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EFFECT OF FIREFIGHTING AND ON-SCENE REHABILITATION ON HEMOSTASIS

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PI: Gavin Horn, PhD
University of Illinois Fire Service Institute
11 Gerty Drive, Champaign, IL, 61820
ghorn@fsi.illinois.edu, 217.265.6563

co-Investigators: Denise Smith, PhD; George Fahey, PhD; Steve Petruzzello, PhD

University of Illinois at Urbana-Champaign
1901 S. First Street, Suite A Champaign, IL 61820

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List of terms and abbreviations

aDBP – aortic diastolic blood pressure (via arterial tonography)
aMP – aortic mean pressure (via arterial tonography)
aPP – aortic pulse pressure (via arterial tonography)
aSBP – aortic systolic blood pressure (via arterial tonography)
ACS – Acute coronary syndromes
ADP – adenosine 5'-diphosphate (as a platelet agonist)
BMI – Body mass index
CBC – Complete blood cell count
CPT - Continuous Performance Test
DBP – diastolic blood pressure (via auscultation)
EPI – Epinephrine (as a platelet agonist)
FVIII – Factor VIII
GI – Gastrointestinal
Hb – hemoglobin
Hct - hematocrit
HDL – High-density lipoprotein
HR – Heart rate
LDL – Low-density lipoprotein
MANOVA - multivariate analysis of variance
NFPA – National Fire Protection Association
OSR – On-scene rehabilitation
pDBP – peripheral diastolic blood pressure (via arterial tonography)
pMP – peripheral mean pressure (via arterial tonography)
pPP – peripheral pulse pressure (via arterial tonography)
pSBP – peripheral systolic blood pressure (via arterial tonography)
Pai-1 act - Plasminogen activator inhibitor activity
Pai-1 agn - Plasminogen activator inhibitor antigen
PF1.2 – Prothrombin fragement
PFA – Platelet function analyzer
PPE – Personal Protective Equipment
RPE – Ratings of perceived exertion
RT – Reaction time
SBP – Systolic blood pressure (via auscultation)
SEVR – Subendocardial Viability Ratio
Tco – Core temperature
TF – Tissue Factor
tPa act – Tissue plasminogen activator activity
tPa agn - Tissue plasminogen activator antigen

Abstract

Firefighting is a dangerous occupation in part because Firefighters are called upon to perform strenuous physical activity in hot, hostile environments. Each year, approximately 100 Firefighters lose their lives in the line of duty and tens of thousands are injured. Over the past 15 years, approximately 45% of line of duty deaths have been attributed to heart attacks and another 650-1,000 Firefighters suffer non-fatal heart attacks in the line of duty each year. From 1990 to 2004, the total number of fireground injuries has continued to decline, yet during this same period, the number of cases related to the leading cause of injury - overexertion/strain – has remained relatively constant.

It is well recognized that firefighting leads to increased cardiovascular and thermal strain. However the time course of recovery from firefighting is not well documented despite the fact that a large percentage of firefighting fatalities occur after firefighting activity. Furthermore, on-scene rehabilitation (OSR) has been broadly recommended to mitigate the cardiovascular and thermal strain associated with strenuous firefighting activity, yet the efficacy of rehabilitation interventions has not been documented.

Twenty-five firefighters were recruited to participate in a within-subjects, repeated measures study designed to describe the acute effects of firefighting on physiological and psychological measures and several key cardiovascular variables, including those that are directly related to cardiac events. The study also provides the first detailed documentation of the time course of recovery during the 2 ½ hours post-firefighting. Additionally, we compared two OSR strategies to determine their effectiveness.

As expected, a short term bout (18 minutes) of firefighting activity results in significant physiological, psychological, and cardiovascular disruptions. Immediately post-firefighting, core temperature, heart rate, blood pressure and blood catecholamine levels are significantly elevated from baseline conditions. Platelet function and number, coagulatory and fibrinolytic variables show significant increases from baseline, suggesting that the hemostatic equilibrium may be elevated, but both clotting and clot breakdown are elevated simultaneously. Vascular function is significantly affected as noted by the reduction in the ability to perfuse myocardial tissue (measured through the Subendocardial Viability Ratio – SEVR). Finally, firefighters' psychological state becomes more dysphoric post-firefighting.

Importantly, the time rate of recovery from many of these affects appears to be on the order of several hours instead of minutes as is often assumed. Heart rate and core temperature did not return to baseline levels for up to 60 minutes into the recovery. Blood pressure was found to drop very rapidly in many individuals during rehab suggesting that we must be aware of the risk of syncope during rehab procedures. Vascular recovery data also shows that SEVR does not return to baseline for up to 60-90 minutes into recovery. After 120 minutes of recovery, it was found that fibrinolytic markers returned to baseline levels, but coagulation (specifically Factor VIII and platelet function) remains significantly elevated, potentially unbalancing the hemostatic equilibrium in favor of clot formation. As many heart attacks on the fireground occur at this timeframe immediately following fire suppression, these results suggest a possible mechanism for the increased risk. At the 120 minute recovery period, firefighter's psychological state appears to have returned to baseline conditions.

The effect of on scene rehabilitation protocol was only measured in a few parameters. OSR had no effect on core temperature, suggesting that the active cooling process was no more affective the passive cooling in cool environmental conditions. There was also no affect on blood pressure, coagulation or fibrinolytic variables or psychological measures. The enhanced rehab protocol resulted in significantly elevated heart rate throughout recovery and a statistically significant delayed return to baseline for both heart rate and SEVR. Platelet number was also significantly elevated in the enhanced condition compared to the standard (which had returned to baseline after 120 minutes of recovery). Each group was equally hydrated from baseline levels (based on changes in plasma volume), so this effect was not due to hemoconcentration. Finally, epinephrine levels remain elevated after 120 minutes of recovery in the standard condition, but returned to baseline in the enhanced condition, potentially due to the additional ingestion of carbohydrates in the recovery drink.

SECTION 1

Highlights/significant findings

The most significant findings from this study pertain to the affect of firefighting activities on the cardiovascular system and the time rate of recovery of several important measures.

We have quantified the change in hemostatic balance following firefighting activities and shown that a disruption in hemostatic equilibrium occurs post-firefighting that remains for at least 2 ½ hours post-firefighting activity. Platelet count and function were significantly elevated as a result of firefighting activities and platelet function remains elevated even after 120 minutes of recovery. Furthermore, by assessing several hemostatic variables, we found that both coagulation (Factor VIII and Tissue Factor) and fibrinolysis (tPa activity and antigen) are elevated immediately post-firefighting, suggesting that factors on both sides of the hemostatic equilibrium are elevated. However, at 120 minutes post-firefighting, all fibrinolytic factors have returned to baseline, while Factor VIII remains significantly elevated, tipping the hemostatic balance even farther towards coagulation. These results suggest that a hypercoagulable state is maintained for at least 2 ½ hours after firefighting has ceased.

Firefighting activities result in a significant elevation of core temperature and heart rate. Importantly, the recovery from these affects occurs over a timecourse of hours, even after a short bout of firefighting in a relatively young and healthy population that recovered in a relaxed environment away from physical or psychological disruptions that are common on the fireground. These results show that the rapid 5 to 10 minute rehabilitation protocol that is often utilized is not sufficient to return firefighters to baseline conditions. Furthermore, the rate at which heart rate returned to baseline appeared to be slowed by the "enhanced" rehabilitation protocol, which may be due to the consumption of the recovery drink.

Arterial function was assessed via arterial tonography throughout rehab and recovery. Importantly, the Subendocardial Variability Ratio (SEVR) calculated from arterial tonography suggests that the heart may be facing a reduction in perfusion for up to 90 minutes into the recovery from firefighting, again suggesting that the time rate of recovery from even a short bout of firefighting is on the order of hours, not minutes. The depressed SEVR measurements imply that firefighters will have a reduced tolerance for subsequent suppression activities for up to 2 hours after the initial firefighting activity has ended. The rate at which SEVR returned to baseline again appeared to be slowed by the "enhanced" rehabilitation protocol.

Systolic blood pressures displayed a significant and rapid decline shortly after firefighting activities and into the rehab period. Blood pressure returns rapidly to stable baseline levels in recovery. While firefighters are often concerned about elevated blood pressures, this study suggests that firefighters should be aware of the potential dangers of hypotension as well.

These results were generated from a population of young, healthy firefighters who were immediately removed from the firefighting activities into a relatively controlled, relaxed environment for 15 minutes of rehab and 120 minutes of recovery. This scenario represents a likely best case. Often firefighters will return to work after consuming 1 cylinder of air. Then, once the firefighting operation has ended, they will be involved in overhaul and clean up operations, which may further exacerbate the perturbations measured and the time rate of recovery.

Translation of findings

These findings suggest that the time frame for recovery from even a short bout of firefighting activity is on the order of hours, not minutes and that the nutritional intake during rehab can affect the rate at which a firefighter recovers. While the full time scale for recovery was not investigated in this study, we did find that firefighters may be at increased risk for cardiovascular events due to disruptions in hemostatic balance for at least 2 hours after recovery. This issue can be partially addressed by

maintaining fire suppression crews under close observation for at least 3 hours after completion of a fire suppression task, such that assistance may be immediately rendered during the time when firefighters appear to be most at risk for a cardiovascular event. Additionally firefighters who are involved in a strenuous fire attack are at increased risk for injury due to the reduced energy reserves and thus should not be asked to return to strenuous duty such as overhaul or clean up immediately after rehab. Further investigations are suggested to determine methods to counteract the hemostatic imbalance and performance deficit through either a nutritional or drug based intervention.

This study did show that the rehabilitation protocol can have an effect on an individual's ability to recover from firefighting activities. While the cooling intervention did not appear to affect core temperature, the nutritional intervention may have had a negative effect on the ability to recover vascular function (heart rate and myocardial perfusion) and return to normal platelet count during recovery. There are several anecdotes in the Fire Service on how to properly recover after a fire, but few that have been scientifically proven to be effective. In this study, it was hypothesized that providing firefighters with a drink purported to assist athlete's recovery from a workout, would assist firefighters in recovering from a short bout of firefighting activity. Instead, we found a delayed return to baseline for several important measures affecting physical performance and coagulatory function. In order to follow up this R03 study, a more detailed nutritional analysis will be necessary to isolate the specific components that elicited these responses and to determine if alternate components can potentially hasten recovery.

Outcomes/relevance/impact

The pilot nature of this study resulted in important potential outcomes that we have been and will continue to be presented to the Fire Service to influence intermediate and end outcomes through various channels.

Considering the time course of recovery from a short term bout of firefighting activity, the Fire Service should consider reviewing policies and standards regarding rehabilitation practices, post-firefighting recovery protocols, and staffing after a crew has conducted fire suppression or search and rescue activities. The elevated risk due to the increased clotting potential must be addressed for at least several hours after fire suppression activities have completed. The Fire Service should change policy such that EMS is immediately available for potential Fire Service cardiovascular events even if public life safety concerns have been eradicated. After fire suppression, crews should be moved to light duty and placed under visual supervision for at least three hours, but the ultimate timeline must be studied in more detail.

It is also important that the nutritional interventions recommended to the Fire Service be studied in much greater detail. There is currently significant misinformation regarding the appropriate nutritional intervention during rehab and recovery that may put firefighters at increased risk as opposed to assisting them in recovery.

SECTION 2

Scientific Report

A. Background

A.1. Motivation

Firefighters encounter unique occupational risks. Hostile and dangerous conditions at the scene of a structural fire can include fire, heat, smoke, decreased visibility, high noise levels, chaos, and a constantly changing environment. Firefighting is a dangerous occupation, in part because Firefighters are called upon to perform strenuous physical activity in hot, hostile environments, yet little is known about the most effective methods to cool, rehydrate and reverse imbalances caused by working in such stressful environments. Each year, approximately 100 Firefighters lose their lives in the line of duty and tens of thousands are injured. Over the past 10 years, approximately 40-50% of line of duty deaths have been attributed to heart attacks as shown in Figure 1 [1-16]. Another 650-1,000 Firefighters suffer non-fatal heart attacks in the line of duty each year [17-31]. In addition to the risk of a myocardial infarction, Firefighter injuries continue to plague the Fire Service. In 2004, nearly 76,000 Firefighters were injured, with 48% occurring on the fireground [17]. An analysis from 1990 to 2004 reveals that the total number of fireground injuries has continued to decline from 57,100 to 36,880, yet during this same period the number of cases related to the leading cause of injury - overexertion/strain – has remained relatively constant [17-31].

It is well recognized that firefighting leads to increased cardiovascular and thermal strain [32,33]. However the time course of recovery from firefighting is not well documented despite the fact that a large percentage of firefighting fatalities occur after firefighting activity [34]. Furthermore, on scene rehabilitation (OSR) has been broadly recommended to mitigate the cardiovascular and thermal strain associated with performing strenuous firefighting activity, yet the efficacy of different rehabilitation interventions has not been documented.

The purpose of this study was to describe the acute effects of firefighting on a broad array of cardiovascular variables, including those that are directly related to cardiac events, namely, hemostatic variables and vascular function, as well as psychological/perceptual variables, and cognitive variables, and to document the time course of recovery of each. Additionally, we also compared two OSR strategies (standard and enhanced) to determine their effectiveness.

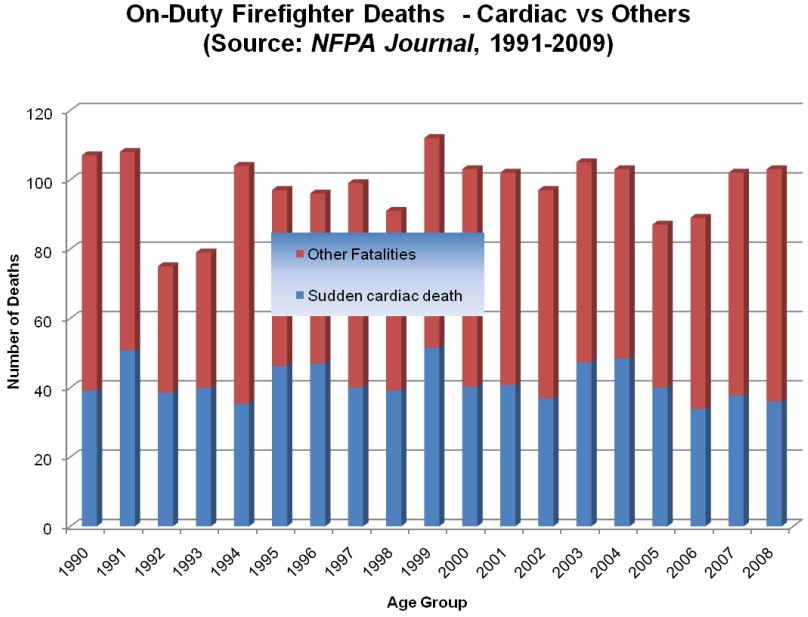

Figure 1. Firefighter fireground fatality trends from 1990-2009 [1-16].

A.2. Literature review – Cardiovascular strain and hemostasis

Acute coronary syndromes (ACS) are life-threatening conditions that range from unstable patterns of angina to acute myocardial infarctions. The majority of ACS result from the disruption of atherosclerotic plaque followed by platelet aggregation and the formation of an intracoronary thrombus [35]. The pathogenesis of an acute coronary event is the transition from chronic atherosclerosis to acute thrombus formation [36]. **Firefighting activities involve strenuous muscular work in a hostile environment and lead to activation of the sympathetic nervous system resulting in hemodynamic changes that increase shear stress. Thus, firefighting is likely to dramatically alter the endothelium, platelets, and the hemostatic system.**

Platelet activation and aggregation are the first step in blood clot formation. Recent evidence suggests that abnormal platelet function also plays a pivotal role in unstable angina, acute myocardial infarction, and sudden cardiac death [37,38]. **Aerobic exercise causes an increase in platelet number [39] and there is strong evidence that intense exercise leads to increased platelet aggregation and function [37,38].**

Maintaining hemostatic balance is necessary in order to prevent dangerous thrombus formation and is determined by complex interactions between circulating proteins, coagulatory and anticoagulatory factors, platelets and endothelial cells lining blood vessels. Research indicates that exercise leads to enhanced coagulatory potential (e.g. increased factor VIII activity) that is dependent upon intensity and duration of activity [40,41]. Fibrinolytic activity is also enhanced following exercise [40]. Importantly, however, research suggests that these coagulatory and fibrinolytic activities do not recover at the same rate following aerobic exercise [40,41]. Hedge et al have reported that both coagulatory and fibrinolytic activity are enhanced following strenuous exercise, but coagulatory potential remains elevated one hour post activity whereas fibrinolytic activity returns to baseline during the same period [42]. Lin et al have reported that elevated coagulatory potential (increased Factor VIII) persisted at 2 and 6 hours of recovery whereas fibrinolytic activity fell sharply [40]. The discrepancy in coagulatory and fibrinolytic potential during recovery from strenuous activity may account for an increased vulnerability to myocardial infarction in the hour following strenuous activity [40,43].

There has been a paucity of research investigating the effects of firefighting on the hemostatic system despite the critical importance of the hemostatic system in acute coronary syndromes, the knowledge that myocardial infarctions are the leading cause of line of duty deaths among Firefighters, and research evidence of hemostatic disruption following strenuous physical activity. Therefore the purpose of this study was to examine the effects of strenuous firefighting activities and recovery from firefighting on key hemostatic variables. A second aim of this study was to investigate the effectiveness of different on-scene rehabilitation interventions following structural firefighting tasks. This study provides important scientific information regarding the effect of firefighting on the hemostatic system and practical information for determining effective rehabilitation strategies for Firefighters in an attempt to lessen the impact of dangerous heat stress conditions, mitigate cardiovascular strain, and improve Firefighter performance.

B. Specific Aims

The purpose of this study was to describe the acute effects of firefighting on a broad array of cardiovascular variables, including those that are directly related to cardiac events - namely, hemostatic variables and vascular function - and to document the time course of recovery. Additionally, we compared two on-scene rehabilitation (OSR) strategies (standard and enhanced) to determine their effectiveness.

Specifically, we measured changes in hemostatic variables following strenuous firefighting activity and documented the extent to which these variables return to baseline following 120 minutes of recovery. In the same study, we investigated changes over 120 minutes of recovery to a control OSR intervention (hydration only – typical Fire Service practice) and an enhanced OSR intervention (aggressive rehydration, electrolyte replacement, and cooling).

Firefighters performed strenuous live-fire drills in a training structure and received on-scene rehabilitation prior to performing a test of anaerobic power in order to allow us to address the following ***specific aims*** of the proposed research:

- Investigate the effects of strenuous firefighting and 120 minutes of recovery from firefighting on hemostasis (platelet function, coagulatory and fibrinolytic potential). It was hypothesized that:
    - Strenuous firefighting leads to increased coagulatory potential – increased platelet number, decreased time for occlusion on a platelet function test, increased Factor VIII (FVIII) and Tissue Factor (TF)- and coagulatory potential remains elevated 120 minutes post-firefighting.
    - Strenuous firefighting leads to increased fibrinolytic activity -increased levels of tissue plasminogen activator (tPA), decreased plasminogen activator inhibitor (PAI-1)- and fibrinolytic potential returns to baseline at 120 minutes post-firefighting.
    - Strenuous firefighting leads to a decrease in systolic blood pressure, whether measured by auscultation or tonography that remains decreased for 120 minutes of recovery.
- Investigate the effects of different OSR protocols on subsequent anaerobic performance and hemostatic variables following 120 minutes of recovery. It was further hypothesized that:
    - Aggressive rehydration, electrolyte and nutritional replacement, and cooling (enhanced OSR condition) results in improved maximal anaerobic performance (increased peak power and decreased fatigue index) on a subsequent power test versus minimal hydration (control OSR condition).
    - Enhanced OSR hasten physiological recovery (faster return to baseline for core temperature, full return to baseline of coagulatory potential) versus the control OSR intervention.
    - Enhanced OSR lead to improved perceptual and cognitive function measures versus the control OSR intervention.
- Bring research to practice, by distributing the results of this research to the Fire Service so that occupation-specific scientific data can be used to inform the development of Firefighter OSR protocols.

At the outset of this study, we added to the depth of the specific aims in bullets #1 and #2 by adding a measure of vascular function to the planned analysis of hemostasis. These additional measures allowed us to describe the cardiovascular system in more detail than is possible through hemostatic variables alone.

C. Procedures

C.1. Study design

Twenty-five firefighters were recruited to participate in a within-subjects, repeated measures study designed to investigate the effects of strenuous firefighting activity on hemostasis and the effectiveness of on-scene rehabilitation interventions on subsequent physical performance and physiological recovery. The two trials were separated by a minimum of 48 hours and administered in a counterbalanced fashion to ensure half of the participants receive the control condition first and half the participants receive the enhanced condition first. Of the 25 recruited subjects, 21 completed both trials of the study. A schematic description of the timeline for each trial is shown in Figure 2. Each of the measures outlined in Section D were obtained at baseline prior to engaging in firefighting drills. The

subject then performed the prescribed firefighting drills in full personal protective equipment (PPE). Immediately upon completion of the firefighting evolution, a second blood sample was obtained. Participants then rehabilitated for 15 minutes (control or enhanced condition) followed by a second data collection period for perceptual and cognitive function measures. Firefighters performed a dummy drag protocol as a measure of maximal anaerobic power. Following rehabilitation, participants changed into dry clothes and walked to an adjacent building (fire station) where they would remain during the recovery period.

Participants then recovered for 120 minutes in their station uniform. During recovery firefighters were in the seated position and engaged in classroom activities or reading, to mimic what may occur at a fire station following a fire call (assuming the suppression crew was relieved of overhaul and clean-up duties). At the end of the 120 minute recovery period a third blood sample was obtained and a third set of perceptual data collected. Throughout the scenario, core temperature, and heart rate were continuously monitored. Blood pressure was assessed via auscultation immediately post-firefighting, every five minutes during rehab, and every 15-30 minutes during recovery. Additionally, vascular function was assessed via peripheral and aortic blood pressures and Subendocaridal Viability Ration (SEVR) with an Atcor Sphygmocor system pre- and post-firefighting as well as post rehab and throughout recovery. All blood samples were subsequently analyzed for key hemostatic variables including: platelet number and function, coagulatory, anticoagulatory, profibrinolytic, and antifibrinoltyic variables, and for blood catecholamine (epinephrine, norepinephrine) and cortisol levels.

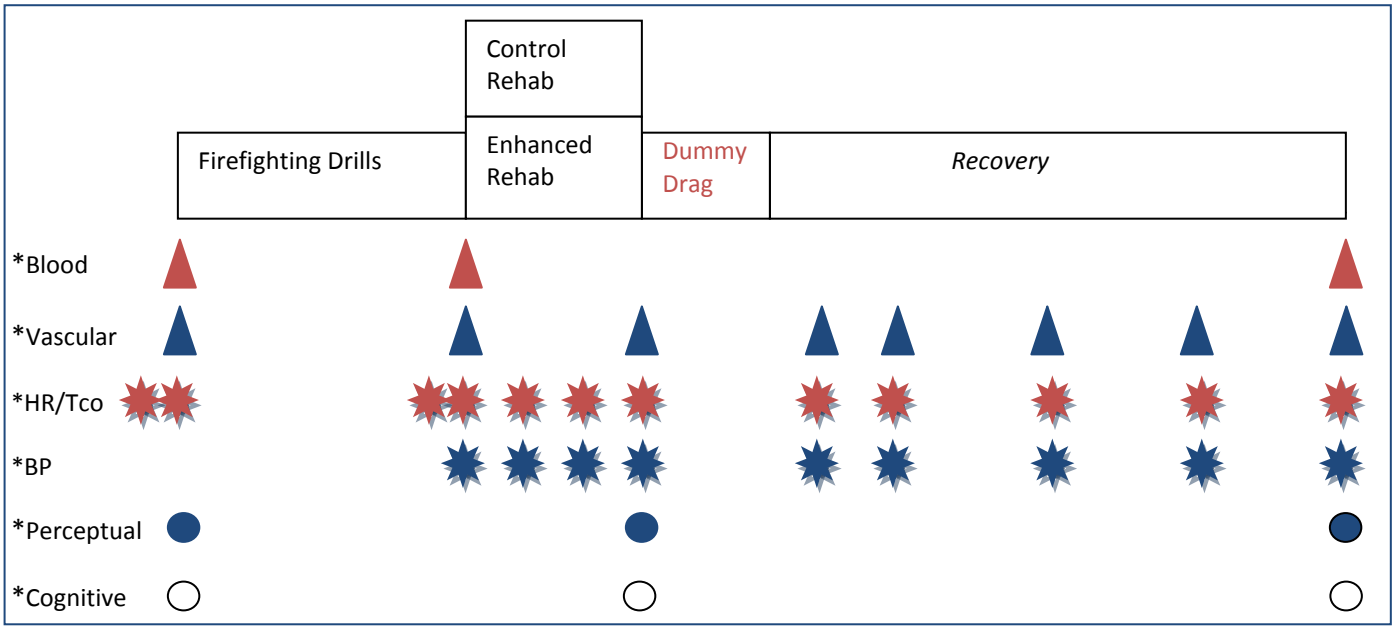

Figure 2. Schematic of study design and timeline. Note that time is not drawn to scale.

Only the OSR protocol differed between the two trials. During the "control" trial participants removed their helmet, hood, and gloves, and bunker coat. Participants were provided with only water and the amount of water ingested was recorded. The control condition was meant to reflect what is typically done at a fire scene - although we recognize there is great. During the "enhanced" trial participants were required to remove all of their turn-out gear (including bunker coat and pants), consume up to 500 ml of water and at least 355 ml of a commercially available sport drink, and were aggressively cooled using cold towels, as is recommended by leading authorities on OSR [44-46]. In addition, during recovery, firefighters conducting the "enhanced" trial were provided with a 355 ml of a

commercially available recovery drink. Assessing maximal anaerobic power via a dummy drag protocol provided a useful measure of the ability of a Firefighter to perform maximal physical work following OSR. In fact, one of the goals of OSR is to ensure that Firefighters have recovered physiologically so that they can perform maximally if called upon to do so.

C.2. Firefighting drills

The firefighting drills were completed in 18 minutes (requiring approximately 1 bottle of air for most subjects) and consisted of nine 2-minute periods of alternating work and rest. The work cycles included stair climbing, simulated forcible entry, a simulated search, and simulated hose advance. These drills have been employed in previous studies and have been published in peer-reviewed articles [e.g. 32,33] and Fire Service journals [e.g. 47-52].

Each participant was paired up with a member of the research staff, trained in firefighting, and wearing full PPE to safely escort them throughout the protocol. Initially, the participant climbed a single flight of stairs to the second floor of the tower, walked to a corner of the room and knelt down for a 2-minute acclimatization period. After acclimatization, the participant proceeded to walk up and down three stairs for 2 minutes. The lower three stairs were used to maintain a consistent thermal loading on the firefighter. These stairs were 7.5 inches high, 11 inches deep, and 30 inches wide. During each test, the escort monitored the participant's heart rate and work completed in each cycle and radioed this information for each station to the investigator downstairs. At the conclusion of each station, the participant rested for 2 minutes as the safety escort demonstrated the next task. Next, the participant straddled a force machine (Keiser Force Machine), and used a 9-pound sledgehammer to drive a sled 5 feet down and back on a metal track for 2 minutes. After another 2-minute rest period, the participant performed a secondary (slow and thorough) search from side to side along the back 14.5-foot wall for 2 minutes. This was again followed by a 2-minute rest period. In the final 2-minute station, the participant repetitively completed a motion similar to advancing a charged hoseline on a 3.8-foot hose segment (1.5 inch diameter) attached to a cable that ran over a pulley and was suspended vertically outside the building with a 10-pound weight on the end. Upon completion of the final test, participants knelt quietly for 2 minutes and then proceeded downstairs.

In order to maintain room temperatures, three thermocouples were installed in the building near the search station: located 6 inches above the floor, 4 feet above the floor and 8 feet above the floor (~1 foot below the ceiling). Type K (chromel-alumel) thermocouples with factory welded beads were utilized in conjunction with a digital data acquisition system (Omega Engineering, OM-DAQPRO-4300). Data were sampled from each thermocouple every 10 seconds and were continuously monitored to maintain the room conditions as consistent as possible

Firesets were lit anywhere from 30 minutes to one hour prior to subjects beginning their live fire testing. By preheating the building, relatively stable conditions could be maintained during testing. Throughout the burn, trained stokers controlled the temperature monitored by the thermocouples by adding small fuel packages to the firesets sequentially and controlling the ventilation conditions in the room. The temperatures at the mid-level point were maintained at roughly 160-180ºF and the floor temperatures were maintained at 95-105^{o}F. The prescribed firefighting activities required subjects to work almost exclusively in the vertical location between the middle and floor thermocouple.

D. Methodology

D.1. Descriptive variables

Descriptive variables were assessed prior to participation in the firefighting drills. After participants had read and signed an informed consent document they were asked to complete a 1) background questionnaire, 2) a cardiovascular health inventory, and 3) a profile of several individual difference measures (e.g. trait anxiety (apprehension), neuroticism (extraversion, conscientiousness)). The

following physiological variables were measured and/or determined: height, weight, body mass index (BMI), body composition/percent body fat (via skinfolds), and fasting glucose and cholesterol (from a finger stick sample via a Cholestek analyzer).

D.2. Body temperature

Body temperature was continuously measured throughout both protocols using a Minimitter VitalSense monitor and a silicone-coated gastrointestinal (GI) core temperature capsules. Relatively little research has measured core body temperature of Firefighters using GI capsules, which is the best technology for non-laboratory settings. Elevated body temperature places significant strain on the cardiovascular system, but the effect of hyperthermia on hemostasis is not well understood. Additionally, hyperthermia leads to early onset of fatigue and may negatively impact maximal force production. Participants swallowed a small disposable core temperature sensor capsule (the size of a multivitamin), which passes through the body and is eliminated in the feces within ~24 hours. While the sensor was in the GI tract it transmitted temperature information to the remote recording device.

D.3. Hemostasis and cardiovascular alterations

Hemostasis and cardiovascular alterations were assessed by measuring: 1) platelet number (CBC) and function (time to occlusion), 2) coagulatory potential (Tissue Factor, Factor VIII), 3) fibrinolytic potential (tPA) and 4) antifibrinolytic potential (PAI-1). Heart rate was continuously measured throughout activities using Polar Heart Rate Watches. Blood samples were drawn from the antecubital vein via venipuncture by a trained phlebotomist. **The literature outlined in Section A.1 lead us to hypothesize that there may be a period of increased vulnerability for an acute cardiac event following firefighting (because of increased coagulatory potential and the return of fibrinolytic activity to baseline).** Therefore, we assessed changes in clotting factors and fibrinolysis after 2 hour of recovery.

D.4. Plasma cortisol and catecholamines

Plasma epinephrine and norepinephrine were assessed via HPLC and used as an index of sympathetic activity. Plasma cortisol was measured using commercially available (Diagnostic Products Corporation, Los Angeles, CA) radioimmunoassay.

D.5. Arterial pulse waves/blood pressure

Radial artery pressure waveforms were attained in the seated position from a 10-second epoch using applanation tonometry and a high-fidelity strain gauge transducer (Millar Instruments, Houston, Texas). Central aortic pressure waveforms were constructed from the radial artery pressure waveforms (SphygmoCor, AtCor Medical, Sydney, Australia). An augmentation index (AIx) was calculated as the ratio of amplitude of the pressure wave above its systolic shoulder to the total pulse pressure and expressed as a percentage, and used as an index of systemic arterial stiffness.

D.6. Myocardial oxygen supply and demand

Subendocardial Viability Ratio (SEVR) was calculated from the central aortic waveform as the ratio of the area under the diastolic pressure-time portion of the waveform to the systolic pressure-time waveform integral. SEVR is related to heart rate, ejection duration and arterial load [53,54], and provides an estimate of the arterial system's ability to perfuse myocardial tissue in order to meet the heart's energy requirements. If SEVR decreases from baseline levels, the heart will be faced with a reduced energy reserve, potentially resulting in lower tolerance for strenuous physical activities such as fighting a fire [55,56]. Finally, Rate Pressure Product (RPP) was calculated

as the product of systolic blood pressure and heart rate divided by 100. RPP provides an estimate of myocardial oxygen consumption [57].

D.7. Psychological/perceptual and cognitive function factors

Psychological/perceptual and cognitive function factors provide researchers with Firefighter self-assessment information, including: 1) how hard they perceive their effort during the firefighting tasks, 2) how they feel, 3) their perceptions of respiratory distress, 4) thermal sensations, and 5) self-report measures of energy/tiredness and tension/calmness. In addition, measures of cognitive function were assessed before and after the drills and recovery. These measures assess decision-making capabilities of the Firefighter, primarily via a choice-reaction time task, which allow the assessment of speed and accuracy of responding at the various test points.

D.8. Data analysis

In order to examine the effects of strenuous firefighting activity and recovery, and specifically rehabilitation interventions on hemostatic variables, cognitive function and psychological state measures, we conducted a repeated measures mixed multivariate analysis of variance (MANOVA, 2 [intervention: control, enhanced] × 3 [measurement period: pre, immediately post, 120 minute post]). The effect of firefighting activities and OSR interventions on heart rate and core temperature measures was examined using a repeated measures mixed multivariate analysis of variance (MANOVA, 2 [intervention: control, enhanced] × 12 [measurement period: baseline (station blues), pre-firefighting, immediately post-firefighting, during rehab (entry, 5 min, 10 min, 15 min), and during recovery (15 min, 30 min, 60 min, 90 min, 120 min)]. The effect of the OSR interventions on blood pressure during rehab and recover was examined using a repeated measures mixed multivariate analysis of variance (MANOVA, 2 [intervention: control, enhanced] × 9 [measurement period: during rehab (entry, 5 min, 10 min, 15 min), and during recovery (15 min, 30 min, 60 min, 90 min, 120 min)]. Vascular function was assessed as a function of the firefighting activities and OSR intervention again using a repeated measures mixed multivariate analysis of variance (MANOVA, 2 [intervention: control, enhanced] × 9 [measurement period: pre-firefighting, immediately post-firefighting, immediately after rehab, and throughout recovery (15 min, 30 min, 60 min, 90 min, 120 min)].The effects of rehabilitation interventions on subsequent performance on the anaerobic power test were compared using a paired t-test.

E. Results and Discussion

E.1. Descriptive measures

Table 1 presents data on 20 of the firefighters who participated in this study (one incomplete data set was excluded). Overall, our subjects were young (25.6± 5.2 years), apparently healthy firefighters. The exclusion criteria employed by this study (no known history of cardiovascular disease or use of pre-

Table 1: Descriptive statistics for the recruited firefighter subjects (n=20).

	Mean (SD)	Range
Age (yr)	25.6 (5.2)	19-39
Height (m)	1.81 (0.008)	1.65-1.98
Weight (kg)	83.3 (11.2)	67.1-111.1
BMI (kg/m^2)	25.4 (2.0)	20.6-28.8
Body Fat (%)	15.5 (4.5)	6.0-24.4
Total Cholesterol (mg/dL)	172.2 (36.8)	126-271
LDL (mg/dL)	106.1 (30.3)	68-195
HDL (mg/dL)	45.4 (12.7)	24-67

scription medication for blood pressure or cholesterol problems) resulted in a group of test subjects who were healthier than the general population. The mean BMI for this group is on the borderline between healthy and overweight, where 8 firefighters had a BMI < 25, while 12 firefighters fell in the "overweight" range (25<BMI<30). None of the recruited subjects was obese based on BMI.

E.2. Heart rate and core temperature

As seen in Figure 3, heart rate increased rapidly with the onset of firefighting activity. Heart rate increased from approximately 80 bpm prior to entering the training course to approximately 162 bpm by the second evolution and remained elevated until the firefighters exit the burn room. Heart rate then decreased rapidly upon completion of the training drill. In the first five minutes of recovery, heart rate dropped by 50 bpm. However, heart rate does not return to baseline until well after the 15 minute rehabilitation period has completed.

As Table 2 shows, there is a significant time and condition affect for heart rate. A post-hoc analysis was conducted with a paired t-test at each timepoint and showed that the standard and enhanced condition trials are identical until the recovery period, during which the enhanced rehab condition resulted in significantly elevated heart rates at 4 of the 5 time points (and nearly significant for the 5th). The post-hoc analysis also showed that heart rate returns to baseline condition (e.g. no longer statistically elevated) at 15 minutes into recovery for the standard condition (or more than 35 minutes post-firefighting), but at 60 minutes into recovery for the enhanced rehab condition.

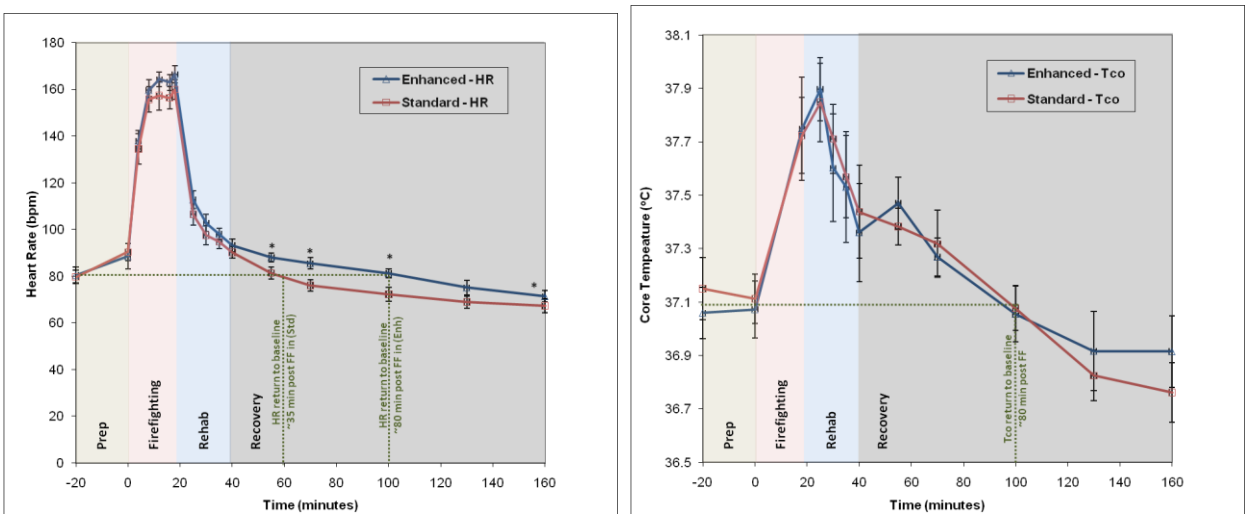

Figure 3. Changes in heart rate(left) and core temperature(right) throughout the test protocol. Data from complete sets only (n=12 for heart rate, n=8 for core temperature.) indicates significant condition affect at these time points.*

Core temperature also increased significantly during the firefighting activities and for the first few minutes of rehabilitation (Figure 3). During firefighting, core temperature increased at a rate of 0.037ºC.min^{-1}. These results are consistent with an earlier study that reported a rate of increase of 0.032^{o}C.min^{-1} during rescue and fire attack activities [58]. Furthermore, for the first seven minutes post-firefighting (prior to entering rehab), core temperature continued to rise at a rate of at least 0.020^{o}C.min^{-1} despite the fact that firefighters had doffed their PPE in order to facilitate data collection (blood collection). Core temperatures began to drop at the same time rehabilitation was initiated (approximately 6-7 minutes after exiting the training course). This finding is consistent with previous

research that documents that core temperature (as measured by gastrointestinal or rectal temperature) continues to rise after the cessation of exercise or work.

While there was again a significant time effect on core tempeature, there was no significant difference in core temperature between treatment conditions (Table 2). However, it is again important to note that firefighter's core temperature does not return to baseline until approximately 80 minutes post-firefighting.

Table 2. Statistical analysis of heart rate and core temperature during firefighting, rehab and recovery.

					Rehab				Recovery	
		Blues Mean (SE)	Pre-FF Mean (SE)	Post-FF Mean (SE)	Entry Mean (SE)	5 min Mean (SE)	10 min Mean (SE)	15 min Mean (SE)	15 min Mean (SE)	30 min Mean (SE)
Heart Rate n=12	Standard	79.7(2.9)	90.3(3.7)	159.8(4.2)	106.5(3.8)	97.5(4.1)	94.7(2.9)	90.2(2.4)	81.3(2.6)	76.0(2.5)
	Enhanced	80.4(3.4)	88.4(5.5)	166.3(3.7)	112.8(3.8)	102.8(4.0)	98.0(2.4)	93.2(2.7)	88.0(2.0)	85.4(2.5)
Core Temp n=8	Standard	37.22(.12)	37.13(.09)	37.79(.14)	37.86(.15)	37.76(.13)	37.60(.15)	37.47(.17)	37.44.07)	37.35(.13)
	Enhanced	37.04(.10)	37.09(.11)	37.77(.19)	37.91(.12)	37.59(.20)	37.53(.21)	37.41(.18)	37.51(.10)	37.29(.07)

		Recovery						
		60 min Mean (SE)	90 min Mean (SE)	120 min Mean (SE)	Condition	Time	Condition x Time	Post hoc
Heart Rate n=12	Standard	72.3(3.0)	75.1(3.1)	71.3(2.5)	p=.003	p< .001	ns	1<2,3,4,5,6,7,8,(9); 3>1-12; etc
	Enhanced	81.2(2.0)	68.9(2.6)	67.3(2.9)				
Core Temp n=8	Standard	37.10(.08)	36.86(.09)	36.76(.11)	ns	p= .009	ns	1,2<3,4,5,6,7,8,(9); 3>1,2,9-12; **etc**
	Enhanced	37.06(.11)	36.92(.15)	36.92(.13)				

E.3. Blood pressure

Blood pressure was assessed via auscultation prior to entering the training course (baseline), upon entry into rehabilitation, at 5 minute intervals within rehabilitation, and at 15-30 minute intervals throughout recovery (Figure 4). As Table 3 shows, there was a significant time effect for systolic blood pressure (SBP) but not diastolic blood pressure (DBP) and no significant condition effect for either SBP or DBP. Post-firefighting systolic blood pressure averaged approximately 136 mm Hg in this group of young healthy firefighters, only slightly higher than baseline values. Baseline systolic blood pressure measurements may have been elevated due to anticipation of firefighting activity. In a similar group of firefighters (similar age, BMI, and firefighting experience) we reported resting blood pressures of 126 mm Hg [59].

Systolic blood pressure dropped rapidly during rehabilitation. On average, SBP decreased 22.5 mm Hg - from 136.5 immediately post-firefighting to 114 at the end of rehabilitation. In 5 cases, SBP dropped by more than 30 mm Hg during the 15 minutes of rehab and in 12 cases more than 20 mm Hg. In fact, in 5 trials, we measured a drop of greater than 20 mm Hg in the first 5 minutes of rehab.

The lowest average systolic blood pressure recorded during rehabilitation (114 mm Hg) is approximately 8.6 mm Hg lower than the values recorded during recovery (which were remarkably stable). A single bout of moderate-intensity exercise lasting 30-60 minutes typically produces post-exercise blood pressure reductions of approximately 5-10 mm Hg, a phenomenon know as post -

exercise hypotension. Post-exercise hypotension caused by a reduction in vascular resistance, mediated by changes in autonomic nervous system and vasodilator substances [60]. Work in hot environments (or in PPE) can exaccerbate post exercise hypotension due to loss of plasma volume and a greater drop in vascular resistance due to vasodilation of the cutaneous circulation [61]. In 17 of the 42 observations, the difference between post-firefighting and recovery was greater than 10 mm Hg and in 6 of the 42 this differnece in blood pressure was greater than 20 mm Hg. One individual had a blood pressure drop from 153 to 106 mm Hg in the first 5 minutes of rehab, maintained ~110 mm Hg throughout rehab, then returned to a stable 122 during the last 90 minutes of recovery.

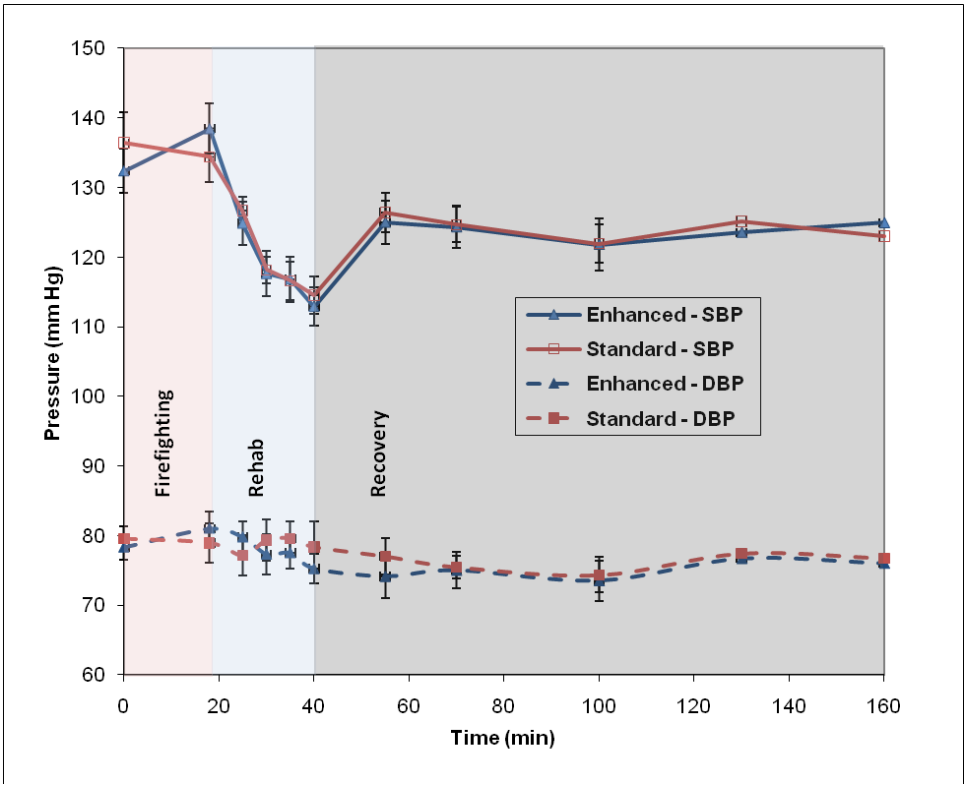

Figure 4. Changes in systolic (SBP) and diastolic (DBP) blood pressure throughout the test protocol. Data from complete sets (n=14).

Following rehabilitation and the dummy drag, which was conducted at room temperature, participants walked to an adjacent building where they recovered for another 120 minutes. The blood pressure values during recovery averaged approximately 122.6 and were remarkably stable. These findings suggests that locomotion was related to increasing venous return. As we did not have a true baseline measure for our participants, we do not know if the blood pressure values recorded during the recovery period reflected post exercise hypotension. However, the recovery values match baseline measures from firefighters in similar BMI categories based on a previous study in firefighters (121 - 126 mm Hg [59]).

While blood pressure is routinely monitored during rehabilitation, most guidelines are concerned about dangerously elevated blood pressure values following strenuous firefighting activities. Our data suggest that individuals overseeing medical monitoring of firefighters during rehabilitation should also be concerned about hypotension and the attending risk of syncope.

Table 3. Statistical analysis of systolic (SBP) and diastolic (DBP) blood pressure during firefighting, rehab and recovery.

		Rehab				Recovery				
		Entry Mean (SE)	5 min Mean (SE)	10 min Mean (SE)	15 min Mean (SE)	15 min Mean (SE)	30 min Mean (SE)	60 min Mean (SE)	90 min Mean (SE)	120 min Mean (SE)
SBP	Standard	130.9(4.4)	118.6(3.7)	117.21(2.0)	114.7(1.8)	127.5(2.7)	125.4(2.6)	123.6(2.9)	127.1(2.6)	122.2(2.8)
n=14	Enhanced	125.4(3.2)	117.0(3.6)	116.3(3.1)	113.5(3.2)	124.6(3.3)	125.1(2.8)	121.9(3.1)	122.8(3.0)	124.5(3.7)
DBP	Standard	76.6(1.8)	78.3(2.8)	78.5(2.9)	77.5(2.9)	77.2(2.5)	76.2(3.7)	74.2(2.6)	77.6(1.6)	74.6(2.5)
n=14	Enhanced	79.2(1.8)	77.1(2.5)	77.7(2.2)	74.6(2.9)	74.9(2.3)	75.7(2.1)	75.7(3.2)	77(2.6)	77.1(2.9)

			Condition	Time	Condition x Time		Post hoc
SBP n=14	Standard Enhanced		ns	p< .001	ns		1<2,3,4; 2<5,6,8; 3,4<5-9; etc
DBP n=14	Standard Enhanced		ns	ns	ns		

E.4. Hemostatic variables

E.4.1. Plasma volume

Dehydration has an effect on cardiovascular and thermal strain, and may influence coagulatory variables. To assess dehydration, we calculated changes(from timepoint *a* to timepoint *b*) in plasma volume using measurements of hemoglobin (Hb) and hematocrit (Hct) via the Greenleaf method,

$$\%\Delta PV = 100\left[\frac{Hb_B}{Hb_A} x \frac{\left(-Hct_A x10^{-2}\right)}{\left(-Hct_B x10^{-2}\right)}\right] - 100$$

Complete blood cell count (CBC) analysis was performed using a Cell-Dyn 3200 automated analysis system (Abbott Diagnostics) using flow cytometry technology, from which hematocrit and hemoglobin were assessed. During the firefighting activities, participants in the standard and enhanced condition lost 6.7% and 4.2% of their plasma volume, respecitvely, with no statistical difference between conditions. During the rehab and 120 minute recovery period, participants' plasma volume increased by 6.9% and 6.1% from post-firefighting levels, again with no significant difference between conditions. From the pre-firefighting condition to the 120-post condition, firefighters plasma volume changed by -0.56% and +1.44% in each condition, resulting in a hydration level that was not statisitcally different from baseline after 120 minutes of recovery.

E.4.2. Platelet number and function

Platelet count increases significantly (18%) and platelet closure time decreases significantly (15% ADP, 20% EPI) following firefighting activity suggesting increased thrombotic potential in the period immediately after firefighting (Figure 5, Table 4). There was no condition effect for platelet number or function between the pre- and post-firefighting condition. The increase in platelet count seen post-firefighting is similar in magnitude to the increase in platelet count that occurs following strenuous exercise. The increase in platelet number likely reflects a combination of hemoconcentration (i.e. the 5-7% decrease in plasma volume) and a release of platelets from the spleen and lymph tissue secondary to sympathetic nerve stimulation (see section on Catecholamine levels below).

Platelet aggregation was assessed by closure time using a platelet function anaylzer (PFA 100; Dade Behring). The PFA measures the time necessary for a platelet plug to occlude an apperture after the blood is stimulated by a platelet agonist (ADP and collagen or Epinephrine and collagen). As such, a reduced closure time reflects increased platelet aggregation. Platelet count was assessed via CBC analysis as outlined above.

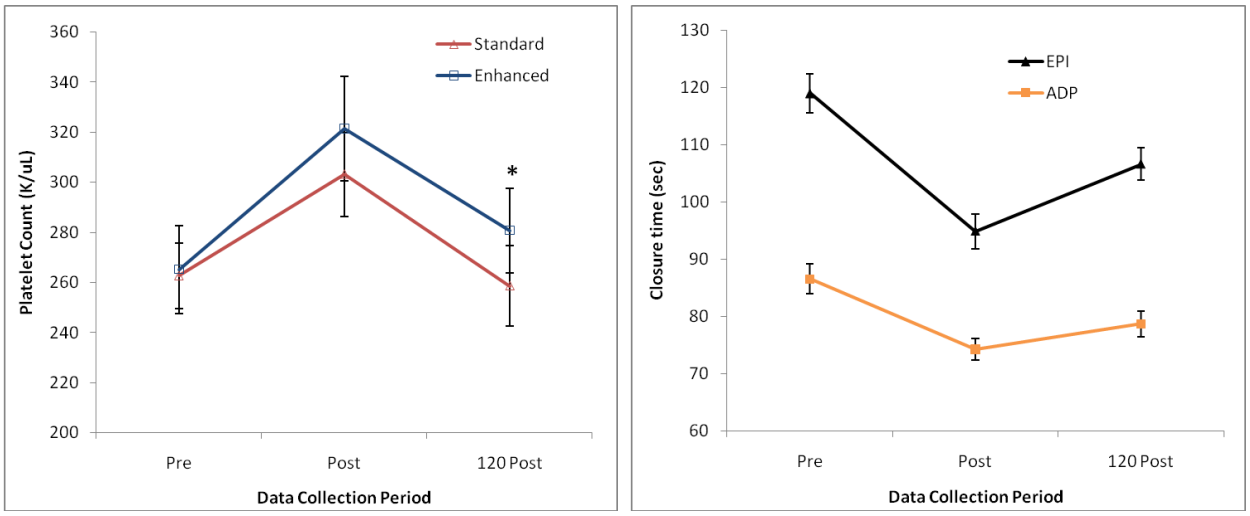

*Figure 5. Platelet count (left) and platelet activity measured via closure time when blood exposed to ADP and EPI (right) at pre-firefighting, post-firefighting, and post 120 minutes of recovery. Data from complete sets (n=17 for closure time and n=21 for platelet count). * indicates significant condition affect at this time point. There is no condition effect for closure time, so the presented data is lumped.*

After rehab and recovery, platelet count had returned to baseline values in the standard rehab condition, but remained significantly elevated from baseline for the enhanced rehab condition. In both cases, firefighters had returned to their baseline hydration level, so the difference between conditions is not a result of differential hemoconcentration effects. Furthermore, the core temperatures were not significantly different between conditions, suggesting that the sports drink and recovery drink are the most likey difference between conditions and may have had an affect on platelet concentration. At the same time, platelet aggregation was enhanced following firefighting activity and remained elevated following 120 minutes of recovery. The decreased closure time that persisted even after 120 minutes of recovery suggests that there is an increased risk of thrombosis at least 2 ½ hours after completion of short bouts of firefighting activity in relatively young, healthy firefighters.

Table 4. Statistical analysis of platelet count and platelet activity (measured via closure time when blood is exposed to ADP and EPI) at pre-firefighting, post-firefighting, and post 120 minutes of recovery.

		Pre Mean (SE)	Post Mean (SE)	Post-120 Mean (SE)	Condition	Time	Condition x Time	Post hoc
Platelet Count (K/uL) n=21	Standard	262.7(13.2)	303.1(16.7)	258.6(16.0)	ns	p< .001	p=.05	1<2, 2>3 (p>.001); Std3<Enh3 (p=.035)
	Enhanced	265.2(17.5)	321.5(20.9)	280.8(16.9)				
Closure time, ADP (sec) n=18	Standard	86.2(3.8)	73.9(2.6)	79.7(3.4)	ns	p< .001	ns	1>2 (p=.001); 1>3 (p>.001)
	Enhanced	90.1(4.3)	76.5(2.9)	79.9(3.0)				
Closure time, EPI (sec) n=18	Standard	117.1(3.3)	94.2(4.8)	107.6(4.4)	ns	p< .001	ns	1>2,2>3(p>.001); 1>3 (p=.004)
	Enhanced	124.1(6.1)	98.6(3.9)	108.8(3.9)				

E.4.3. Coagulation and fibrinolysis

Both Tissue Factor and Factor VIII increased significantly immediatley post-firefighting. Additionally, Factor VIII remained significantly elevated at 120 minutes post recovery. There was no condition effect for any coagulatory variables. These results indicate that even short bouts of firefighting stimulate an increase in coagulatory variables and the time needed for full recovery is greater than 2 ½ hours.

Tissue plasminogen activator (t-PA) activity and antigen levels increased significantly from pre-firefighting to post-firefighting conditions, but returned to baseline conditions at 120 minutes post-recovery regardless of rehab condition. These results suggest that fibrinolysis is activated immediately after firefighting but does not remain elevated for a prolonged period. The increased coagulatory variables and fibrinolytic variables in the immediate post-firefighting period may reflect an increase in coagulatory potential and fibrinolytic potential; in other words, there may be a hemostatic balance but at a higher level than baseline. However, the elevated coagulatory potential at 2 hours post-firefighting at the time when fibrinolytic variables return to baseline may reflect a period of hemostatic imbalance – favoring coagulation. These results are consistent with data from Hedge et al (2001) who reported coagulatory variables remained elevated 90 minutes after strenuous exercise while fibrinolytic factors returned to baseline by that period [42].

Table 5. Coagulatory and fibrinolytic markers measured pre-firefighting, immediately post-firefighting, and 120 minutes post-rehab.

		Pre Mean (SE)	Post Mean (SE)	Post-120 Mean (SE)	Condition	Time	Condition x Time	Post hoc
t-Pa act (ng/mL)	Standard	0.59(0.12)	2.27(0.47)	0.68(0.11)	ns	p=.001	ns	1<2 (p=.001); 2>3 (p=.002)
n=9	Enhanced	0.56(0.08)	2.09(0.29)	0.59 (0.07)				
t-Pa agn (ng/mL)	Standard	5.95(0.73)	11.3(1.9)	6.28(0.60)	ns	p=.003	ns	1<2, 2>3 (p=.001)
n=21	Enhanced	6.47(0.63)	12.1(1.6)	6.77(0.71)				
PAI-1 act (iu/mL)	Standard	2.62(0.64)	1.90(0.53)	1.59(0.46	ns	ns	ns	
n=21	Enhanced	3.27(0.94)	2.86(1.14)	3.10(0.78)				
PAI-1 agn (ng/mL)	Standard	24.4(3.9)	25.2(3.2)	20.3(3.2)	ns	ns	ns	
n=20	Enhanced	23.1(2.4)	25.4(3.1)	22.9(3.2)				
PF1.2 (pmol/L)	Standard	194.3(95.2)	356.3(112.6)	239.3(106.3)	ns	ns	ns	
n=20	Enhanced	278.5(109.0)	196.1(95.6)	239.3(99.1)				
Factor VIII (%)	Standard	94.1(5.5)	135.7(9.4)	129.5(11.0)	ns	p< .001	ns	1<2; 1<3 (p>.001)
n= 15	Enhanced	80.3(7.9)	127.4(12.5)	121.4(11.0)				
TF (pg/mL)	Standard	68.7(7.8)	74.3(6.8)	66.0(7.4)	ns	p= .006	ns	1<2 (p=.001); 2>3 (p=.030)
n=20	Enhanced	64.9(8.0)	79.2(9.0)	69.6(6.3)				

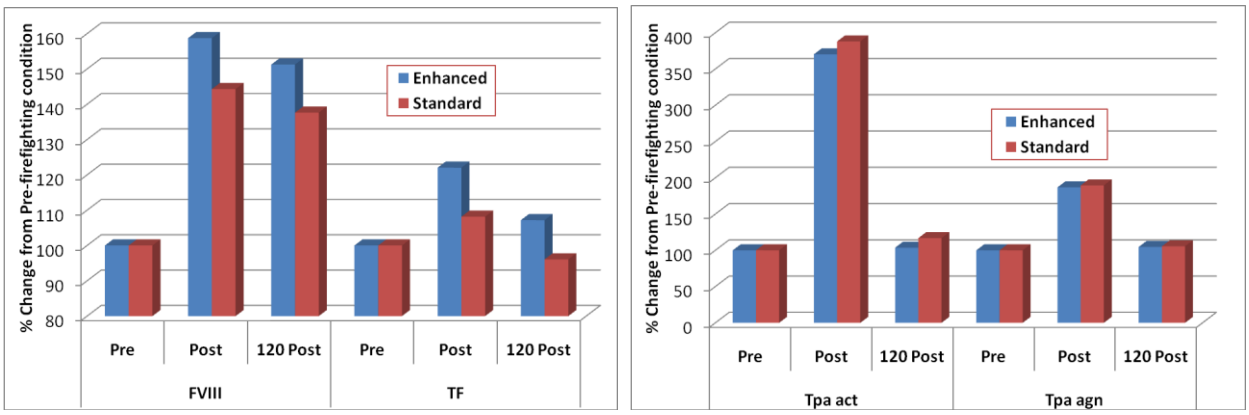

Figure 6. (left)Factor VIII increases post-firefighting and remain elevated at 120 minutes into recovery, but (right) Fibrinolytic variables that increase post-firefighting return to near baseline levels after 120 minutes of recovery, suggesting a potentially hypercoagulable state in the hours after firefighting.

E.4.4. Cortisol and catecholamine response

As shown in Table 6 and Figure 7, we measured no significant change in Cortisol levels from baseline to immediately post but a significant reduction from immediately post to 120 post, with no condition effect. There was an increase in epinephrine levels from baseline to immediately post-firefighting activity and a significant decrease from levels immediately post to 120 post with the enhanced rehab but not with the standard rehab. Finally, we measure an increase in norepinephrine from baseline to immediately post-firefighting, followed by a decrease in levels after 120 post-firefighting though there was no significant difference between the two treatments.

Table 6. Catecholamine levels pre-firefighting, immediately post-firefighting, and 120 minutes post-rehab.

		Pre Mean (SE)	Post Mean (SE)	Post-120 Mean (SE)	Condition	Time	Condition x Time	Post hoc
Cortisol (µg/mL) n=21	Standard	10.4 (1.0)	10.5 (0.9)	4.9 (0.4)	ns	p< .001	ns	1>3; 2>3 (p<.001)
	Enhanced	10.9 (1.3	10.9(1.1)	5.1 (0.4)				
Epinephrine (ng/mL) n=19	Standard	2.20 (0.43)	3.46(0.58)	3.43 (0.71)	ns	p= .001	p=.007	1<2 (p<.001), 2>3 (p=.043); Std3>Enh3 (ns,p=0.075)
	Enhanced	2.29(0.23)	4.29(0.61)	2.38(0.43)				
Norepinephrine (ng/mL) n=18	Standard	2.86(0.30)	8.82(2.18)	5.19(0.74)	ns	p=.005	ns (p=.087)	1<2 (p=.003); 1<3 (p<.001)
	Enhanced	3.54(0.55)	6.57(0.67)	5.99 (0.81)				

The finding that catecholamines were significantly higher than baseline more than 2 hours after firefighting activities were completed is surprising given the half life of these hormones. Furthermore, given the anticipation that firefighters were likely to have felt prior to performing the firefighting activities, it is reasonable to believe that true resting levels of catecholamines would have been lower than the pre-firefighting values we reported here.

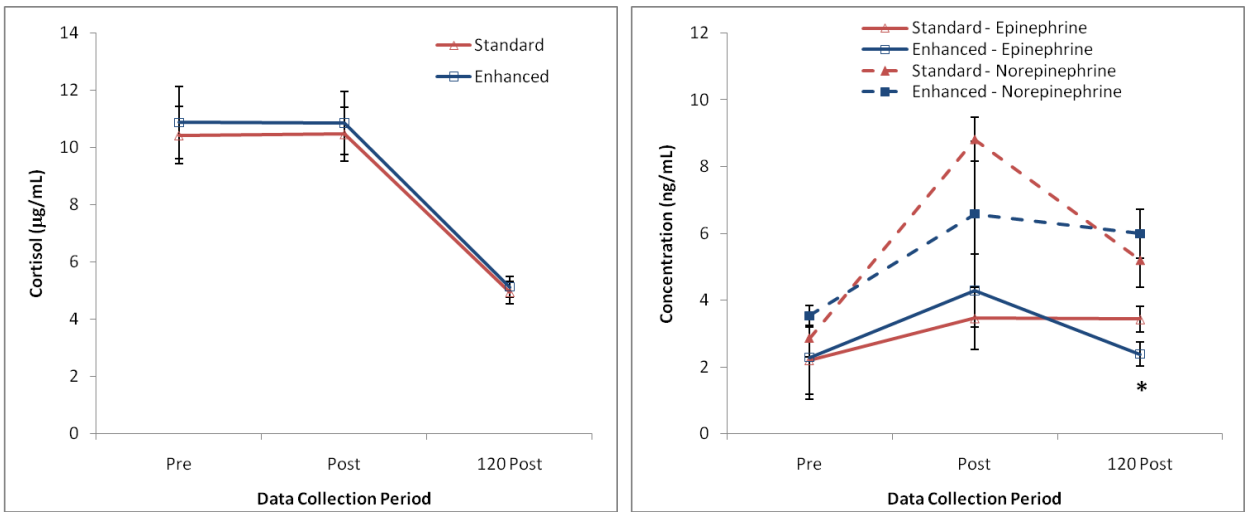

*Figure 7. Cortisol, epinephrine, and norepinephrine at pre-firefighting, post-firefighting, and post 120 minutes of recovery. Data from complete sets (n=21, 19, and 18 for cortisol, epinephrine, and norepinephrine respectively). * indicates significant condition affect at this time point.*

E.5. Arterial function

We used arterial tonography (ShygmoCor, Australia) to obtain radial artery pulse waves. Peripheral and aortic blood pressure and subendocardial viability ratios were calculated from these plusewaves using the ShygmoCor software (Table 7). The peripheral blood pressure measurements closely matched those obtained via auscultation. In general there was a significant time effect for both systolic blood pressure and mean arterial pressure, with blood pressure decreasing below baseline levels following rehabilitation, but there was no condition effect. There was no significant time effect for peripheral diastolic blood pressure. Aortic blood pressure followed a similar pattern: there was a significant time effect for systolic and mean arterial pressure but not for diastolic pressure, and there was not significant condition effect. However, the aortic systolic blood pressures were considerably lower than those obtained via auscultation.

An important measure calculated from the radial artery pulse waves, the Subendocardial Viability Ratio (SEVR) provides an estimate of the arterial system's ability perfuse myocardial tissue (i.e. supply oxygen to the heart muscle), in order to meet the heart's energy requirements. If SEVR decreases from baseline levels, the heart will be faced with a reduced energy reserve, potentially resulting in lower tolerance for strenuous physical activities such as fighting a fire.

As expected, SEVR was significantly reduced post-firefighting and recovered rapidly during rehab and into recovery (Figure 8). However, there is a significant difference between the rehab interventions with SEVR more rapidly returning to baseline with the Standard recovery protocol as compared to the Enhanced protocol. On average, firefighters returned to baseline for the standard condition at the 60 minutes into recovery and after 90 minutes of recovery for the enhanced rehab protocols. This result has significant implications since it suggests that myocardial blood supply may be decreased for up to 2 hours after firefighters have completed just one air cylinder, particularly if they return to the fire fight without a significant rehab period. Furthermore, the time scale for recovery to baseline levels - assuming full rehab and recovery in a controlled, relaxed environment – is on the order of hours, not minutes. As most firefighters will be required to return to work for clean up or overhaul, this extended rest period is not likely to be available. Finally, these results suggest that firefighters' may actually have a slower recovery following the enhanced rehab as compared to the standard rehab

Table 7 Statistical analysis of arterial function asssessed via radial artery pulse wave analysis during firefighting, rehab and recovery.

				Rehab	Recovery				
		Pre-FF Mean (SE)	Post-FF Mean (SE)	15 min Mean (SE)	15 min Mean (SE)	30 min Mean (SE)	60 min Mean (SE)	90 min Mean (SE)	120 min Mean (SE)
pSBP	Standard	130.8(3.9)	133.1(3.2)	119.2(2.1)	125.6(3.3)	125.2(2.7)	122.1(3.2)	125.1(3.6)	121.1(2.2)
n=10	Enhanced	128.5(3.3)	137.2(2.1)	114.5(5.1)	126.6(3.5)	123.4(3.2)	120.8(4.0)	118.6(3.1)	121.4(3.2)
pDBP	Standard	76.6(3.2)	76.9(3.0)	75.1(4.0)	74.6(2.0)	72.5(5.3)	73.0(2.7)	74.9(1.8)	75.5(2.4)
n=10	Enhanced	74.4(1.5)	78.6(2.2)	72.4(3.3)	73.1(2.6)	73.8(1.9)	71.1(2.55	71.5(2.5)	73.3(2.8)
pMP	Standard	92.6*3.5)	95.6(3.0)	88.5(3.3)	89.8(2.1)	88.8(4.2)	88.1(2.8)	90.8(2.1)	89.7(1.6)
n=10	Enhanced	91.7(2.1)	98.2(1.8)	85.1(3.4)	90.4(2.8)	89.4(2.2)	86.4(3.2)	85.5(2.5)	78.6(2.7)
pPP	Standard	54.2(2.3)	56.2(2.9)	44.1(3.0)	51.0(3.1)	52.7(4.4)	49.1(2.5)	50.2(3.5)	45.6(3.2)
n=10	Enhanced	54.1(2.3)	58.6(3.0)	42.1(2.7)	53.5(2.6)	49.6(2.9)	49.7(3.4)	47.1(2.4)	48.1(3.2)
aSBP	Standard	111.0(4.2)	113.0(3.3)	102.3(2.6)	106.7(2.6)	106.3(4.8)	105.0(3.3)	107.8(3.2)	105.3(1.9)
n=10	Enhanced	109.9(2.9)	115.6(2.0)	98.3(3.8)	106.9(3.6)	105.1(3.0)	102.7(4.0)	101.0(2.8)	103.5(3.2)
aDBP	Standard	77.6(3.2)	80.2(2.8)	76.1(4.0)	75.6(2.0)	73.9(5.1)	73.9(52.6)	75.8(1.7)	76.5(2.3)
n=10	Enhanced	75.5(1.6)	82.1(2.0)	73.7(3.1)	74.9(2.8)	75.3(1.9)	72.4(2.6)	72.5(2.5)	74.3(2.8)
aMP	Standard	92.6(3.5)	95.6(3.0)	88.5(3.3)	89.8(2.1)	88.8(4.2)	88.1(2.8)	90.9(2.1)	89.7(1.6)
n=10	Enhanced	91.7(2.1)	98.2(1.8)	85.1(3.4)	90.4(2.8)	89.4(2.2)	86.4(3.2)	85.5(2.5)	87.6(2.7)
aPP	Standard	33.4(1.7)	32.8(2.2)	26.2(1.9)	31.1(1.9)	32.4(2.9)	31.1(2.1)	32.0(3.0)	28.8(2.6)
n=10	Enhanced	34.4)1.7)	33.5(2.1)	24.6(1.6)	32.0(2.3)	29.8(2.7)	30.3(3.1)	28.5(1.9)	29.2(2.6)
SEVR	Standard	168.2(12.0)	113.2(7.6)	139.3(8.6)	153.0(8.5)	153.9(10.2)	169.1(9.5)	182.7(7.3)	177.2(8.0)
n=10	Enhanced	164.8(9.7)	110.5(6.2)	131.0(5.9)	136.9(6.1)	145.4(8.6)	147.5(6.3)	161.0(6.2)	173.4(10.0)

	Condition	Time	Condition x Time	Post hoc
pSBP n=10	ns	p< .001	ns	2>3,6,7,8;4>8
pDBP n=10	ns	ns	ns	
pMP n=10	ns	p= .001	ns	2>6,7
pPP n=10	ns	p<.001	ns	1>3; 2>3,8
aSBP n=10	ns	p< .001	ns	2>3,7,8
aDBP n=10	ns	ns	ns	
aMP n=10	ns	p= .001	ns	2>6,7
aPP n=10	ns	p=.002	ns	1>3
SEVR n=10	p=.016	p< .001	ns	1>2,3; 2<3,4,5,6,7,8;3<7,8; 4<7,8;5<8;6<7

E.6. Myocardial oxygen supply and demand

There was a significant Time effect ($p<0.001$), Condition effect ($p=0.002$) and Time x Condition interaction ($p=0.048$) for Subendocardial Viability Ratio (SEVR). SEVR was significantly reduced post-firefighting and recovered relatively slowly during rehabilitation and into recovery (Figure 8). As shown in Figure 9, there was a significant Time effect ($p<0.001$), Condition effect ($p=0.012$) and Time x Condition interaction ($p=0.010$) for Rate Pressure Product (RPP). As expected, the RPP increased significantly during firefighting activity due to the increase in myocardial oxygen consumption during firefighting. However, RPP rapidly decreased below pre-firefighting values by the end of the rehabilitation period (40 minutes). There was a significant Condition effect with RPP being significanlty lower in the control condition.

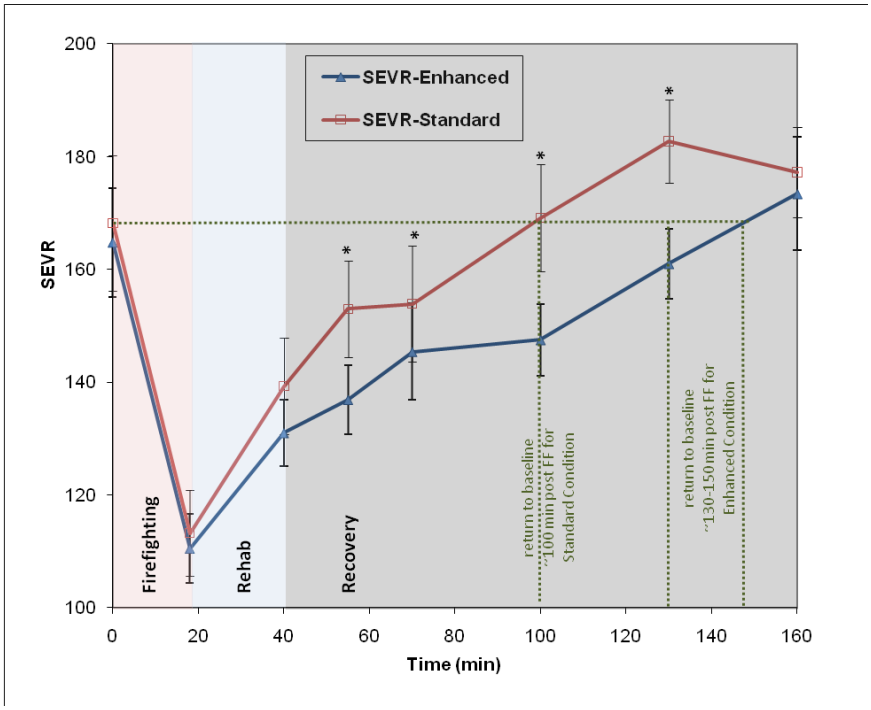

*Figure 8. Changes in Subendocardial Viability Ratio (SEVR) throughout the test protocol. Data from complete sets only (n=10) * indicates significant condition affect at these time points.*

The decrease in SEVR immediately post-firefighting reflects a decrease in myocardial perfusion relative to cardiac workload, while the significant increase in RPP reflects an increase in the myocardial tissue demand for oxygen. However, as Figure 9 shows, RPP rapidly returns to levels below pre-firefighting values by the first recovery time period. As the pre-firefighting RPP levels may be slightly elevated from baseline due to increase in heart rate at pre-activity and RPP remains relatively stable throughout recovery, it is expected that the rate pressure product has recovered to near baseline levels by this time period. However, SEVR does not return to pre-firefighting levels until sometime between the 30 and 60 minute time points for control rehabilitation and between 60 and 90 minutes for enhanced recovery. Thus, even though the myocardial demand for oxygen rapidly returns to baseline levels, the subendocardial perfusion remains reduced for another 30-90 minutes. Additional research is needed to determine if a reduced SEVR during recovery may be related to an increased

vulnerability to sudden cardiac events or if there is in fact a balance between oxygen supply and demand.

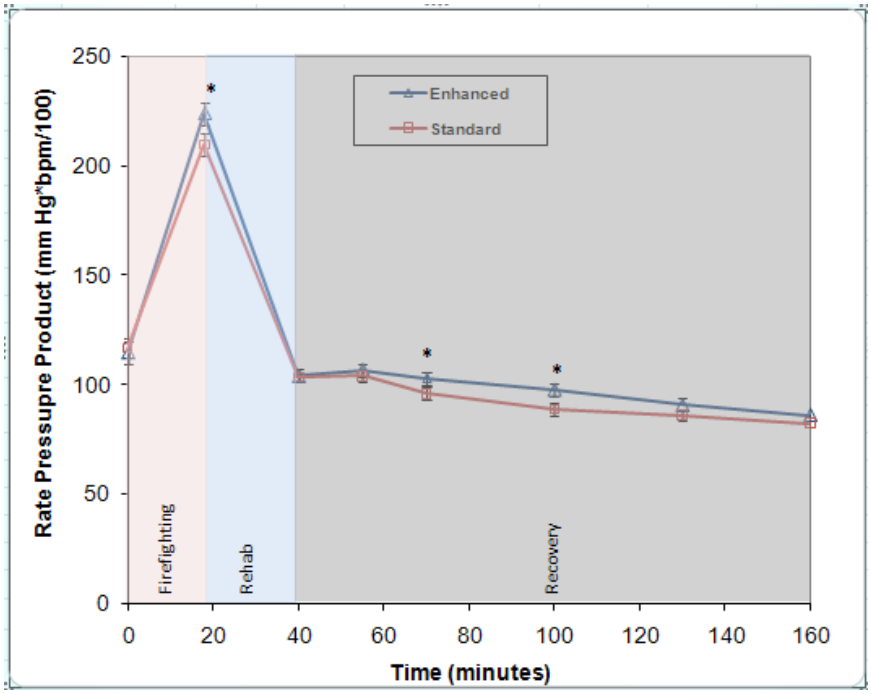

Figure 9. Changes in Rate Pressure Product (RPP) throughout the test protocol (n=20). All timepoints are significantly different than prefirefighting condition, dropping below this level after rehab. (indicates significant condition effect)*

E.7. Psychological & cognitive responses

The firefighting activities undertaken in the trial resulted in significant psychological effects as shown by significant Time main effects. However, there was virtually no difference seen for the perceptual and psychological variables between the different rehabilitation conditions (Table 8). Overall, findings revealed a more negative psychological profile following firefighting activities compared to the pre-firefighting state followed by a return to pre-firefighting levels following recovery and rehabilitation. Feeling Scale ratings decreased ~1.5 units, revealing a decrease in pleasantness immediately following firefighting. Self-rated energy increased following firefighting (~16.4%), but then decreased significantly from that post-firefighting level during the rehabilitation period (~19.5%); self-rated Calmness had a non-significant decrease. State Anxiety was increased significantly (increase of ~1.4 units; ~8.8%) from pre-trial to post-trial, followed by a return to pre-firefighting levels following rehabilitation (~12.1%); Self-rated Tension, a conceptual analogue to anxiety, also increased (~0.7 units; ~10.6%) from pre-trial to post-trial, followed by a return to pre-firefighting levels following rehabilitation (~13.7%). A significant Intervention x Time interaction was noted for Tension, but practically there was no meaningful change in this psychological variable as a result of the rehabilitation intervention. Consistent with the decrease in Energy, self-rated Tiredness decreased significantly (~18%), but then increased significantly from that post-firefighting level during the rehabilitation period (~28.7%). Taken together, each of these psychological constructs indicate that the effects of the firefighting activities served to either decrease positive and/or increase negative feelings. It is worth noting that the psychological constructs (State Anxiety, Energy, Tension, Tiredness, Calmness) were all assessed ~20-30 min following completion of the firefighting activities and then again 120 min after completion. (Only Feeling Scale was assessed

immediately following the activities). In spite of this relatively long lag time, these constructs still revealed a generally more dysphoric psychological profile following firefighting activities (with the exception of the increased Energy and decreased Tiredness following the activity). It is reasonable to assume that this psychological profile was likely even more dysphoric in the time period immediately following the activities.

Table 8. Psychological measures pre-firefighting, immediately post-firefighting, and 120 minutes post-rehab.

		Pre Mean (SE)	Post Mean (SE)	Post-120 Mean (SE)		Condition	Time	Condition x Time		Post hoc
Energy n=20	Standard	11.5(0.8)	12.8(0.8)	10.3(0.5)		ns	p=.012	ns		2>3
	Enhanced	10.5 (0.7)	12.8(0.8)	10.3(0.5)						
Tiredness n=20	Standard	10.4(0.8)	8.9(0.5)	10.6(0.8)		ns	p=.004	ns		1>2,2<3
	Enhanced	10.9(0.7)	8.6(0.7)	11.9(0.7)						
Tension n=20	Standard	6.9(0.5)	7.2(0.5)	6.0(0.3)		ns	p= .006	p=.028		1<2,2>3
	Enhanced	6.4(0.4)	7.3(0,5)	6.7(0.5)						
Calmness n=20	Standard	13.4(0.7)	10.7(0.5)	13.4(0.7)		ns	p< .001	ns		1<2, 1<3
	Enhanced	12.4(0.6)	10.6(0.4)	13.1(0.6)						
State Anxiety n=20	Standard	15.7(0.8)	17.3(0.5)	14.7(0.6)		ns	p=.004	ns		1<2,2>3
	Enhanced	16.2(0.6)	17.4(0.7)	15.7(0.7)						

As shown in Table 9, performance on the Continuous Performance Test (CPT), essentially a decision-making task yielding a behavioral measure of reaction time (RT), was unaffected by the rehabilitation intervention (i.e., no significant interaction effect) . For all trials, there was a significant reduction in RT from pre- to post-firefighting activities (~25 msec), indicating faster responses following firefighting activity; RTs at the end of the rehabilitation period were not different from pre-RT values. Because the CPT had what could be considered frequently appearing stimuli (the numbers between and including 1and 8, occurring on 80% of trials) and less frequently appearing stimuli (the numbers 0 and 9, occurring on the other 20% of trials), each type of stimulus was examined separately. As with the overall analysis of all trials, for the frequent trials there was a significant reduction in RT from pre- to post-firefighting (~27 msec), again indicating faster responses following firefighting activity. RTs at the end of the rehabilitation period were not different from pre-firefighting levels. Finally, for the rare trials the same pattern emerged. RTs were significantly faster following firefighting activity (~20 msec) and then similar to pre-activity levels following rehabilitation. Very few errors were made and there were no differences across time or intervention type. Somewhat surprisingly, decision-making seemed to be facilitated (i.e., RTs were faster without increased errors) by the firefighting activity. This could have been due, in part, to the timing of the performance of the decision-making task. This was not done immediately following the firefighting activity, but was done following measurements of blood flow and blood draws. Thus, the behavioral task was usually performed after approximately 15-20 min had elapsed following completion of the firefighting activity. The faster performance could be reflected by the perception of greater Energy and decreased Tiredness.

Table 9. Cognitive function measure assessed via Continuous Performance Test (CPT) pre-firefighting, immediately post-firefighting, and 120 minutes post-rehab.

		Pre Mean (SE)	Post Mean (SE)	Post-120 Mean (SE)		Condition	Time	Condition x Time		Post hoc
CPT-all	Standard	399.7(14.9)	370.3(14.1)	387.0(11.9)		ns	p=.001	ns		1>2
n=17	Enhanced	395.3(15.6)	374.3(11.8)	384.6(13.5)						
CPT-rare	Standard	444.3(16.8)	420.4(17.1)	426.6(14.3)		ns	p=.012	ns		1>2
n=17	Enhanced	432.4(14.7)	417.1(14.0)	432.86(15.6)						
CPT-frequent	Standard	388.8(14.8)	358.0(13.9)	377.2(12.1)		ns	p= .002	p=.028		1>2
n=17	Enhanced	386.3(16.1)	363.7(12.2)	372.8(13.3)						

E.8. Anaerobic power

Immediately post rehab, firefighters maximal anaerobic power was assessed via a dummy drag task. In this case, firefighters were asked to drag an 81.5 kg mannequin across a concrete floor over a distance of 12 m. The time to complete the task was measured via laser triggering at the start and end of the course. On average, the firefighters required just over 9 seconds to complete the task (Table 10). The rehab condition displayed no significant affect on the maximal anaerobic power as assessed by the dummy drag task, suggesting that an immediate, short term expenditure of energy is not affected by rehab protocols.

Table 10. Dummy drag times for firefighters post rehab in the standard and enhanced conditions (n=19).

	Mean (SD)	Range
Standard (sec)	9.11 (1.69)	6.34-13.52
Enhanced (sec)	9.27 (2.06)	6.71-12.65

The maximal anaerobic power protocol was modified from the proposed Wingate Anaerobic Test (WAT) after initial pilot testing. Several subjects reported lightheadedness and nausea after the WAT, requiring short term observation. While the WAT protocol is common protocol, we felt that conducting the test after subjects were severely fatigued from firefighting activities would result in unsafe conditions for our firefighters. The dummy drag test was then devised as a less demanding, yet commonly used protocol to assess a realistic scenario for the fire service.

E.9. Research-to-practice

The final specific aim of this study was to bring research to practice by broadly disseminating the results of this study to the Fire Service in order to bring awareness to the level of physiological and cardiovascular strain that results from firefighting and promote methods to improve the health and safety in the Fire Service. We have already begun this effort, by presenting data at multiple national and statewide conferences and workshops including

- NIOSH Firefighter Exposures Workshop (Cincinnati, OH – October 2009).
- Illinois Fire Service Institute Winter Fire School (Champaign, IL - January 2010)
- Fire Department Instructors Conference (FDIC, Indianapolis, IN - April 2010)
- Incorporated into a 12 hour course on Firefighter Rehab at the Illinois Fire Service Institute Fire College (Champaign, IL June 2010)
    - This rehab course has been presented across the country and has recently been utilized as the basis for the CERT Rehab team training through efforts led by Dr.

Denise Smith and Chief Craig Haigh (Hanover Park (IL) FD). As such, these results will inform rehab protocols across the country.

- Fire Rescue International (FRI) conference (Chicago, IL - August 2010)

This report will be summarized in several publications for Fire Service trade journals (*Fire Engineering, Fire Chief*, *Fire Rescue*). Finally, the attached executive document will be distributed broadly through the IFSI Firefighter Life Safety Research Center website and through our national Fire Service partners.

F. Conclusions

Several important conclusions can be drawn from this study regarding the affect of firefighting activities on the cardiovascular system and the time rate of recovery of several important measures.

It should be stressed that these results were generated from a population of young, healthy firefighters who were immediately removed from the firefighting activities into a relatively controlled, relaxed environment. Firefighters were provided with 15 minutes of rehab prior to completing a 10 second maximal aerobic fitness test and then were in recovery for 120 minutes without physical or psychological interruption. This scenario represents a likely best case. Often firefighters will return to work after consuming 1 cylinder of air. Then, once the firefighting operation has ended, they will be involved in overhaul and clean up operations, which may further exacerbate the perturbations measured and the time rate of recovery.

F.1. Summary of effect of time

Firefighting activities result in a significant elevation of core temperature and heart rate. Importantly, the recovery from these affects occurs over a timecourse of hours, even after a relatively short bout of firefighting in a relatively young and health population that were in a controlled and relaxed environment away from physical or psychological disruptions that are common on the fireground.

- Systolic blood pressures displayed a significant and rapid decline shortly after firefighting activities and into the rehab period. Blood pressure returns rapidly to stable baseline levels in recovery. While firefighters are often concerned about elevated blood pressures, this study suggests that firefighters should be award of the potential dangers of hypotension as well.
- Platelet count and function were significantly elevated as a result of firefighting activities and platelet function remains elevated even after 120 minutes of recovery. Platelet count is affected by rehab condition, such that it may or may not return to baseline post 120 minutes of recovery. This study suggests that the hypercoagulable state that is known to occur after firefighting activities does not fully return to baseline even 2 ½ hours after firefighting has ceased.
- By assessing several hemostatic variables, we found that both coagulation (Factor VIII and Tissue Factor) and fibrinolysis (tPa activity and antigen) were elevated immediately post-firefighting, suggesting that factors on both sides of the hemostatic equilibrium were elevated. However, at 120 minutes post-firefighting, all fibrinolytic factors have returned to baseline, while Factor VIII remains significantly elevated, tipping the hemostatic balance even farther towards coagulation.
- Arterial function assessed via arterial tonography revealed that the pattern derived peripheral blood pressure values very closely match blood pressure values determined via auscultation. Importantly, the Subendocardial Variability Ratio (SEVR) calculated from arterial tonography suggested that the heart may be facing a reduction in perfusion for up to 90 minutes into the recovery from firefighting, again suggesting that the time rate of recovery from firefighting is on the order of hours, not minutes. The depressed SEVR measurements imply that firefighters will have a subendocardial blood flow for up to 140 minutes after an initial firefighting activity.

- Catecholamine levels were significantly elevated post-firefighting and remained elevated at 120 minutes post recovery.
- Assessment of several psychological constructs revealed a generally more dysphoric psychological profile following firefighting activities that returned to baseline at 120 minutes post recovery. Cognitive function values actually appeared to improve immediately post-firefighting, possibly due to the slightly elevated core temperature.

F.2. Summary of effect of rehab condition

There were four important measurements in which rehab condition displayed a significant affect.

- The enhanced rehab condition appeared to have a negative effect on cardiovascular function as firefighters displayed an elevated heart rate and reduced subendocardial viability ratio (SEVR) throughout recovery as compared to the standard condition. In both cases the enhanced condition appears to have a negative effect on firefighter recovery from firefighting activities. The rehab conditions had no affect on core temperature, suggesting that the cooling portion of the intervention had no effect. Therefore, the only difference between the conditions was the additional nutrition from the sports drink during rehab and recovery drink ingested during the first 15 minutes of recovery. Importantly, the changes in HR and SEVR do not become significant until 15 minutes into recovery (i.e. not during rehab).
- Platelet count was significantly affected by rehab condition at the 120 minute post rehab time point. While firefighter's platelet count returned to baseline levels after recovery in the standard condition, the count remained elevated after recovery from the enhanced rehab condition. Firefighters were equally hydrated after recovery (as assessed via changes in plasma volume – assuming equal hydration prior to firefighting), so this affect is not likely due to hemoconcentration.
- Epinephrine levels remained elevated post recovery for the standard condition, yet returned to baseline for the enhanced condition. Previous research has shown that ingesting carbohydrates can reduce the elevation of epinephrine, but it is not clear how this may affect catecholamines in recovery.
- The rehab condition had no affect on post-rehab anaerobic power as measured by a dummy drag protocol.

It is difficult to pinpoint the exact nutrient or combination of nutrients that could cause these changes, and further research will be necessary to determine the specific components that elicited these outcomes.

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Publications

As a result of this study, the authors have prepared one manuscript that has been accepted for publication.

1. Horn, G.P., Gutzmer, S., Fahs, C.A., Petruzzello, S.J., Goldstein, E., Faney, G.C., Fernhall, B., Smith, D.L., "**Physiological recovery from firefighting activities in rehabilitation and beyond**", accepted for publication in *Prehospital Emergency Care*.

while two more are in preparation:

- Mattila, T.L., Petruzzello, S.J., Horn, G., Smith, D.L., "**Cognitive Behavior on a Continuous Performance Task Following Short-Term Firefighting Activity"**.
- Smith, D.L., Fernhall, B., Fahs, C.A., Goldstein, E., Horn, G.P., "**Changes in hemostasis after firefighting and during recovery**".

As outlined in section E.9. above, we have spent considerable effort disseminating the results of this study such that we can bring Research to Practice, by presenting data at multiple national at state Fire Service conferences and workshops including

- NIOSH Firefighter Exposures Workshop (Cincinnati, OH – October 2009).
- Illinois Fire Service Institute Winter Fire School (Champaign, IL - January 2010)
- Fire Department Instructors Conference (FDIC, Indianapolis, IN - April 2010)
- Incorporated into a 12 hour course on Firefighter Rehab at the Illinois Fire Service Institute Fire College (Champaign, IL June 2010)
- Fire Rescue International (FRI) conference (Chicago, IL - August 2010)

Inclusion of gender and minority study subjects

All subjects who completed the study were white males. One Black male was initially enrolled, but did not complete the study due reasons other than the study. We only recruited male firefighters due to the small sample size.

Inclusion of children

No children were involved in this study.

Materials available to other investigators

The data collected during this study will be shared with other investigators through peer reviewed journal articles and can be made available as requested.