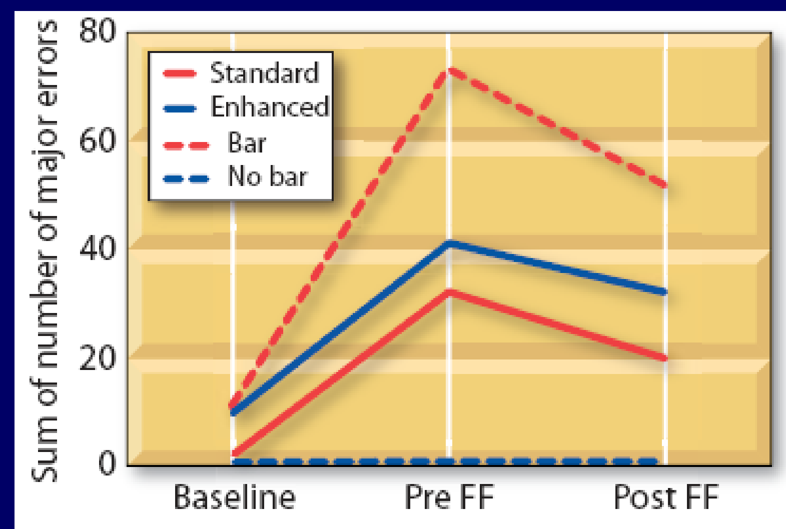
Balance Data







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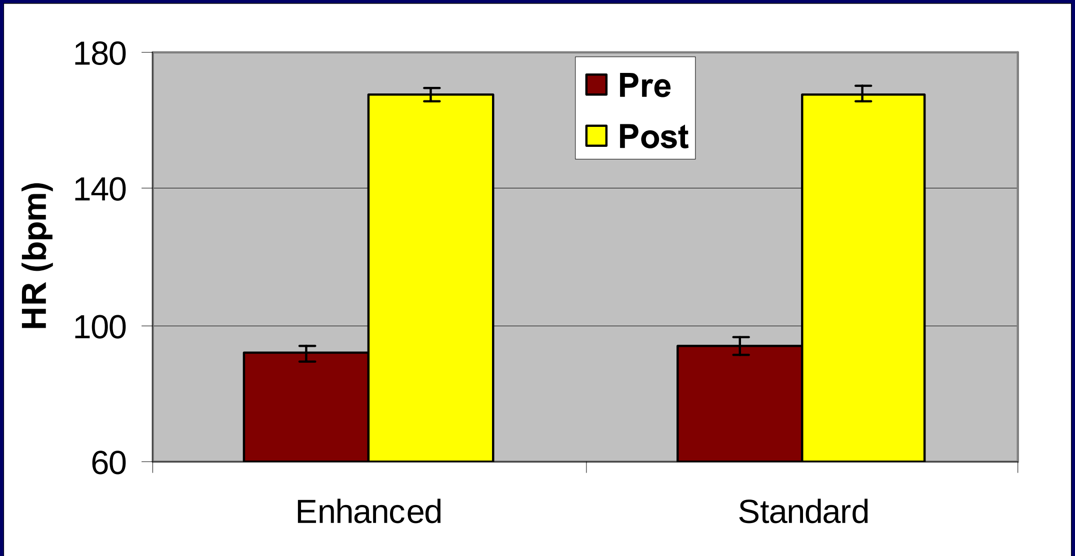
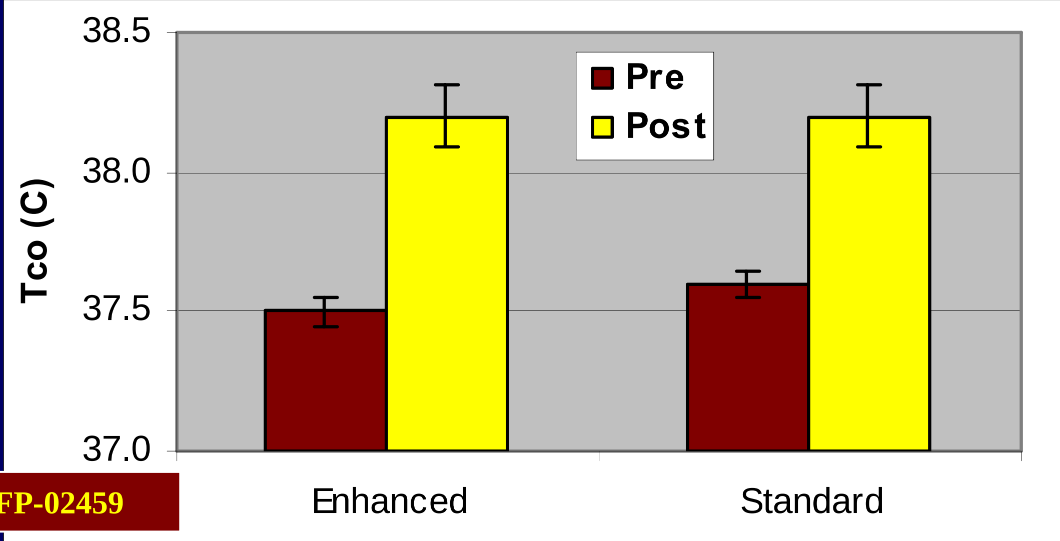
Physiological Data





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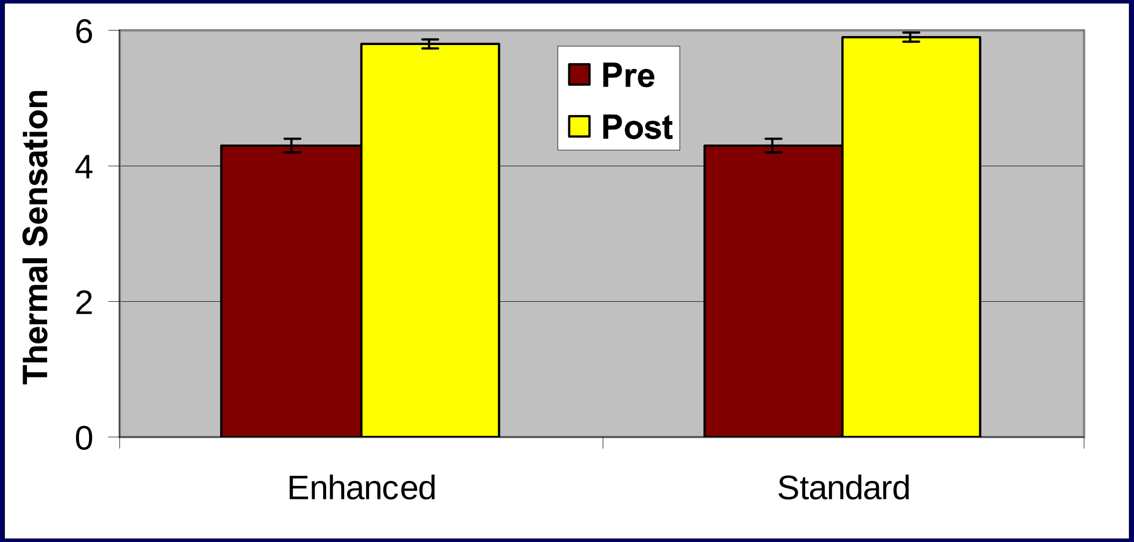
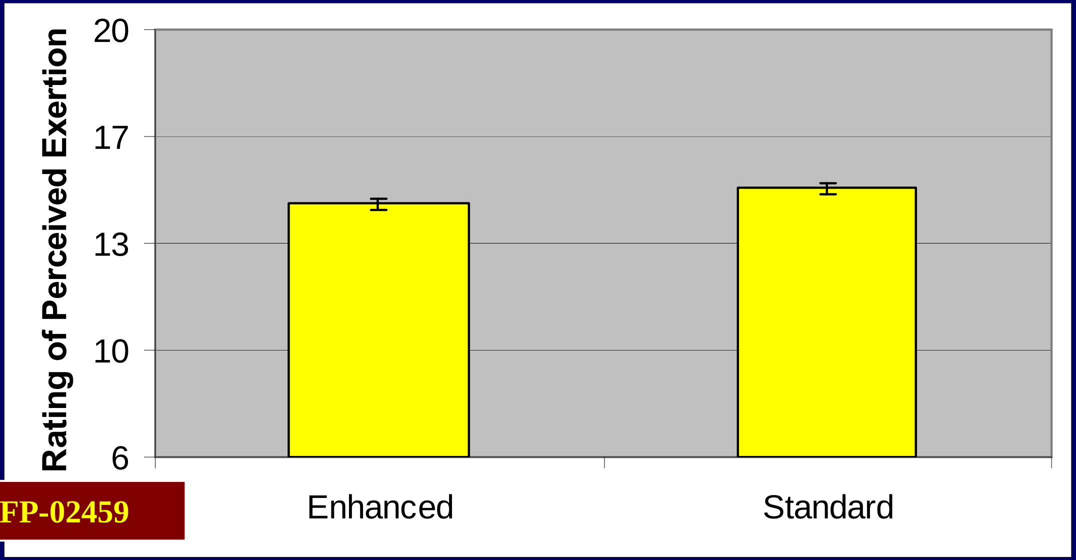
Perceptual Data





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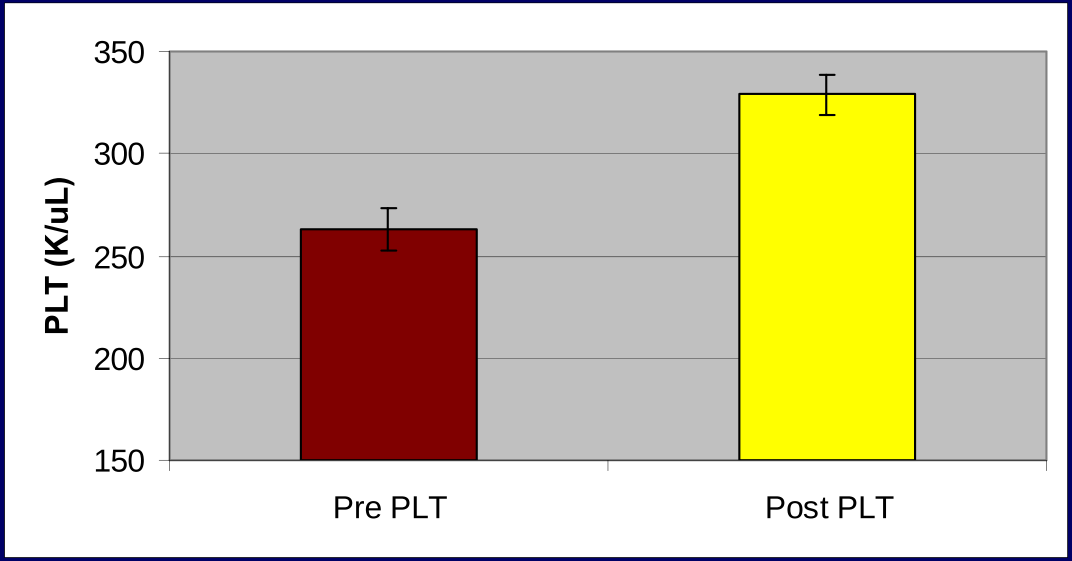
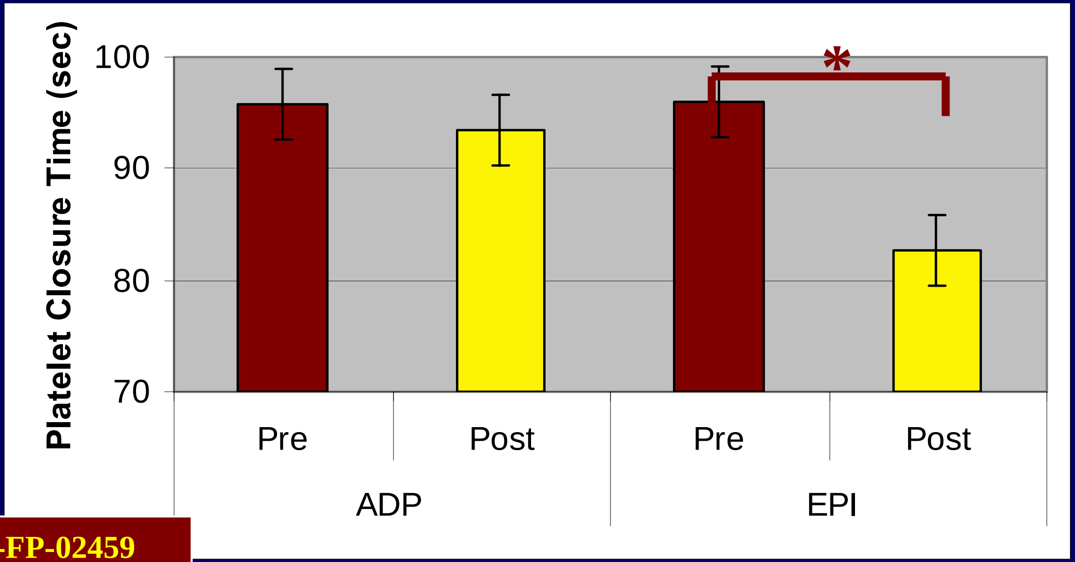
Platelet Data





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Coagulatory and Fibrinolytic Factors

	Pre FF	Post FF
Factor VIII (iu/mL)	.96 ± 0.33	1.71 ± 0.61
PF 1.2 (pmol/L)	143 ± 51	153 ± 49
tPA-agn (ng/mL)	10.0 ± 10.7	19.2 ± 13.4
PAI-1- agn (ng/mL)	31.1 ± 19.3	33.4 ± 19.2

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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

HEAT STRESS

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

Pre-Event

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

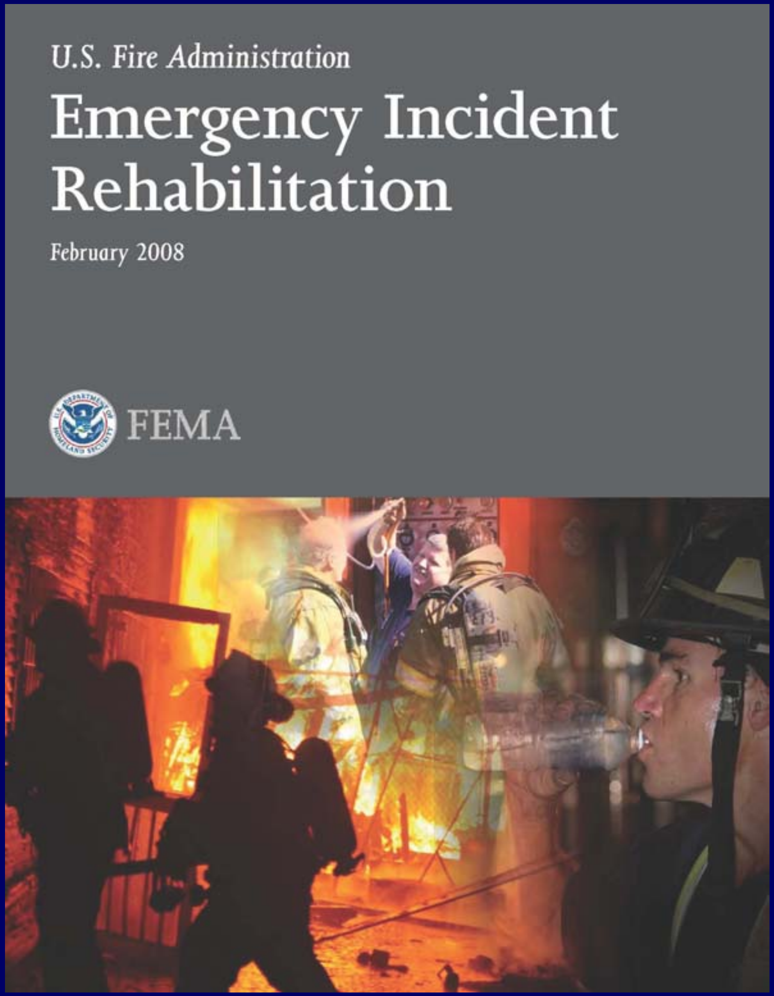
Medical Readiness

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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