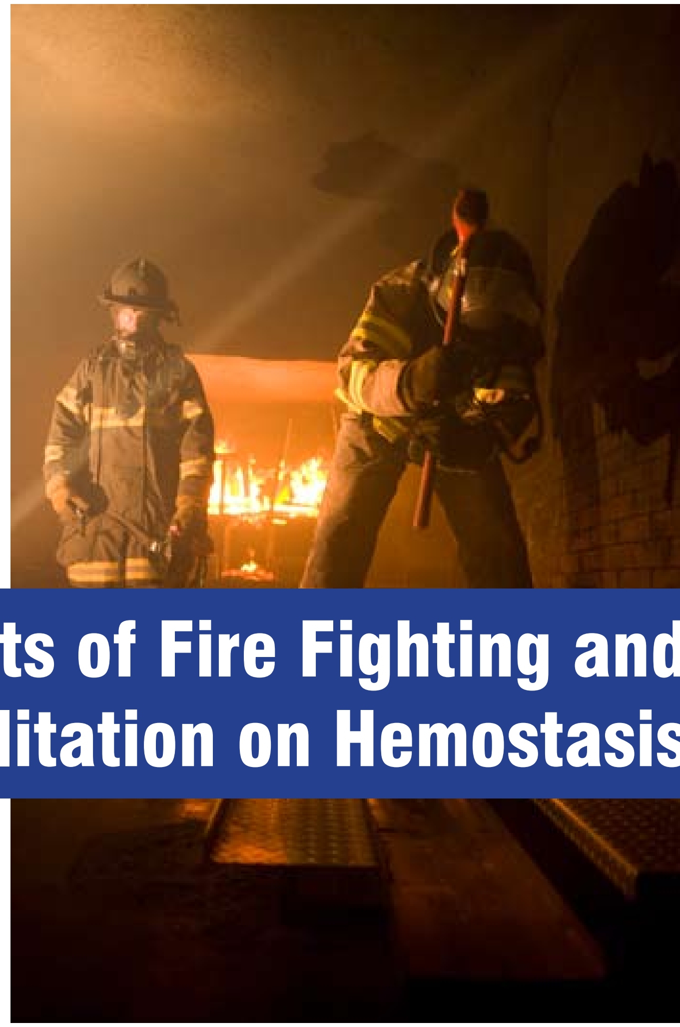

# The Effects of Fire Fighting and On-Scene Rehabilitation on Hemostasis

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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
**BMI** – Body mass index
**CBC** – Complete blood cell count
**CPT -** Continuous Performance Test
**DBP** – diastolic blood pressure (via auscultation)
**EPI** – Epinephrine
**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 fragment
**PFA** – Platelet function analyzer
**PPE** – Personal Protective Equipment
**RPE** – Ratings of perceived exertion
**RPP** – Rate Pressure Product
**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
**WAT** – Wingate Anaerobic Test

# Abstract

Fire fighting 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 declined, yet during this same period, the number of cases related to the leading cause of injury - overexertion/strain – remained relatively constant.

It is well recognized that fire fighting leads to increased cardiovascular and thermal strain. However, the time course of recovery from fire fighting is not well documented, despite the fact that a large percentage of fire fighting fatalities occur after fire fighting activity. Furthermore, on scene rehabilitation (OSR) has been broadly recommended to mitigate the cardiovascular and thermal strain associated with performing strenuous fire fighting activity, yet the efficacy of different 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 fire fighting on a broad array of physiological and psychological measures and several key cardiovascular variables. This study provided the first detailed documentation of the time course of recovery during 2½ hours post-fire fighting. Additionally, we compared two OSR strategies (standard and enhanced) to determine their effectiveness.

As expected, a short term bout (18 minutes) of fire fighting activity resulted in significant physiological, psychological, and cardiovascular strain. Immediately post-fire fighting, core temperature, heart rate, blood pressure and blood catecholamine levels were significantly elevated from baseline conditions. Platelet function and number, along with coagulatory and fibrinolytic variables, showed significant increases from baseline, suggesting that the hemostatic equilibrium was disrupted. Vascular function was significantly affected, as evidenced by a reduction in the ability to perfuse myocardial tissue (measured through the Subendocardial Viability Ratio – SEVR). Finally, firefighters' psychological state became significantly more dysphoric post-fire fighting.

Importantly, the time rate of recovery from many of these effects appeared to be closer to 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 showed that SEVR did 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) remained significantly elevated. As many heart attacks on the fireground occur following fire suppression, these results suggested a possible mechanism for the increased risk. At the 120 minute recovery period, firefighters' psychological state appeared to have returned to baseline conditions.

OSR had no effect on core temperature, suggesting that the active cooling process was no more effective than passive cooling in cool environmental conditions in which rehab was conducted in a cool room. There was also no significant effect on blood pressure, coagulation or

fibrinolytic variables or psychological measures as a result of the enhanced rehab protocol. 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. However, the practical/clinical significance of these small differences in heart rate are unclear. 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 is not due to hemoconcentration. Finally, epinephrine levels remained 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.

# Background

**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.

Fire fighting is a dangerous occupation, in part because firefighters are called upon to perform strenuous physical activity in hot, hostile environments. However, 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 declined from 57,100 to 36,880, yet during this same period the number of cases related to the leading cause of injury – overexertion/strain – remained relatively constant [17-31].

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

The purpose of this study was to describe the acute effects of fire fighting on a broad array of cardiovascular variables, hemostatic variables, vascular function, psychological/perceptual variables, cognitive function, and to document the time course of recovery of each. Additionally, we compared two OSR strategies (standard and enhanced) to determine their effectiveness.

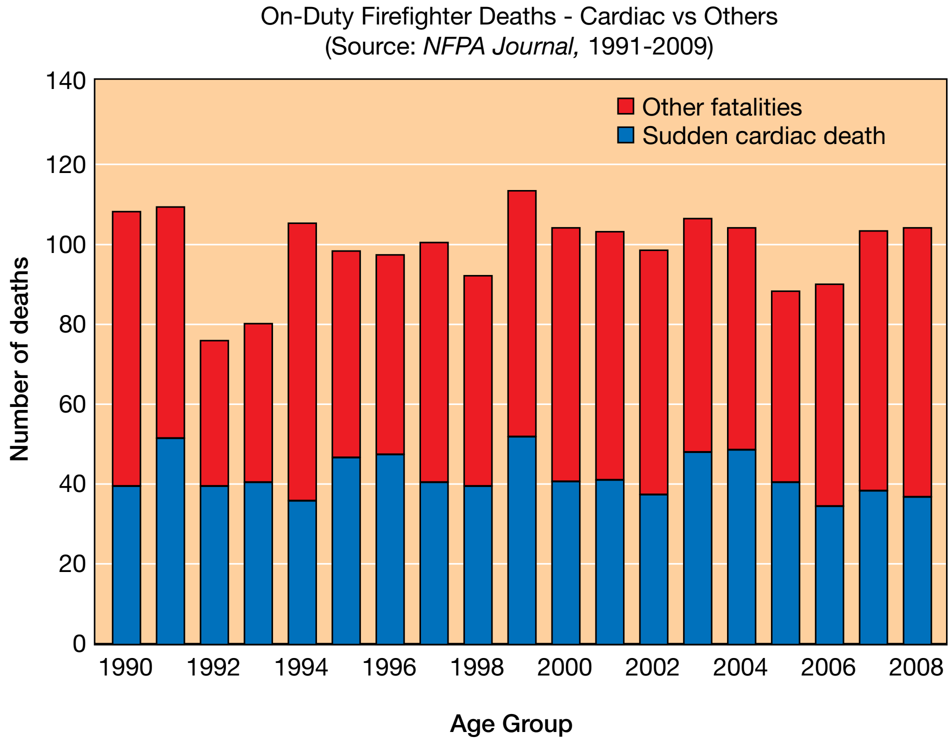



*Figure 1. Firefighter fireground fatality trends from 1990-2009 [1-16].*

**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 heart attacks result from the disruption of atherosclerotic plaque followed by platelet aggregation and the formation of an intracoronary thrombus [35]. The development of an acute coronary event involves the transition from chronic atherosclerosis (plaque build up) to acute clot formation [36]. Fire fighting activities involve strenuous muscular work in a hostile environment and leads to activation of the sympathetic nervous system (adrenaline surge). The increase in sympathetic nervous system activity can result in increases in heart rate and blood pressure that may cause a plaque to rupture. Thus, fire fighting is likely to dramatically alter the the blood vessel wall, platelets, and the the blood clotting system (hemostatic system).

Platelet activation and aggregation are the first step in blood clot formation. 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]. Our recent work has demonstrated that even short bouts of firefighting increases platelet number and activity. [40]

Hemostatic balance refers to the balance between blood clot formation (coagulation) and blood clot breakdown (fibrinolysis). Hemostasis is carefully regulated to keep blood fluid under normal circumstances and to promote the rapid formation of a blood clot when necessary. The rapid formation of a blood clot in response to injury is essential to the preservation of life and depends on the coordinated activity of platelets, the blood vessel wall, and plasma proteins (coagulatory and fibrinolytic factors). On the other hand, excessive clot formation or the inability to dissolve a clot once a wound is repaired can also present life-threatening challenges. A blood clot that forms in the cardiovascular system is called a thrombus, and it is the primary cause of a heart attack.

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 the 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 [41,42]. Fibrinolytic activity is also enhanced following exercise [41]. Importantly, however, research suggests that these coagulatory and fibrinolytic activities do not recover at the same rate following aerobic exercise [41,42]. 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 [43]. 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 [41]. 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 [41,44].

There is a lack of research investigating the effects of fire fighting 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 fire fighting activities and recovery from fire fighting on key hemostatic variables. A second aim of this study was to investigate the effectiveness of different on-scene rehabilitation interventions following structural fire fighting tasks. This study provides important scientific information regarding the effect of fire fighting 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.

## Specific Aims

The purpose of this study was to describe the acute effects of fire fighting on a broad array of cardiovascular variables - 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 fire fighting 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 fire fighting on hemostasis (platelet function, coagulatory and fibrinolytic potential).

- Investigate the effects of different OSR protocols on subsequent anaerobic performance and hemostatic variables following 120 minutes of recovery.
- Investigate the effects of OSR on vascular function.
- 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.

# Procedures

**Study Design**

Twenty-five firefighters were recruited to participate in a study designed to investigate the effects of strenuous fire fighting activity on hemostasis and the effectiveness of on-scene rehabilitation interventions on subsequent physical performance and physiological recovery. Each subject performed the same set of fire fighting drills on 2 separate days and participated in each OSR protocol. The two trials were separated by a minimum of 48 hours and administered in a counterbalanced fashion to ensure half of the participants received the control condition first and half the participants received 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 fire fighting drills. The subject then performed the prescribed fire fighting drills in full personal protective equipment (PPE). Immediately upon completion of the fire fighting 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-fire fighting, every five minutes during rehab, and every 15-30 minutes during recovery. 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. Additionally, vascular function was assessed via peripheral and aortic blood pressures and Subendocardial Viability Ration (SEVR) with an Atcor Sphygmocor system pre- and post-fire fighting 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.

Only the OSR protocol differed between the two trials. During the "control" trial, participants removed their helmet, hood, gloves, and bunker coat. Participants were provided with only water

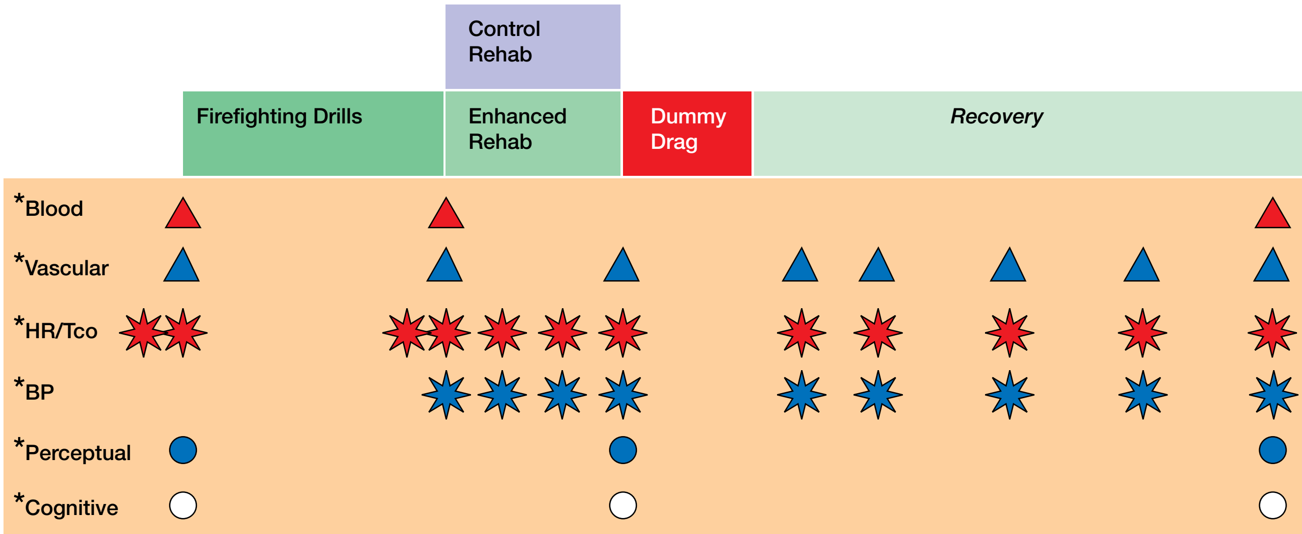



*Figure 2. Schematic of study design and timeline. Note that time is not drawn to scale.*

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 variability in how rehab is conducted. 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 [45-47]. In addition, during recovery, firefighters participating in the "enhanced" trial were provided with 355 ml of a commercially available recovery drink. Assessing maximal anaerobic power via a dummy drag protocol provided estimates 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.

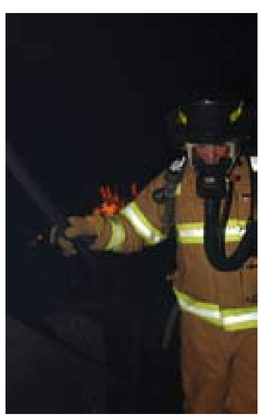
**Fire fighting drills**

The fire fighting 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. 48-43].

Each participant was paired up with a member of the research staff, trained in fire fighting, 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 kneeled 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.

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 95-105ºF. The prescribed fire fighting activities required subjects to work almost exclusively in the vertical location between the middle and floor thermocouple.



**Descriptive variables**

Descriptive variables were assessed prior to participation in the fire fighting drills. After participants read and signed an informed consent document, they were asked to complete 1) a 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).

**Body temperature**

Body temperature was continuously measured throughout both protocols using a Minimitter VitalSense monitor and a silicone-coated gastrointestinal (GI) core temperature capsule. Relatively little research has measured core body temperature of firefighters using GI capsules, which is the best technology for non-laboratory settings. Participants swallowed a small disposable core temperature sensor capsule (the size of a multivitamin), which passes through the body and is eliminated in feces within ~24 hours. While the sensor was in the GI tract, it transmitted temperature information to the remote recording device.

**Hemostasis and cardiovascular alterations**

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. Blood samples were used to assess hemostasis by measuring: 1) platelet number and function, 2) coagulatory potential, and 3) fibrinolytic potential (tPA and PAI-1).

**Plasma cortisol and catecholamines**

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

**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, TX). 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.

**Psychological/perceptual and cognitive function factors**

Psychological/perceptual and cognitive function factors provided self-assessment information, including: 1) how hard they perceive their effort during the fire fighting 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.

**Data analysis**

In order to examine the effects of strenuous fire fighting activity and recovery, and specifically, rehabilitation interventions, on hemostatic variables, cognitive function and psychological state measures, we conducted a study designed to compare enhanced and standard rehab conditions in the same firefighters (i.e., all participants repeated testing in both conditions) where we collected measurements pre-fire fighting, immediately after fire fighting and 120 minutes after rehab had completed. This type of study design was analyzed with a mixed multivariate analysis of variance (MANOVA). The effect of on-scene rehab on heart rate and core temperature was compared at 12 different measurement periods, including baseline (station blues), pre-fire fighting, immediately post-fire fighting, during rehab (entry, 5 min, 10 min, 15 min), and during recovery (15 min, 30 min, 60 min, 90 min, 120 min). This study also determined the effect of rehabilitation protocol on blood pressure during rehab and recovery at 9 measurement periods: during rehab (entry, 5 min, 10 min, 15 min), and during recovery (15 min, 30 min, 60 min, 90 min, 120 min). Vascular function also was assessed at 9 measurement periods: pre-fire fighting, immediately post-fire fighting, immediately after rehab, and throughout recovery (15 min, 30 min, 60 min, 90 min, 120 min). Finally, the effects of rehabilitation interventions on subsequent performance on the dummy drag task were compared using a paired t-test.

**Descriptive measures**

Table 1 presents data from 20 of the firefighters who completed 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 prescription 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 (25.4) 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.

It is important to note that the sample of the fire fighting population included in this study is leaner than that typical of the fire service population. For example, Clark et al. (2002) found that 80.7% of a cohort of career firefighters had a body mass index of greater than 25 [54]. Soteriades et al. (2005) conducted a study in which more than 300 career firefighters underwent a baseline physical and were retested after five years [55]. At these two timepoints, the average BMI was 29 and 30, respectively. In a previous study conducted at IFSI, which included 110 firefighters assessed for body composition, the average BMI was greater than 28 while 75% of the participants had a BMI greater than 25 and more than a quarter were classified as obese [56].

*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 |

**Heart rate and core temperature**

As seen in Figure 3, heart rate increased rapidly with the onset of fire fighting 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 exited 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 did not return to baseline until well after the 15 minute rehabilitation period was completed.

As Figure 3 shows, heart rate is strongly affected by fire fighting activities and the recovery from such activities as well as by the type of rehab undertaken. With a more detailed analysis, 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 analysis also showed that heart rate returned to baseline condition (e.g., no longer elevated) at 15 minutes into recovery for the standard condition (or more than 35 minutes post-fire fighting), but at 60 minutes into recovery for the enhanced rehab condition.

Core temperature also increased significantly during the fire fighting activities and for the first few minutes of rehabilitation (Figure 3). During fire fighting, core temperature increased at a rate of 0.067$^{o}$F.min$^{-1}$. These results are consistent with an earlier study that reported a rate of increase of 0.058$^{o}$F.min$^{-1}$ during rescue and fire attack activities [57]. Furthermore, for the first seven minutes after fire fighting (prior to entering rehab), core

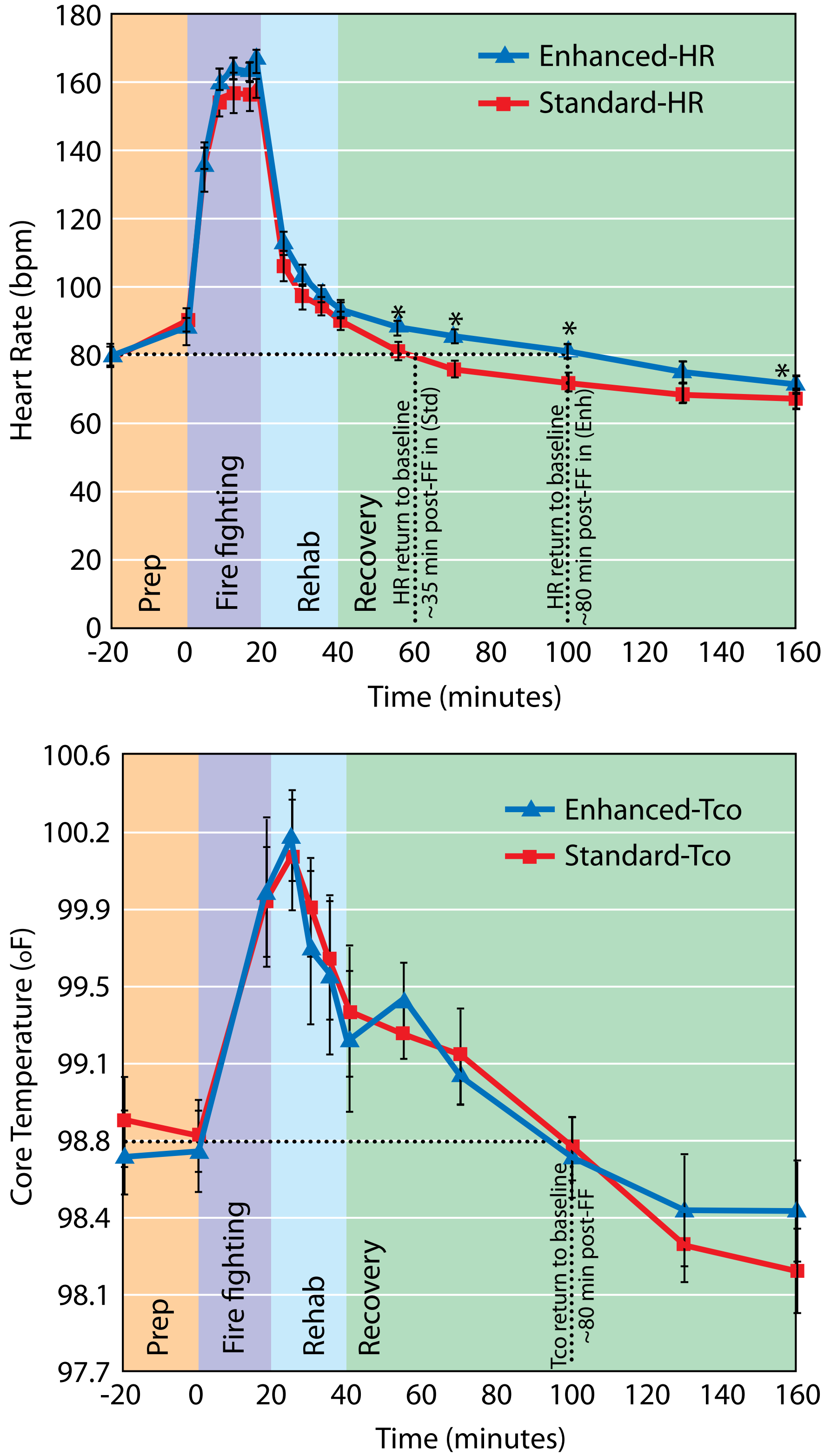



*Figure 3. Changes in heart rate (top) and core temperature (bottom) throughout the test protocol. Data from complete sets only (n=12 for heart rate, n=8 for core temperature.)* indicates significant effect of rehab conditions at these time points.*

temperature continued to rise at a rate of at least 0.036°F.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 a significant effect of the timeline of recovery on core tempeature, there was no significant difference in core temperature between rehabilitation conditions. However, it is again important to note that firefighter's core temperature does not return to baseline until approximately 80 minutes post-fire fighting.

### Blood Pressure

Blood pressure was assessed via auscultation prior to entering the training course (baseline),

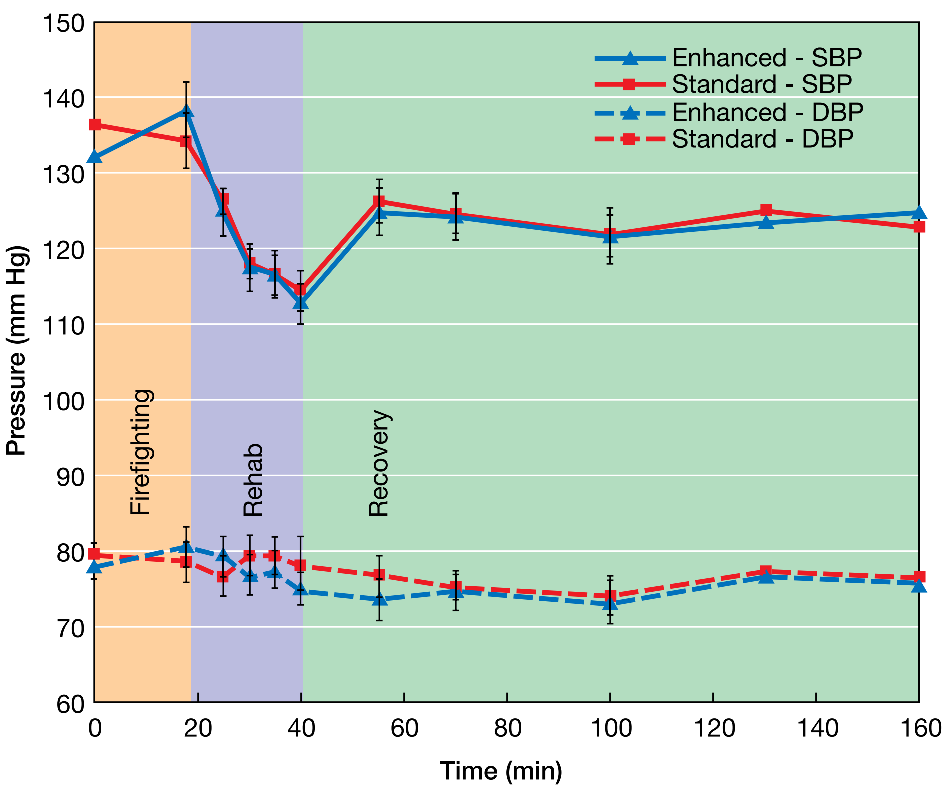



*Figure 4. Changes in systolic (SBP) and diastolic (DBP) blood pressure throughout the test protocol. Data from complete sets (n=14).*

upon entry into rehabilitation, at 5 minute intervals within rehabilitation, and at 15-30 minute intervals throughout recovery (Figure 4). Systolic blood pressure (SBP) was strongly affected by fire fighting activities and recovery from these activities, but diastolic blood pressure (DBP) was not. Furthermore, rehabilitation protocols did not influence either SBP or DBP. Post-fire fighting 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 slightly elevated due to anticipation of fire fighting activity. In a similar group of firefighters (similar age, BMI, and fire fighting experience), we reported resting blood pressures of 126 mmHg [58].

Systolic blood pressure dropped rapidly during rehabilitation. On average, SBP decreased 22.5 mmHg - from 136.5 immediately post-fire fighting to 114 at the end of rehabilitation. In 5 cases, SBP dropped by more than 30 mmHg 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) was 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 known as post-exercise hypotension. Post-exercise hypotension is caused by a reduction in vascular resistance, mediated by changes in autonomic nervous system and vasodilator substances [59]. Work in hot environments (or in PPE) can exacerbate post-exercise hypotension due to loss of plasma volume and a greater drop in vascular resistance due to vasodilation of the cutaneous

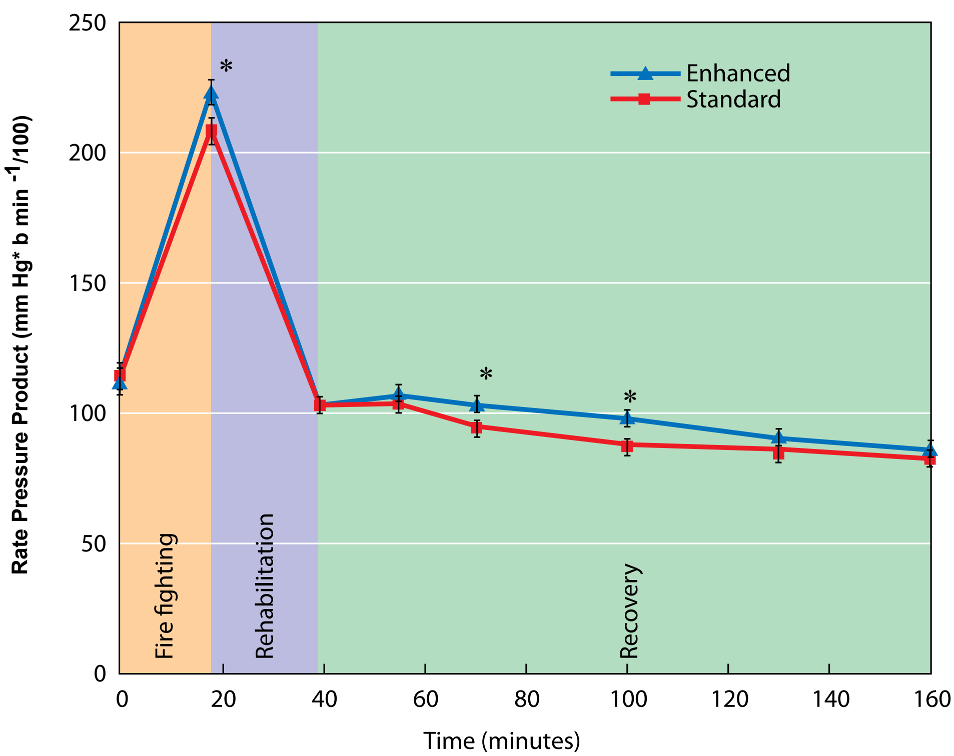



*Figure 5. Changes in Rate Pressure Product (RPP) throughout the test protocol. All timepoints are significantly different than pre-fire fighting condition, dropping below this level after rehabilitation (* indicates significant effect of rehab condition).*

circulation [60]. In 17 of the 42 observations, the difference between post-fire fighting and recovery was greater than 10 mm Hg and in 6 of the 42 observations, the difference 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.

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 suggest 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 [58]).

While blood pressure is routinely monitored during rehabilitation, most guidelines are concerned about dangerously elevated blood pressure values following strenuous fire fighting 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.

As shown in Figure 5, Rate Pressure Product (RPP) changed significantly with time. 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 significantly lower in the standard condition.

**Hemostatic variables**

*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.

$$\%\Delta PV = 100\left[\frac{Hb_B}{Hb_A} x \frac{\left(1 - Hct_A x10^{-2}\right)}{\left(1 - Hct_B x10^{-2}\right)}\right] - 100$$

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 fire fighting activities, participants in the standard and enhanced condition lost 6.7% and 4.2% of their plasma volume, respectively, with no measureable difference between conditions. During the rehab and 120 minute recovery period, participants' plasma volume increased by 6.9% and 6.1% from post-fire fighting levels, again with no significant difference between conditions. From the pre-fire fighting condition to the 120-post condition, firefighters plasma volume changed by -0.56% and +1.44% in each condition, resulting in a PV level that was not statistically different from baseline after 120 minutes of recovery. Thus, both rehab conditions were equally effective in rehydrating firefighters from this relatively short bout of fire fighting activity.

*Platelet number and function*

Platelet count was assessed via CBC analysis as outlined above. 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 increased significantly (18%) and platelet closure time decreased significantly (15% ADP, 20% EPI) following fire fighting activity suggesting increased thrombotic potential in the period immediately after fire fighting (Figure 6). There was no condition effect for platelet number or function between the pre- and post-fire fighting condition. The increase in platelet count seen post-fire fighting 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).

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 PV 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 likely difference between conditions and may have had an effect on platelet concentration. At the same time, platelet aggregation was enhanced following fire fighting activity (as evidenced by a shorter time to occulsion) and remained elevated following 120 minutes of recovery. The decreased closure time that persisted even after 120 minutes of recovery

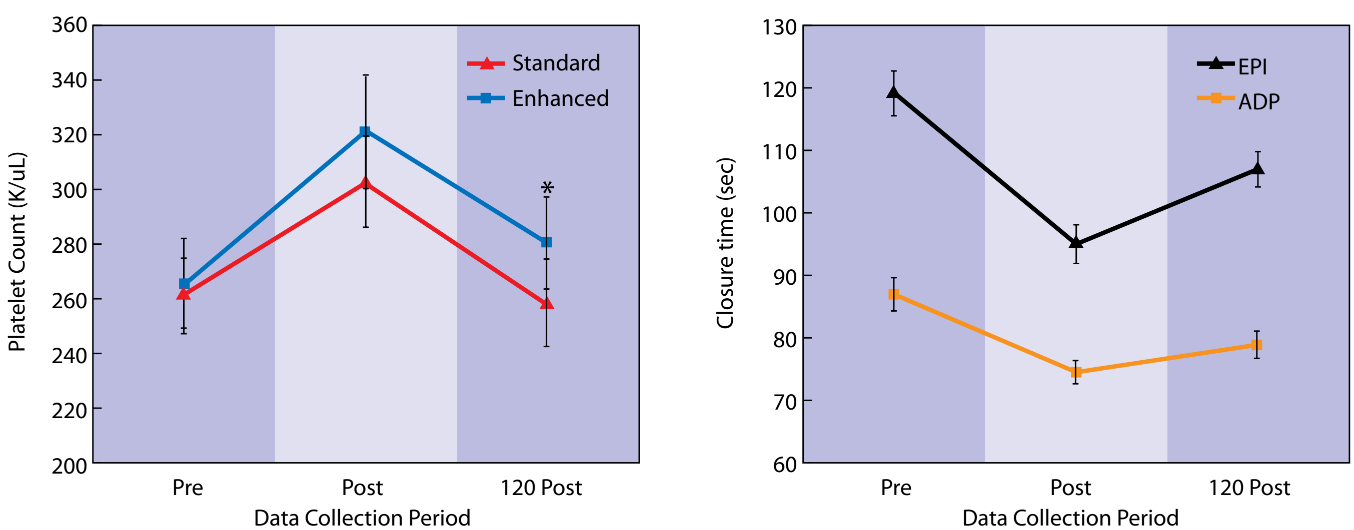



*Figure 6. Platelet count (left) and platelet activity measured via closure time when blood exposed to ADP and EPI (right) at pre-fire fighting, post-fire fighting, and post 120 minutes of recovery. Data from complete sets (n=17 for closure time and n=21 for platelet count).*

suggests that there is an increased risk of thrombosis at least 2 ½ hours after completion of short bouts of fire fighting activity in relatively young, healthy firefighters.

*Coagulation and fibrinolysis*

As shown in Figure 7 (left) both Tissue Factor and Factor VIII significantly increased immediately post-fire fighting. Additionally, Factor VIII remained significantly elevated at 120 minutes post-recovery. None of these coagulatory variables were affected by the different rehab protocols. These results indicate that even short bouts of fire fighting 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-fire fighting to post-fire fighting conditions, but returned to baseline conditions at 120 minutes post-recovery regardless of rehab condition (Figure 7 - right). 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-fire fighting 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-fire fighting 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 [43].

*Catecholamine response*

As shown in Figure 8, we measured an increase in epinephrine levels from baseline to immediately post-fire fighting activity and a significant decrease from levels in the time between measurements taken immediately after fire fighting to those taken after 120 minutes of recovery with the enhanced rehab but not with the standard rehab. In addition, we measured an increase in norepinephrine from baseline to immediately post-fire fighting, followed by a decrease in levels after 120 post-fire fighting although there was no significant difference between the two treatments.

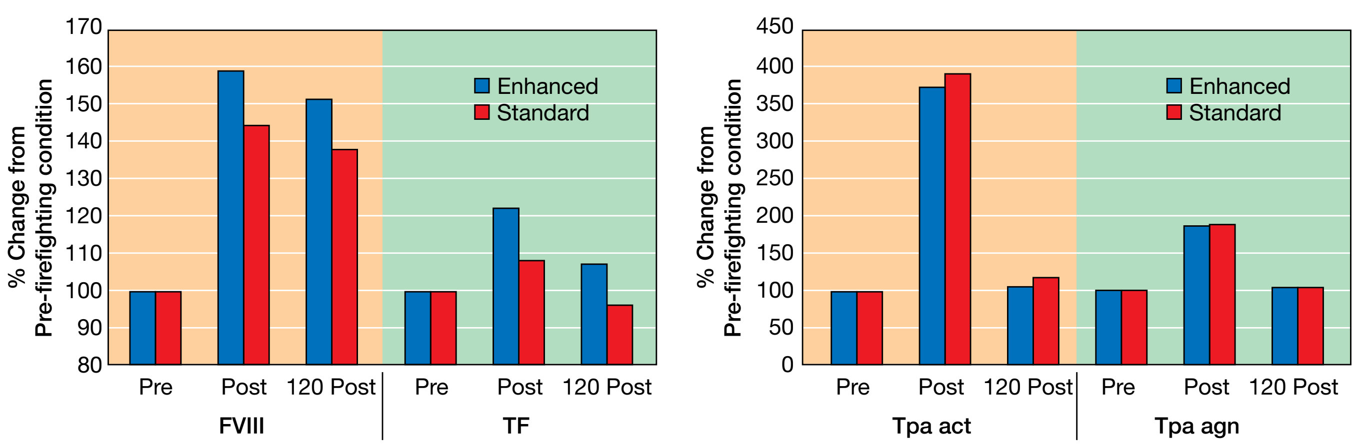



*Figure 7. (left) Factor VIII increases post-fire fighting and remain elevated at 120 minutes into recovery, but (right) Fibrinolytic variables that increase post-fire fighting return to near baseline levels after 120 minutes of recovery, suggesting a potentially hypercoagulable state in the hours after fire fighting.*

The finding that catecholamines were significantly higher than baseline more than 2 hours after fire fighting 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 fire fighting activities, it is reasonable to believe that true resting levels of catecholamines would have been lower than the pre-fire fighting values we reported here.

**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 2). The peripheral blood pressure measurements closely matched those obtained via auscultation. In general, there was an effect of time (e.g., changed significantly during fire fighting and recovery) for both systolic blood pressure and mean arterial pressure, with blood pressure decreasing below baseline levels following rehabilitation. However, there was no difference between rehab conditions. Peripheral diastolic blood pressure did not change significantly throughout the study. Aortic blood pressure followed a similar pattern, systolic and mean arterial pressure changed significantly with time but diastolic pressure did not, and there was no significant effect of rehab. 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

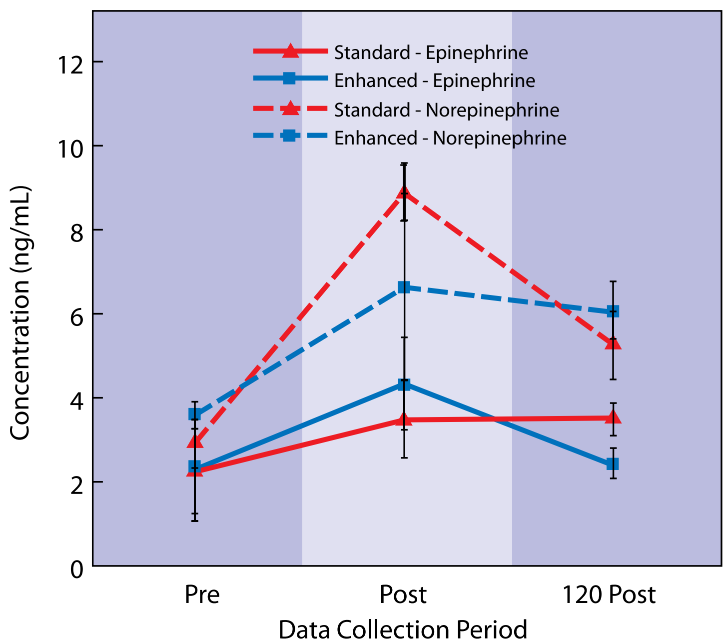



*Figure 8. Epinephrine and norepinephrine at pre-fire fighting, post-fire fighting, and post 120 minutes of recovery. Data from complete sets (n=19 and 18 for epinephrine and norepinephrine, respectively).*

Viability Ratio (SEVR) provides an estimate of the arterial system's ability to 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 immediately post-fire fighting and recovered rapidly during rehab and into recovery (Figure 9). 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 from the standard condition at 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.

*Myocardial oxygen supply and demand*

The decrease in subendocardial viability ratio (SEVR) immediately post-fire fighting reflects a decrease in myocardial perfusion relative to cardiac workload, while the significant increase in rate pressure product (RPP) reflects an increase in the myocardial tissue demand for oxygen. However, as Figure 5 shows, RPP rapidly returns to levels below pre-fire fighting values by the first recovery time period. As the pre-fire fighting

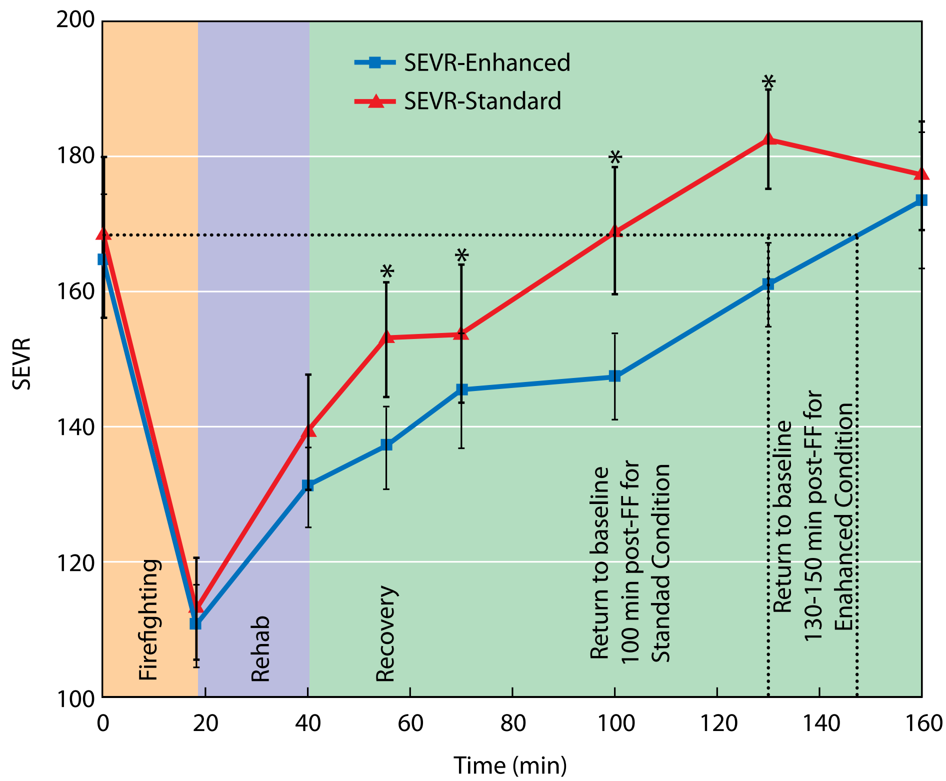



*Figure 9. Changes in Subendocardial Viability Ratio (SEVR) throughout the test protocol. Data from complete sets only (n=10) * indicates significant condition effect at these time points.*

| | | | | Rehab | | | Recovery | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre-FF | Post-FF | 15 min | 15 min | 30 min | 60 min | 90 min | 120 min | | | |
| | | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Condition | Time | Post hoc |
| 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) | ns | p< .001 | 2>3,6,7,8;4>8 |
| 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) | ns | ns | |
| 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) | ns | p= .001 | 2>6,7 |
| 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) | ns | p<.001 | 1>3; 2>3,8 |
| 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) | ns | p< .001 | 2>3,7,8 |
| 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) | ns | ns | |
| 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) | ns | p= .001 | 2>6,7 |
| 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) | ns | p=.002 | 1>3 |
| 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) | p=.016 | p< .001 | 1>2,3; 2<3,4,5,6,7,8;3<7,8; 4<7,8;5<8;6<7 |
| 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) | | | |

*Table 2. Statistical analysis of arterial function asssessed via radial artery pulse wave analysis during fire fighting, rehab and recovery.*

RPP levels may be slightly elevated from baseline due to an increase in heart rate at pre-activity, and RPP remains relatively stable throughout recovery, it is expected that the RPP has recovered to near baseline levels by this time period. However, SEVR does not return to pre-fire fighting levels until sometime between the 30 and 60 minute time points for standard 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.

**Psychological & Cognitive Responses**

The fire fighting activities undertaken in the trial resulted in significant psychological effects as shown by significant time main effects. However, there was virtually no difference between the different rehabilitation conditions (Table 3). Overall, findings revealed a more negative psychological profile following fire fighting activities compared to the pre-fire fighting state followed by a return to pre-fire fighting levels following recovery and rehabilitation. Feeling Scale ratings decreased ~1.5 units, revealing a decrease in pleasantness immediately following fire fighting. Self-rated Energy increased following fire fighting (~16.4%), but then decreased significantly from that post-fire fighting 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-fire fighting 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-fire fighting levels following rehabilitation (~13.7%). Consistent with the decrease in Energy, self-rated Tiredness decreased significantly (~18%), but then increased significantly from that post-fire fighting level during the rehabilitation period (~28.7%). Taken together, each of these psychological constructs indicate that the effects of the fire fighting 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 fire fighting activities and then again 120 min after completion. (Only Feeling Scale was assessed

*Table 3. Psychological measures pre-fire fighting, immediately post-fire fighting, and 120 minutes post-rehab.*

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

immediately following the activities). In spite of this relatively long lag time, these constructs still revealed a generally more uncomfortable psychological profile following fire fighting 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.

As shown in Table 4, 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-fire fighting activities (~25 msec), indicating faster responses following fire fighting activity; RTs at the end of the rehabilitation period were not different from pre-RT values.

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 fire fighting 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 fire fighting 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 fire fighting activity. The faster performance could be reflected by the perception of greater Energy and decreased Tiredness.

**Analysis of anaerobic power**

Immediately post-rehab, firefighters' ability to perform a simulated rescue 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 5). The rehab condition displayed no significant effect 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 5. 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 aerobic power protocol was modified from the proposed Wingate Anaerobic Test (WAT) after initial pilot testing. Several subjects reported lightheadedness and nausea after

*Table 4. Cognitive function assessed via Continuous Performance Test (CPT) pre-fire fighting, immediately post-fire fighting, 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) | | | | |

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 fire fighting 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.

# Conclusions

Several important conclusions can be drawn from this study regarding the effect of fire fighting activities on the cardiovascular system and the time rate of recovery.

It should be stressed that these results were generated from a population of young, healthy firefighters who were immediately removed from the fire fighting 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 fire fighting 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.

**Summary of effect of fire fighting recovery**

Fire fighting activities resulted in a significant elevation of core temperature and heart rate. Importantly:

- The recovery from these effects occurred over a timecourse of hours even after a relatively short bout of fire fighting in a relatively young and healthy population. Plus, the firefighters 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 fire fighting activities and into the rehab period. Blood pressure returned rapidly to stable baseline levels in recovery. While firefighters often are concerned about elevated blood pressures, this study suggested that firefighters should be aware of the potential dangers of hypotension as well.
- Platelet count and function were significantly elevated as a result of fire fighting activities and platelet function remained elevated even after 120 minutes of recovery. Platelet count was affected by rehab condition - it may or may not return to baseline post-120 minutes of recovery. This study suggests that a hypercoagulable state occurred after fire fighting activities and did not fully return to baseline even 2½ hours after fire fighting has ceased.
- Both coagulation (Factor VIII and Tissue Factor) and fibrinolysis (tPa activity and antigen) were elevated immediately post-fire fighting, suggesting that factors on both sides of the hemostatic equilibrium were elevated. However, at 120 minutes post-fire fighting, all fibrinolytic factors returned to baseline, while Factor VIII remained significantly elevated, tipping the hemostatic balance towards coagulation.
- Arterial function assessed via arterial tonography revealed that the peripheral blood pressure values very closely matched 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 fire fighting is on the order of hours, not minutes.

- Catecholamine levels were significantly elevated post-fire fighting and remained elevated at 120 minutes post-recovery.
- Firefighters had a generally more dysphoric psychological profile following fire fighting activities that returned to baseline at 120 minutes post-recovery. Cognitive function values actually appeared to improve immediately post-fire fighting.

**Summary of effect of rehab condition**

- 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. However, the practical/clinical significance of the elevated heart rate (~5 bpm) and SEVR (~30) in recovery is unknown.
- The rehab condition had no effect on core temperature, suggesting that the cooling portion of the intervention had no effect in the mild ambient environment in which we conducted rehab. 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 platelet 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 fire fighting), so this effect is not likely due to hemoconcentration.
- Epinephrine levels remained elevated post-recovery from 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 effect on post-rehab dummy drag, which suggested that the maximal anaerobic power was not affected by the rehab protocol.

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

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