Physiological Stress Associated with Structural Firefighting Observed in Professional Firefighters

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FOREWORD

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My fire service career spans 30 years; and I have lost track of the thousands of firefighters that I have had a chance to meet. Yet, when the name of Dr. Jim Brown is mentioned in a conversation, I am struck by the image of a person who has never pulled a hose line or climbed a ladder. But this man however will be remembered as one of the true leaders of the fire service. From our first meeting I was impressed by his sincere interest in the well being of firefighters. It was a meeting that I will never forget.

Fast-forward to 2007, Dr. Brown received approval of a firefighter health and safety grant. This grant finally gave the fire service something we desperately need; accurate data on the physical strain a firefighter endures. For six months Dr. Brown and his associates lived, ate and slept with firefighters. This research group compiled data on the physical effects of firefighters at working fires and EMS incidents, from sleeping at night to nights with no sleep, from the coldest nights of winter to the warmest days of summer.

After a few months into the study, I met with Dr. Brown and he provided information and data from the study. I became even more fascinated by what this report will mean to the fire service today and in the future. This report will give the leaders of the fire service the needed data to tackle the prevalent issues to firefighters such as physical stress on the body, sleep disorders and the necessity of rehab at emergency incidents. Using this data as a road map, the fire service can make a commitment to address the needs and improve the quality and longevity of the firefighter.

Therefore, it is a pleasure and a unique honor to be able to write a forward of this report, and it is my honor to be associated with this project. Also, as a third generation firefighter and the father of a firefighter it is my duty to constantly work with visionaries like Dr. Brown to improve conditions for all those that follow me.

Robin Nicoson

Chief of Safety

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INTRODUCTION

INTRODUCTION

U.S. Department of Labor statistics indicate that firefighters are three times more likely to die on the job than any other occupation (43). Improvements in tactics and equipment have reduced the overall number of on-duty deaths. However, the number of annual firefighter deaths in the US remains high. Recently released data indicates that 104 U.S. firefighters lost their lives on duty during 2006 (3) while 115 were lost in 2005 (2). Of the deaths reported during 2005, more than half (54%) can be attributed to stress or overexertion including heart attacks, cerebrovascular events (stroke) or other types of cardio-respiratory system collapse (heat exhaustion etc.). These 2005 stress and overexertion deaths rates echo data reported over the last 25+ years (1). With the reduction of fatalities related to other causes, the prevalence of cardiovascular-related deaths has emerged as a significant problem for the fire service. On average, 50% of on-duty firefighter deaths are due to cardiovascular system failure (1).

The fire service responded to this high incidence of heart attack and cardiovascular-related fatalities with programs to reduce this type of line of duty death (LODD). The National Fire Protection Association (NFPA) has established guidelines governing health and fitness characteristics of firefighters and firefighter candidates. NFPA 1582, outlines mechanisms of health-related physical fitness assessment and physical training programs to improve fitness. The stated goal of these standards is to reduce LODD by improving the general health of firefighters. Indeed, improving the overall health of firefighters would significantly improve their fire ground survivability, especially those with underlying cardiovascular disease or cardiovascular disease risk factors. However, recent investigation of the physical stress associated with firefighter training activities suggests these goals may fall short of protecting firefighters from the risk of physical overexertion. Data collected during a 2005 study by Maryland Fire & Rescue Institute (MFRI), indicate that firefighter fitness level and pre-participation hydration status were the primary determinants of the cardiovascular stress experienced by firefighters (2). More importantly, physiology of firefighters described as having average fitness levels responded in a manner similar to those of low fitness levels during training activities. The study also pointed out that firefighters demonstrating high levels of physical fitness experienced much less physical stress during the same training activities. In addition, that study pointed out that regardless of fitness level, firefighters demonstrating even moderate levels of dehydration experienced severe levels of cardiovascular stress. These findings suggest that firefighting activity may represent greater levels of physical stress than previously expected and may be in excess of what standing fitness goals may alleviate. Recent efforts to monitor training activities have provided much needed insight into the stress of firefighting activities. However, little or no useful physiological data exists from real fire ground operations. Realization of this fact has led to recent initiatives to secure such information.

A workshop convened by the National Institute of Standards and Technology (NIST) identified firefighter physiology as a significant need in the fire service (44). More recently, the National Fallen Firefighter Foundation (NFFF) conducted a symposium to identify and prioritize research needs within the fire service (45). The workshop report identified firefighter physiological responses to heat stress and acute physiological responses to emergency call as high priority areas of research need. The study described herein undertook this challenge by measuring firefighter physiology on the real world fire ground.

Study Goals

A primary goal of this project was to investigate the physical rigor of real fire scene work. Fire scene work tasks may differ widely with respect to their cardiovascular and respiratory stress. Therefore, the project sought to illustrate normative data for multiple fire ground tasks including fire attack, search & rescue, exterior ventilation, and overhaul activities.

The presence of an independent observer (scientist) on the fire ground provided opportunity to describe the fire scene environment under which firefighter physiology data was being collected. Subsequent analysis allowed the identification of the fire scene factors having the greatest impact on firefighter physiology. Further, these factors were also prioritized with respect to their relative importance.

The full access to firefighters provided by the study also allowed some investigation into the psychological aspects of answering emergency call. Specifically, a comparison of emotional stress and anxiety between on and off duty life may provide some insight in to a source of firefighter risk for development of heart disease.

Research Partnerships

Accomplishing the goals of this project required the cooperation of many organizations. A research consortium was established among the primary organizations involved. However, the ultimate responsibility for success or failure of the project lay with the individual firefighters invited to participate. It was the role of the following institutions to provide support for participating firefighters.

Indiana University Firefighter Health & Safety Research

The Firefighter Health & Safety Research program is component of Indiana University's Harold H. Morris Human Performance Laboratory. It is governed by the Department of Kinesiology and the School of Health, Physical Education & Recreation. The program was organized to specifically to support faculty research interests in the health and safety of First Responder populations. The mission of the program is to support the reduction of firefighter line of duty deaths through applied research.

Indianapolis Fire Department

Indianapolis is a rapidly growing, outstanding community that is recognized as a great place to work and live. Hailed as the 12th largest city in America and home to a diverse population, the city attracts millions of visitors annually. Indianapolis is proud to offer its citizens a world class Fire Department. IFD, with over 150 years of proud tradition, is made up of men and women with diverse cultural backgrounds, each who have taken the oath to protect and serve the citizens of Indianapolis.

Indianapolis Firefighters work closely with the residents and businesses through fire prevention and safety education programs to make their city as safe as possible. The Indianapolis Fire Department is made up of over 940 sworn members and a 50-member civilian support team. The IFD fire service district covers 198 square miles of downtown Indianapolis and surrounding areas.

With a strong history of being progressive thinking forward in areas of firefighter health and safety, IFD provided an ideal organization to participate in the study. Health status and work capacity of IFD firefighters are regularly tested. This provided a population of highly trained, medically supervised career professional firefighters.

Indianapolis Metropolitan Professional Firefighters Association

The International Association of Fire Fighters granted Indianapolis Firefighters their Charter in October of 1934. Today, Indianapolis (Marion County) and its citizens are served by 17 different fire departments are represented by Local 416. Currently Local 416 membership includes over 2,300 firefighters, paramedics, dispatchers and retirees. Local 416 fosters and encourages a high degree of skill, and efficiency, the cultivation of friendship among its members and the support of moral, intellectual and economic development of its membership.

Endorsement of the project by Local 416 leadership facilitated the recruitment of firefighters for the research project. A union representative accompanied the scientific team to fire stations during recruitment. Their presence put potential subjects at ease and helped remove any suspicions or concerns the firefighters had. In addition, Local 416 worked closely with the research team to provide support and to facilitate compensation of participating firefighters.

Indiana Homeland Security

The Indiana Department of Homeland Security, in collaboration with citizens, government, and private entities, will achieve the common purpose of preventing, protecting against, responding to and recovering from man-made or natural threats and events to people, property, and the economy. The IDHS Division of Fire and Building Safety investigates suspicious fires, promotes prevention, administers building plan review, enforces fire and building safety codes in all public buildings, regulates and coordinates emergency services, emergency medical services and hazardous material response and oversees and conducts inspections of child care facilities, boilers and pressure vessels, elevators and amusements. The IDHS Office of the State Fire Marshal represented Indiana's volunteer firefighters throughout the study. Upon completion of the study, this office facilitated distribution of pertinent information to Indiana's volunteer firefighting force.

Embedded Scientists

A unique aspect of the study was the need for continuous scientific observation of on-duty firefighters. IFD rotates three shifts of firefighters on a 24-hour on / 48-hour off duty cycle. To accomplish continuous monitoring, a scientist was assigned to each IFD shift. The scientist lived in the fire station and accompanied firefighters on all fire runs. Scientists were trained in fire station etiquette and fire ground safety procedures. Scientists worked under the command of the station's shift officer and Incident Commander at the station and on fire scenes respectively. Scientists were uniformed for identification both in the fire station and on the fire ground. Scientist uniforms distinguished them from IFD personnel but made them easily recognizable as fire ground qualified.

Delimitation of the Study

The study is bound by the architectural and geographical character of Indianapolis, Indiana. In order to obtain sufficient fire scene data, a high-fire-volume region of the city of Indianapolis was chosen for the study site. Architecturally, this area of the city is populated by single and double wood framed residences. Typically, these structures are less than 2000 ft^2. From a geographical stand point, Indianapolis enjoys a fairly moderate climate. Accordingly, Indianapolis does not provide exposure to extremes of weather, hot or cold. The study was conducted during the winter months in order to avoid the complication of atmospheric heat stress. The goal of the study was to assess, as much as possible, the physical aspects of fire fighting work. The avoidance of added heat stress provides a more focused examination on that factor. This will allow us to identify firefighter and fire scene variables impacting the physiological responses of firefighters.

Unfortunately, these delimiting factors may limit the applicability of the findings to areas outside Indianapolis or central Indiana. In order to address the impact of weather and other atmospheric extremes (elevation), a future study is planned to assess the same physiological stress on firefighters in areas of the country that will provide access to these weather extremes. In addition, US cities providing access to other architectural character will also be utilized in that future study.

Finally, the study represents physiological responses of a firefighting corps that is known to be well trained technically and monitored by a medical program adhering to NFPA standards (31). This group of firefighters was chosen because it may be used as a model corps. Other, less fit firefighters should not expect to respond in a similar manner.

Scope of the Report

This document reports the physiological aspects of structural firefighting and the psychological impact of answering emergency call as outlined in the associated application for funding. The use of continuous physiological monitoring to capture data required the report resulted in the capture of much information not associated with fire scenes. Every heartbeat, breath, and footstep is captured throughout the duty shift. As a result, many other aspects of firefighter physiology were captured and should be evaluated despite being outside the scope of the original project proposal. This report is limited to reporting the goals of the original funded protocol. Other physiological issues identified during the course of the study will be pursued in subsequent peer-reviewed scientific publications. These subsequent reports will cover such topics as sleep dysfunction, Heart rate variability analysis for determination of sympathetic / parasympathetic balance, respiratory mechanics associated with positive pressure SCBA systems, and a comparison of physical activity levels on and off duty.

DEFINITION OF TERMS

Physiology

HR: Heart Rate in beats per minute

HR_{MAX}: Maximal heart rate as determined by the formula: HR_{MAX} = (220-Age)

Alarm HR_{MAX}: Maximal HR attained during the first 90 seconds after alarm.

%HR_{MAX}: Percentage of a person's predicted maximal heart rate

Alarm %HR_{MAX}: Percentage of predicted maximal HR following alarm

PHR*t*: Time to reach peak heart rate

V_E: Minute ventilation or volume of air moved by the lungs in one minute expressed in Liters of air per minute.

Tidal Volume: Volume of air moved with each breath expressed in milliliters

Breathing Freq: Frequency with which breaths are taken expressed in breaths per minute.

Vo_{2MAX}: Maximal rate Oxygen consumption, generally considered a measure of cardiovascular fitness (expressed in milliliters of Oxygen consumed per kilogram of body weight per minute).

EPOC: Excess Post-exercise Oxygen Consumption. Consumption of Oxygen in excess of that dictated by physical demand after work ceases.

AccM: Physical activity score derived by integration of rectified outputs of all accelerometer axes. Output samples are converted to positive values and added together to give a score representative of total body movement.

SBP: Systolic Blood Pressure in millime ters of Mercury

DBP: Diastolic Blood Pressure expressed in millimeters of Mercury

Firefighting

Alarm: 90 second period of time following the sounding of audible alarm to alert personnel.

Ingress: Period of time from exiting the fire station until arrival at fire scene.

Fire Attack: Hose line work executed by an En gine company to extinguish fire

Ventilation: Vertical or horizontal ventilation of a burning structure generally executed by a the outside team of a Ladder company

SAR: Search and rescue operations executed by the outside team of a Ladder company or by a Rescue Squad crew

Ladder: Fire apparatus staffed by a company of four firefighters and carrying a rear-mounted aerial ladder, several ground ladders, extrication and EMS gear.

Engine: Fire apparatus staffed by a company of four firefighters and carrying 1.5" & 2.0" hand lines, 3" & 5" supply lines, 250 gallons of water, and basic& advanced life support EMS gear.

Squad: Fire apparatus staffed by two firefighters and carrying basic and advanced life-support EMS gear along with extrication equipment.

TSU: Tactical Service Unit:. Apparatus dispatched on working incidents to support fire scene operations.

PPV Fan: Positive Pressure Ventilation: Fan used to clear smoke from a structure..

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Duration: Elapsed time to complete a single phase of fire scene work.

Brief Review of Literature

BRIEF REVIEW OF LITERATURE

Firefighters face many hazards, including chemical exposure, thermal injury, and trauma. From 1995 to 2007, there were 1,345 on-duty firefighter fatalities (1-3). What is surprising, however, is that over 44% of these deaths were classified as sudden cardiac death (1-3). Volunteer firefighters (VFF) fall victim to sudden cardiac death at a disproportionate rate when compared to professional firefighters (PFF). Of the 440 sudden cardiac death victims from 1995 to 2004, nearly 70% were VFF (1). Of the victims over 60 years of age, 93% were VFF (1). It was proposed that this might reflect the tendency of VFF to remain active beyond retirement age. From 2001 to 2005, over 80% of the victims were over the age of 40 and over half were over the age of 50 (4). In a review of all on-duty firefighter deaths between 1994 and 2004, 32% were associated with fire suppression duties, 31% involved firefighters responding to or returning from alarms, 13% occurred during training activities, and the remaining 24% occurred during other firefighting duties, such emergency medical services and administrative tasks (5). The author suggests the risk of sudden cardiac death during fire suppression may be increased due to inadequate physical fitness, the presence of cardiovascular risk factors, and existing medical conditions (5). Possible explanations for the increased risk of sudden cardiac death in firefighters include psychological stressors, heat stress, smoke and chemical exposure, and high physical demands (6-7). It is unclear which and to what degree occupational and personal risk factors increase the risk of sudden cardiac death.

The prevalence of cardiovascular disease risk factors in firefighters has been investigated (8-14). Obesity is known to be a significant risk factor for cardiovascular disease and is associated with adverse health conditions. In a study by Soteriades et al. (8), baseline and 5-year follow-up measurements of body mass index (BMI) and blood pressure were evaluated in municipal firefighters. Of those studied 53% were found to be overweight and 34.9% were obese upon entering the study. After 5 years, obesity prevalence increased significantly to 39.7%. Obese individuals were also more likely to have hypertension at both baseline and follow-up. A separate study conducted by Clark et al. (9) observed similar results. This study also reported significant increases in diastolic blood pressure, total cholesterol and triglyceride levels with increasing BMI (9).

Elevated cholesterol levels are another known cardiovascular risk factor. Hypercholesterolemia has been observed in 69.4% of firefighters as reported by Soteriades et al. (10). In this study, firefighters with higher cholesterol levels were more likely to be older, obese, and have higher triglyceride levels. Likewise, Licciardone et al. (11) reported an age-related increase in body weight, total cholesterol, and blood pressure. Byczek et al. (12) found the prevalence of obesity, hypertension, and high total cholesterol in male firefighters to be higher than those in U.S. adult men. There is limited research investigating the presence of cardiovascular disease risk factors in VFF (13). Swank and colleagues reported similar prevalence of all modifiable cardiovascular disease risk factors between VFF and the general population. In general, an individual's risk for cardiovascular disease increases with the presence of multiple risk factors, advancing age, or elevations in risk factor severity (14).

The presence of cardiovascular risk factors, especially obesity, is known to limit the performance of firefighters (15). Extra fat adversely affects job performance (16) and hinders heat dissipation, which creates strain upon the heart. Overall, the upper body fat distribution typically found in men is associated with higher blood pressure, higher serum glucose and cholesterol levels, and coronary heart disease (17). The high prevalence of cardiovascular risk factors found in firefighters may contribute to a higher risk of sudden cardiac death and adversely affect firefighting performance.

Little research has examined the physiological requirements of firefighting in order to characterize the physical demands and identify fitness characteristics needed for successful job performance (116, 18-29). Firefighting is known to induce significant demands on cardiovascular functioning as well as require substantial physical strength for prolonged periods (18-20). Firefighters endure long periods of inactivity followed by high degrees of physical stress (6). During the immediate response to an alarm, firefighters experience significant increases in heart rate (21). Upon arrival at the fire scene, firefighters work at levels above 80% of their maximal heart rate (HR_{max}) for a substantial period of time completing fire suppression duties (18). However, quantifying workload from heart rate alone is difficult due to the influence of heat stress, decreased oxygen, and increased carbon dioxide levels.

Maximal oxygen consumption ($VO_{2\,max}$) has consistently been identified as an important factor in the association of firefighting demands and physiological requirements (22-23). Lemon and Hermiston observed that firefighters complete simulated duty tasks at 60-80% $VO_{2\,max}$ even without the external stress of the fire scene (22). Duncan et al. (24) reported that the workload imposed in a hot environment by the properties of the protective clothing significantly increases the oxygen requirements. In addition, wearing a self-contained breathing apparatus (SCBA) has been observed to change firefighters' breathing pattern and increase oxygen consumption during exercise (25). Thus, firefighting requires individuals to perform at high levels for substantial periods of time. Yet, it is still difficult to determine the physical stress experienced by firefighters during on-duty fire suppression because the research is consisted mainly of firefighting simulation studies and there is an unaccounted psychological component.

Because firefighting is one of the most physically demanding occupations, it is recommended that firefighters possess a high level of fitness to

ensure the safety of the general public and themselves (16, 26). It is important to realize, though, that all recommendations have been based on research conducted using simulated firefighting activities. Most investigators recommend a minimum $VO_{2\,max}$ between 39.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and 48.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (16, 26). Sothmann et al. (27) found that individuals with $VO_{2\,max}$ values below 33.5 $ml \cdot kg^{-1} \cdot min^{-1}$ were unable to complete a standard fire suppression protocol. Lemon and Hermiston concluded that firefighters must possess high levels of anaerobic power (28). High levels of upper and lower body strength and muscular endurance have also been recommended for increased job performance and reduced risk of injury (16, 29). However, previous research has reported that the fitness characteristics of professional firefighters are comparable to the normal range of U.S. adult men with sedentary lifestyles (28). A sample of PFF were found to have a mean $VO_{2\,max}$ value of 40.57 $ml \cdot kg^{-1} \cdot min^{-1}$ (28). VFF were found to be overweight and have an average VO_2 max value of 31.5 $ml \cdot kg^{-1} \cdot min^{-1}$, with 75% of those tested falling between 20 and 39 $ml \cdot kg^{-1} \cdot min^{-1}$ (19). In addition, the decline

in $VO_{2\,max}$ of both PFF and VFF with age is similar to the general population (19, 28).

In 2004, 16 Firefighter Life Safety Initiatives were identified to aid the US Fire Administration's goal of reducing firefighter fatalities by 25% within the following 5 years and 50% within the following 10 years (30). Experts concluded there is a need to develop national medical, training, and physical fitness standards based upon the duties each firefighter is expected to perform. However, before any standards can be developed, the physical demands need to be determined, as well as which physical fitness and fire scene characteristics affect the required workload. A model may then be built to predict the interaction of relevant variables and determine which firefighters are at a higher risk of injury due to overexertion.

While the National Fire Protection Association recommends fire department medical examinations and specific fitness for duty criteria (31), more than 70% of the fire departments do not have programs to maintain firefighter fitness and health (1). Most do not require firefighters to exercise regularly or undergo periodic medical examinations even though exercise intervention programs have shown to decrease the incidence of accidents and increase job performance (32).

Although there has been beneficial research regarding the physiological response to firefighting, all but two of the previously referenced articles were conducted during fire simulations and training. While simulation and training studies provide insight, they do not translate well to real-life scenarios due to the ever-changing environment and emotional response. Thus, it is still unclear how the cardiorespiratory system responds to the demands of real-world on-duty fire suppression, specifically in regards to each firefighter's role at the fire scene. Additionally, the most important occupational and fitness characteristics for predicting the physiological response to firefighting have yet to be determined.

STUDY METHODS

STUDY METHODOLOGY

Subject Recruitment & Informed Consent

In cooperation with the Indianapolis Fire Department (IFD), fire stations historically working the greatest number of structural fires were identified as possible study sites. The architectural character of the station's primary response area and the station's ability to provide physical space for researchers were considered. Two stations offering the most advantageous profiles were selected for recruitment. Firefighters staffing these stations and meeting eligibility requirements were extended an invitation to participate by the research team.
A subject's eligibility to participate was their designation as "fit for duty" duty as defined by the Indianapolis Fire Department. To determine fitness for duty, IFD firefighters undergo annual physical fitness evaluations that meet or exceed NFPA standard 1583. All medical examination procedures outline in NFP 1583 Chapter 2, Section 2-1 are addressed annually. In addition, all IFD firefighters undergo a graded exercise test (with a 12-lead ECG) annually. Finally, IFD firefighters must submit to and pass a Firefighter-specific work capacity test annually in order to be declared fit for duty.

Invitation was made in person at the fire station. Interested firefighters were provided with study information and given sufficient time to consider participating in the study. Fifty seven (57) subjects volunteered to participate in the study. Informed Consent was provided by each subject as dictated by the Indiana University Institutional Review Board (IRB).

Orientation and Physical Assessment

Once identified, subjects were orientated with study procedures and key study personnel. Additionally, the physiological monitoring system was introduced. Subjects were fitted with the LifeShirt™(LS) device and instructed as to its operation. To engage the LS device, firefighters removed their shirts and placed ECG electrodes at the upper left and upper right torsos as well as the lower left torso. With electrodes in place, subjects donned the LS vest and closed the inner of two zippers. Through holes provided, ECG electrodes were connected to a data collection cable and respiratory inductive plethysmography (RIP) bands embedded in the vest were connected to the cable.

This data cable (which also houses a two-axial accelerometer) was then connected to the LS data recorder. Subjects then stood erect, powered up the system and placed the LS recorder in a provided holding pouch. With the system operational, the device was calibrated by repeated re-breathing from a disposable, 800 milliliter calibration bag provided by the manufacturer. The active system was then worn under standard firehouse duty garments for the remainder of the duty shift.

Subjects completed a demographic and health history questionnaire (Appendix C), as well as relevant information concerning the firefighter's career (time in service, rank and position, etc.). After completing these questionnaires, the physical assessment commenced within the fire station apparatus bay. The assessment consisted of resting measures of heart rate and blood pressure, accomplished by palpation and auscultation respectively. Body composition was determined using a three-site, gender-specific Skinfold analysis (Jackson, Pollack, 1980). Aerobic capacity was assessed using the Queens College Step Test. For this test, subjects step on and off a 16.25 inch box at a paced rate. Subjects stepped continuously for three minutes and then stood quietly for another minute. Heart rate at 20 seconds post test was obtained from the LifeShirt data and used to estimate aerobic capacity (VO_2max) for each individual. Post test heart rates will be entered into one of the following, gender specific equations to estimate Vo_{2MAX}:

Male: Vo_{2MAX} ($ml \cdot kg^{-1}\text{-}min^{-1}$) = 111.33 – (0.42 x HR)

Female: Vo_{2MAX} ($ml \cdot kg\text{-}1 \cdot min\text{-}1$) = 65.91 – (0.1847 x HR)

Where: HR = Mean heart rate during the period 5 seconds to 20 seconds after exercise

Handgrip strength was assessed in both hands using a handgrip dynamometer (Lafayette Instruments). Subjects were asked to squeeze the handle of a dynamometer, exerting a maximal effort. Each subject performed three trials with the greatest measure of strength recorded as hand grip strength. General muscular strength and endurance were assessed by 1-minute pushup and curl-up tests respectively. Flexibility was assessed with a standard sit-and-reach box.

Data Collection

General Firefighter Protocol

Subjects donned the LS system at the beginning of each duty shift and wore the system throughout their 24-hour shift for a six month period. All LS data clocks were synchronized with the fire department dispatch clock upon start up. Subjects provided information concerning their duty assignment for the shift including station, apparatus, and apparatus seat). When necessary (showering, damage to the system etc.), subjects removed and replaced system components to maintain data stream. Research team personnel were available to assist with equipment problems or answer subject questions at all times. At each shift change event, research team personnel were present to assist in equipment turnaround and to retrieve collected data.

Fire Scene Data Collection

A member of the science team accompanied dispatched companies on all fire runs. When fire runs were designated working structural fire inci-

dents scientists recorded fire-ground descriptive information as well as operational milestone time periods pertinent to the study. This data was subsequently uploaded to the study database. In addition to the physiological and operational data, a helmet mounted thermal imaging video camera (Fire Warrior, Total Fire Croup, Dayton, OH) was utilized to record firefighter physical activity inside burning structures. Weather data including temperature, wind speed, and relative humidity were recorded on the fire scene using a handheld weather monitor (Cole-Parmer, Model R-99756-17). Scientist wore small bullet cameras (Oregon Scientific, Portland, OR) mounted on their helmets and fire apparatus to provide a video record of the fire scene. Scientists were issued departmental radios to monitor fire ground activity. Scientist-collected video and radio communications were used to assure capture of subject fire ground activity.

Data Handling: Physiology and Fire Scene Data

Research team personnel collected all firefighter-based data at the end of each duty shift. Fire scene descriptive data was immediately uploaded to the database and stored for later analysis. Firefighter physiology data was uploaded from individual LS data cards using LS-accompanying VivoLogic® software. Events expected to result in significant physiologic response were identified from the fire department dispatch log and fire-scene collected data. Using these event markers, firefighter physiology data was extracted from the full data set for subsequent analysis.

One minute averages of data were extracted from the time-series data based upon an event log. The event log was generated from a combination of fire department dispatch time data and fire scene data. This log provided markers representing physiologically significant time periods in the subject data stream. A list of fire-run markers included alarm, arrival on scene, fire attack, ventilation, search & rescue operations, overhaul, rehabilitation operations, scene departure, and return to station.

Qualitative Biomechanical Analysis

Using video data obtained from thermal imaging and visible light cameras, aspects of physical motion (typical movement patterns), were observed and examined for their physiological relevance. In conjunction with the LifeShirt® accelerometer data, this analysis provided needed insight into subject movement and posture during interior and exterior work periods. Video was analyzed during all three periods of suppression work and overhaul.

Data Analysis

ANOVA and Measures of Association

Breakdowns included average physiological responses to fire run events (alarm, fire suppression operations, rehab, overhaul, search & rescue operations, etc.). These data were also broken down further into responses based upon firefighter age, service experience gender, physical fitness level, and presence vs. absence of entrapped victims. Analysis of Variance (ANOVA) techniques were utilized to detect differences between the groups outlined in descriptive analyses. On and off duty STAI and Cortisol data were compared in similar fashion. Bivariate correlations (Pearson r) were examined among all physiological and fire-scene data to determine significant relationships.

To ensure subject number (N) is large enough to provide sufficient statistical power, a power analysis was performed a priori. A power analysis requires establishment of a desired statistical power level (in our case 0.80), a desired level of statistical significance (alpha level, in this case alpha ≤ 0.05), and an estimate of the size of an examined factor's effect on the dependent variable. Although little or no data exists on the physiological responses of firefighters to fire ground activity, our recent work with training firefighters (MFRI, 2006) provided sufficient data to estimate effect size for the majority of physiological variables to be examined. Based upon these estimates of effect size and our desired power level of 0.80, an ANOVA procedure performed at alpha ≤ 0.05 would require a minimum N of 50 individuals.

Data Modeling: Principle Components Analysis and Multiple Regression

A Principle Components Analysis (PCA) using physiological, fire scene, environmental and firefighter descriptive data was executed. This analysis illustrated relationships among firefighter responses and variables suspected of having significant physiological impact. Variables extracted by the PCA procedure were then subjected to multiple-regression in order to determine their relative importance in determining fire scene physiological responses. Using beta weights derived from regression, the relative impact of fire scene and firefighter descriptive data on various physiological responses will be determined.

This principle component analysis (PCA) procedure typically requires many measures (or cases) of independent and dependent variables. Tabachnick & Fidell (1996) suggest that PCA procedures include a minimum of 300 cases. Comrey & Lee (1992) rank case requirements on the following scale: 50 cases (very poor), 100 cases (poor), 200 cases (fair), 300 cases (good), and 500 cases (very good). This study monitored an average of 6.2 firefighters on 88 working structural fire incidents.

Indianapolis Fire Department Fire Equipment

To some extent, firefighter physiology will be affected by the tools of their trade. This includes how an individual apparatus is equipped. The two stations involved in the study possessed engine and ladder companies. A two-man rescue squad and a single-man tactical support vehicle were assigned to one of the participating stations.

Engines staffed by monitored firefighters included a 2007 Ferrara and a 2002 American LaFrance. Ladder companies staffed a 2002 American LaFrance 85ft tower and a 2007 Ferrara 100ft tower. The rescue squad is a 2004 F450 equipped for both ALS and BLS services.

Indianapolis Fire Department Fire Scene Duty Assignments

IFD standard operation procedures (SOP) dictate fire scene duty assignments are based upon the order of apparatus arrival. The first arriving engine company secures a primary water source and is responsible for primary fire attack. The first arriving ladder company consists of an inside team and an outside team. The inside team is responsible for primary search operations while the outside team is responsible for exterior ventilation operations. A second arriving engine company secures a secondary water source and is responsible for back-up attack operations. The second ladder company again is divided into inside and outside teams. The outside team assists the first ladder with ventilation operations. The inside team assists inside with fire attack operations. IFD's two-man rescue squads generally assist with search operations unless there is an immediate need for EMS operations on scene.

STUDY RESULTS

STUDY RESULTS

Station Selection

Stations were selected for study participation based upon multiple factors. However, the fundamental factor for selection was a station's volume of fire work. Table 1.1 illustrates recent run histories of the two stations selected for participation. Two fire stations were selected from IFD's available 35. These two stations chosen were located 1.5 miles apart and historically run together on many fires. The stations chosen are two of the busiest in the department and regularly the busiest in terms of working incidents (structural fires). The combination of these two stations provided a potential subject pool of 69 firefighters for recruitment. The primary coverage areas of these two stations (area where an engine and ladder company is first due at a fire scene) contained similar architectural styles. Lastly, Station B is a 4-apparatus station with a building large enough to accommodate the embedded scientists over the study period.

The embedded science team accompanied Stations A, B or both on 796 fire runs during the study period. Of those fire runs, 121 were declared working incidents by IFD. During 32 of those working incidents, studied firefighters were designated as RIT teams or were otherwise not involved in suppression operations. These incidents were eliminated from analyses leaving 88 working structural fires during which, studied firefighters were directly involved in suppression operations.

Table 1.1: 2006 Station Run History

	Fire Runs	EMS Runs	Total Runs
Engine A	1149	2013	3162
Ladder A	1023	326	1349
Engine B	1129	497	1626
Ladder B	1017	211	1228
Squad B	1096	2039	3135
TSU B	348	8	356

*Statistics Courtesy of Indianapolis Fire Department

Subject Descriptive Data

Fifty-six (56) firefighters from Stations A and B volunteered for the study, representing a recruitment rate of 81%. Tables 2.1 through 2.3 provide mean physical characteristics of participating firefighters as well as measures of health related components of physical fitness. Additionally, tables provide comparative information from age and gender matched general US populations. Table 1.2 provides descriptions of the total subject pool while tables 1.2 and 1.4 break these data into gender specific descriptions. These gender-based data are provided only for descriptive purposes. For the purposes of examining firefighter responses, all subjects will be pooled. Table 2.4 outlines measures of association among demographic and fitness variables. Of particular significance is the lack of significant relationship between firefighter age and cardiovascular fitness (Vo_{2MAX})

Table 2.1: Physical Description and Fitness Data (ALL SUBJECTS)

	N	Minimum	Maximum	Mean ± STD
Age (yrs)	56	26	61	43.1 ± 7.95
Yrs of Service	56	3	34	16.8 ± 8.26
Height (in)	56	64	76	70.9 ± 2.17
Weight (lb)	56	132.31	321.7	200.8 ± 34.14
Systolic BP (mmHg)	56	104	160	127.9 ± 11.15
Diastolic BP (mmHg)	56	58	130	82.5 ± 10.1
Body Mass Index	56	22.2	43.7	28.1 ± 4.00

*Firefighter was not able to complete this portion of the test due to temporary physical limitation

Table 2.2: Physical Description and Fitness Data (MALES)

	N	Minimum	Maximum	Mean ± STD	US Population
Age (yrs)	52	26	61	43.1 ± 7.98	
Yrs of Service	52	3	34	17.0 ± 8.40	
Height (in)	52	66	76	71.2 ± 1.80	69.4 ± 0.1 [1]
Weight (lb)	52	154.4	321.7	204.2 ± 32.28	191.0 ± 1.0 [1]
Systolic BP (mmHg)	52	110	160	128.9 ± 10.83	
Diastolic BP (mmHg)	52	68	130	83.4 ± 9.70	
Body Mass Index	52	22	44	28.0 ± 3.96	27.9 ± 0.11
Hand Grip R	52	32	69	54.0 ± 8.16	35 - 62 [3]
Hand Grip L	52	32	68	53.0 ± 7.35	
Pushups	50	3	67	32.0 ± 15.24	10 - 30 [3]
Curlups	50	18	80	49.0 ± 3.20	15 - 60 [3]
Vo_{2MAX} (ml/kg/min)	51	34	65	47.0 ± 6.24	33.0 - 55.9 [2]

[1] Population statistics reflect values (Mean ± SEM) for the adult male US population (20 -70 years of age) National Center for Health Statistics 2004
[2] Wilmore, J.H. & Costill, D.L. 2005
[3] Canadian Physical Activity: Fitness & Lifestyle Approach

Table 2.3: Physical Description and Fitness Data (FEMALES)

	N	Minimum	Maximum	Mean ± STD	US Population
Age (yrs)	4	31	52	42.8 ± 8.69	
Yrs of Service	4	7	21	13.5 ± 5.80	
Height (in)	4	64	69	66.8 ± 2.63	64.0 ± 0.1 1
Weight (lb)	4	132.3	199.6	157.2 ± 30.31	164.3 ± 1.0 1
Systolic BP (mmHg)	4	104	122	115.5 ± 7.90	
Diastolic BP (mmHg)	4	58	84	71.5 ± 10.63	
Body Mass Index	4	22.8	29.5	24.7 ± 3.23	28.2 ± 0.2 1
Hand Grip R (kg)	4	28	37	33.0 ± 3.74	25 - 36 3
Hand Grip L (kg)	4	25.5	36	32.8 ± 4.91	
Pushups (1 min)	4	22	44	33.3 ± 10.44	5 - 30 3
Curlups (1 min)	4	44	63	52.3 ± 7.93	10 - 50 3
Vo_{2MAX} (ml/kg/min)	4	34.7	45.9	38.8 ± 4.91	23.6 - 41.0 2

[1] Population statistics reflect values (Mean ± SEM) for the adult male US population (20 -70 years of age) National Center for Health Statistics 2004
[2] Wilmore, J.H. & Costill, D.L. 2005
[3] Canadian Physical Activity: Fitness & Lifestyle Approach

Studied male firefighters were similar in stature, body weight, and body composition compared to their general population counterparts. Studied female firefighters were similar in stature while somewhat heavier and possessing a higher body mass index compared to their general population counterparts. Similar comparisons to the general populations were observed in firefighters studied in the MFRI study (MFRI, 2006).

Cardiovascular fitness of male firefighters was toward the higher end of the normal range for the general male population. In addition, male firefighters possessed a level of general muscular strength (as indicated by their push up and hand grip scores), as well as general muscular endurance (as indicated by their curl up score). By comparison, Female firefighters scored at or above their general population counterparts in every fitness category measured. Again, this trend is similar to that reported in the MFRI study (MFRI 2006) where female firefighters are generally stronger and more fit than their general population counterparts. Heart rate responses to the Queens College Step test enabled a field estimate of cardiovascular fitness (Vo_{2MAX}). Across all studied firefighters (male & female), cardiovascular fitness was normally distributed and tightly centered near a mean value (Graph 2.1). This mean was considerably higher than the general population.

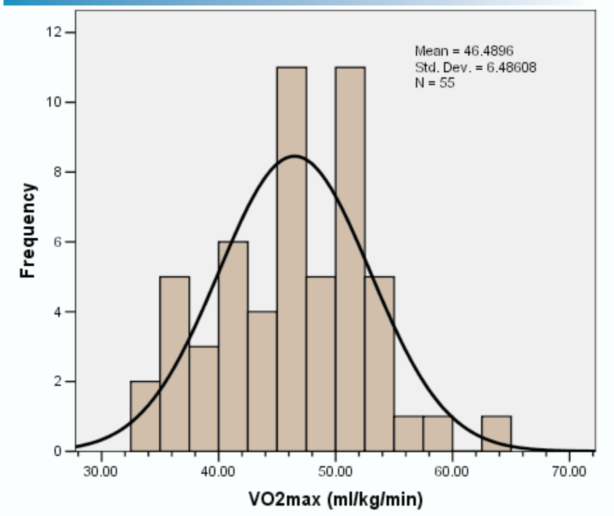
Table 2.4: Correlations Among Fitness-Related Variables

		Age	Yrs of	BMI	Hand Gr	Pushups	Curlups	Sys BP	Dia BP	VO2max
Age	Correlation	1	0.891	.016	-0.131	-0.471	-.064	0.127	0.161	-0.257
	Sig. (2-tailed).		0.000	0.932	0.335	0.000	0.646	0.352	0.235	0.058
Yrs	Correlation	0.891	1	0.110	-0.054	-0.505	-0.033	0.303	0.194	-0.203
	Sig. (2-tailed)	0.000		0.417	0.689	0.000	0.814	0.000	0.153	0.137
BMI	Correlation	0.012	0.110	1	0.420	-0.215	-0.097	0.230	0.162	-0.209
	Sig. (2-tailed)	0.932	0.417		0.001	0.119	0.487	0.000	0.233	0.126
Hand Gr	Correlation	-0.131	-0.055	0.420	1	0.172	-0.067	0.156	0.252	0.132
	Sig. (2-tailed)	0.335	0.689	0.001		0.214	0.630	0.250		0.337
Pushups	Correlation	-0.471	-0.506	-0.215	0.172	1	0.274	-0.384	-0.268	0.273
	Sig. (2-tailed)	0.000	0.000	0.119	0.214		0.045	0.004	0.050	0.046
Curlups	Correlation	-0.064	-0.033	-0.097	-0.630	0.274	1	0.057	-0.125	0.101
	Sig. (2-tailed)	0.646	0.814	0.487	0.63	0.045		0.680	0.369	0.466
Sys BP	Correlation	0.127	0.303	0.230	0.156	-0.384	0.057	1	0.704	0.009
	Sig. (2-tailed)	0.352	0.023	0.088	0.250	0.004	0.680		0.000	0.944
Dia BP	Correlation	0.161	0.194	0.162	0.252	-0.268	-0.125	0.704	1	0.004
	Sig. (2-tailed)	0.235	0.153	0.233	0.006	0.050	0.369	0.000		0.806
VO2max	Correlation	-0.257	-0.203	-0.209	0.132	0.272	0.101	0.000	0.003	1
	Sig. (2-tailed)	0.058	0.137	0.126	0.337	0.004	0.466	0.944	0.806	

** Significant at the p = 0.001 level

* Significant at the p = 0.005 level

Graph 2.1: Cardiovascular Fitness Distribution



In general, the firefighters studied here were larger, stronger and possessed better cardiovascular fitness than the average person on the street. This fact will become extremely important when responses to fire scene work are considered. Because of their high fitness level, this group of firefighters can be considered a model or ideal group when examining their responses to fire scene work. A specific job or workload will result in lower cardiovascular and respiratory responses in this group compared to a lesser fit group of individuals. Unfortunately, previous studies of firefighter physiological responses to fire ground work either have few subjects (18) or do not report physical characteristics of their subjects (21).

Firefighter Demographics

Racial distribution among the studied firefighters reflects that of Marion County Indiana (US Census Bureau, 2006). The average firefighter studied was 43 years of age, married and had 16 years of experience in the fire service). Apparatus assignments were evenly distributed between Engine and Ladder companies providing equal opportunity to study engine and ladder company work. Firefighter service ranks reflect the standard distribution of personnel (NFPA 1710) with approximately half of the studied individuals on the back step and half engineers and company officers. Charts 2.1 and 2.2 provide demographic characterization of the subject pool with respect to race and marital status.

Chart 2.1: Subject Racial Distribution

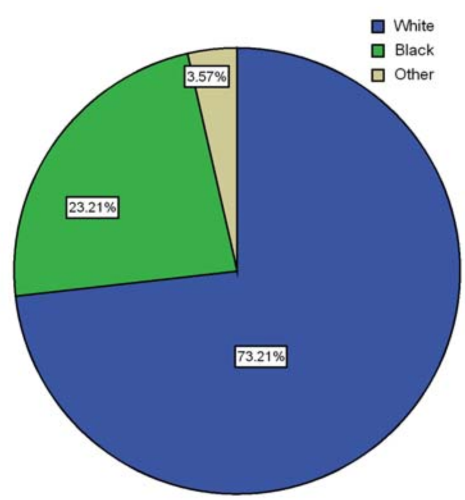


Chart 2.2: Subject Marital Status Distribution

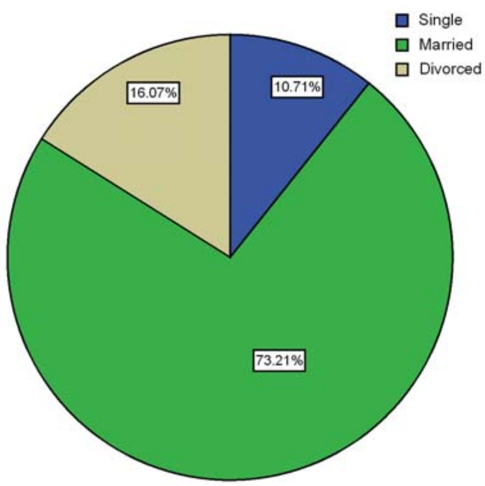
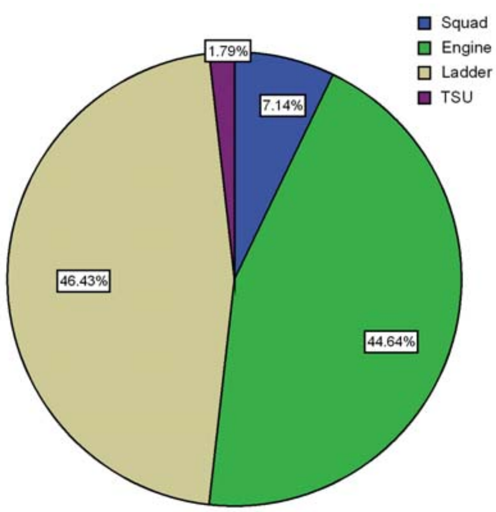
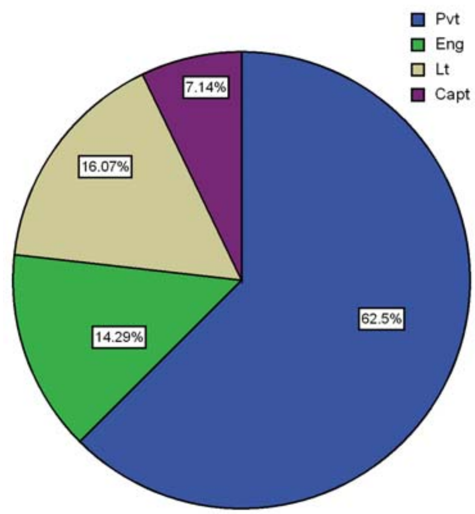


Chart 2.3: Subject Apparatus Assignment



Charts 2.3 and 2.4 represent distributions of the subject pool across fire apparatus assignments, ranks and duty shifts respectively

Chart 2.4: Subject Fire Service Rank



Dispatch & Arrival Information

Charts 2.5 through 2.7 illustrate descriptive information concerning Alarm and Dispatch information alerting subject firefighters to emergency runs. Considering the typical structure size in the primary study's primary response area, the distribution of Still vs. Box alarms appears appropriate. IFD standard operating procedures require dispatch to apartments as Box alarms. Other structures in the primary response area include large commercial buildings and schools. This is reflected in the overwhelming majority of dispatch to residences vs. apartments or other structures.

Information provided to responding companies by dispatchers (Chart 2.7) indicate the possibility of entrapped occupants or other situational factors occurred in approximately 25% of runs. The influence of this information on firefighter physiology will be discussed later

Chart 2.5: Alarm Type

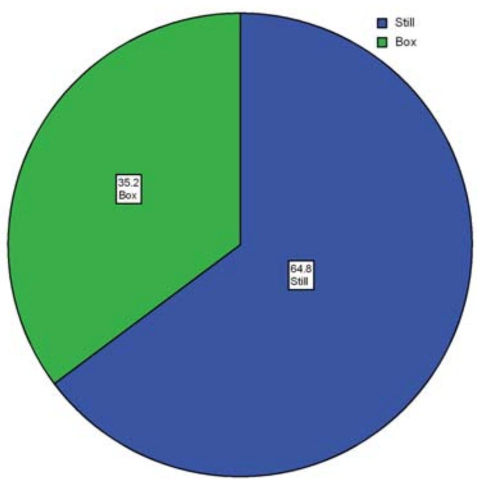


Chart 2.6: Dispatch Type

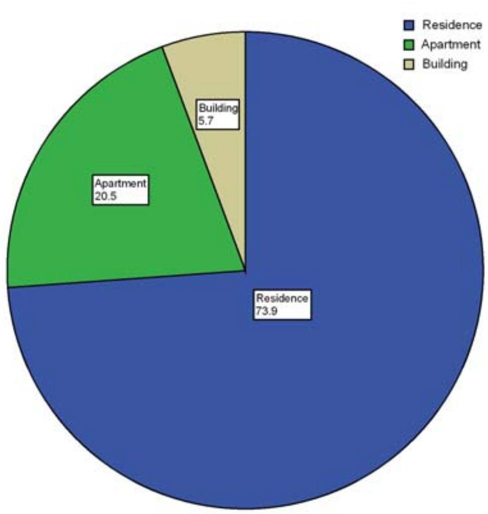
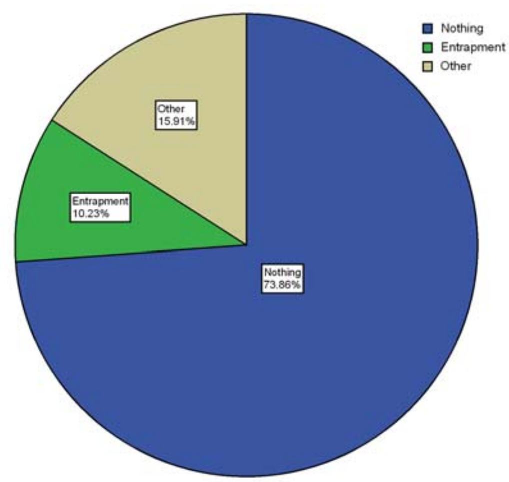


Chart 2.7: Dispatch Information



During the study period, scientists and monitored firefighters answered 723 fire runs. 118 of those runs were determined to be working structural fire incidents. During thirty (30) of the structural fire incidents, studied personnel were designated as a rapid intervention (RIT) team or were not otherwise involved in suppression operations. Those incidents were removed from the analysis. The 88 structural fire incidents entered in the analysis averaged 6.2 monitored firefighters per incident (range: 4-13).

Operational assignments for firefighters are established by the arrival order of their company. Table 2.5 outlines the frequency of arrival order for each ladder and engine company participating. IFD Standard operating procedures (SOPs) indicate only one Rescue Squad (Squad 10) and Tactical Service Unit (TSU10) is dispatched on single alarm incidents. Therefore, those apparatus were always 1st arrival.

Table 2.5: Summary of Company Arrival Order

Apparatus	Arriving 1st		Arriving 2nd		Arriving 3rd		Arriving 4th	
Engine B	22	41.5%	19	35.8%	10	18.9%	2	3.8%
Ladder B	29	52.7%	18	32.7%	7	12.7%	1	1.8%
Engine A	8	44.4%	9	50.0%			1	5.6%
Ladder A	6	30.0%	10	55.0%	3	14.9%	1	5.0%

On arrival at the fire scene, descriptive information about the burning structure was collected. Charts 2.8 and 2.9 show nominal data utilized to describe structures. These data reflect the distribution of architectures within the response area studied. The area is typified by wood framed residential structures with a lesser portion made up of apartments and other structure types

Chart 2.8: Building Type

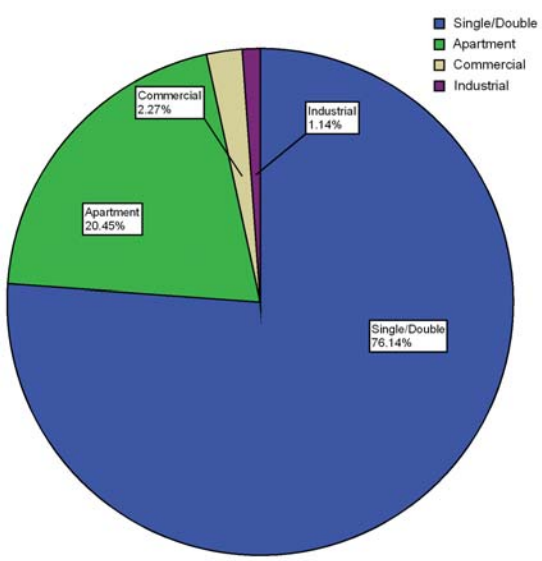


Chart 2.9: Construction Type

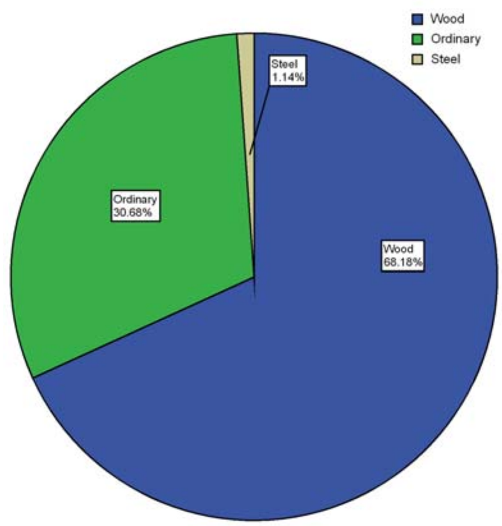


Table 2.6 outlines frequencies of fire scene size up data collected to establish the situation upon arrival of the first working company. First on scene companies typically find structures 0-25% involved with fire & heavy grey to black smoke showing. Fires are generally located on the first floor of the structure primarily due to the fact that the majority of the structures are single story residences

Table 2.6: Fire Scene Size-up Information

Descriptor		Frequency	Sig
Situation	Nothing Showing	3	3.4
	Smoke Showing	48	54.5
	Fire Showing	3	3.4
	Fire/Smoke Showing	34	38.6
Involvement	0-25%	38	43.2
	25-50%	24	27.3
	50-75%	18	20.5
	75-100%	8	9.1
Fire Location	Basement	15	17
	1st Floor	41	46.6
	2nd Floor	18	20.5
	2nd Floor & Exposures	3	3.4
	1st & 2nd Floors	4	4.5
	1st & 2nd Floors & Exposures	1	1.1
	3rd Floor	3	3.4
	Basement & 1st Floor	1	1.1
	Attic	2	2.3
Smoke Color	White	10	11.4
	Gray	43	48.9
	Brown	6	6.8
	Black	29	33
Smoke Volume	Light	25	28.4
	Moderate	22	25
	Heavy	41	46.6

Weather conditions on the fire ground were also monitored. Ambient air temperature and relative humidity were recorded. Where appropriate, wind chill or heat index was calculated for each scene. Table 2.7 outlines the mean weather parameters observed on scene. These weather data are typical for central Indiana during the winter and spring months. As such, they present little or no ambient heat stress for the firefighters. Thus, examination of the physiology of firefighting here reflects a more accurate picture of the cardiovascular and respiratory stress associated with the work of fighting fire than if the study was conducted during the summer months. The effects of ambient heat stress will be addressed in subsequent studies by collecting data in a more heat stressed geographic region of the country.

Table 2.7: Summary of Fire Scene Weather

	N	Min	Max	Mean	STD
Temperature (C)	88	-7.6	29	8.3	8.9
Humidity (%)	88	28.4	96	65.3	18.9
Wind Chill (C)	88	-14	28	5.5	9.7

Cardiovascular and Respiratory Responses to Alarm

In order to determine the extent of heart stress associated with being alerted by alarm, heart rate was examined over a 90 second period immediately following the alarm. Heart rate and relative heart rate (%HR_{MAX}) during the 90 second period were examined as well as the time to peak heart rate (HRP*t*). Table 3.1 describes the HR responses to the alarm across all alarm types.

In Table 3.2, the relationships between alarm heart rate response and subjects are characterized. These data indicate that heart rate responses are closely associated with firefighter experience (years of service) and fitness (Vo_{2MAX}). Relative heart rate response is also associated with fitness. Reporting on 35 firefighters responding to 189 alarms, Barnard & Duncan (21) reported similar

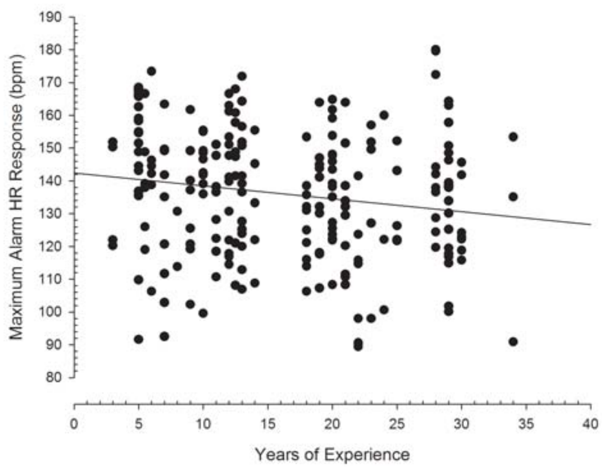
Table 3.1: Alarm Response Descriptives

	Min	Max	Mean	STD
Alarm HRmax	89.4	180.1	136.1	19.584
% HRmax	48.7	108.5	76.9	11.320
HRP*t*	0.270	2	1.2	0.4633

Table 3.2: Alarm Response Variable Correlations

		Alarm HRmax	% HRmax	HRPt	Age	Yrs service	VO2max
Alarm HRmax	Correlation	1	0.950	-0.116	-0.099	-0.169	-0.219
	Sig. (2-tailed)		0.000	0.084	0.138	0.011	1.10
% HRmax	Correlation	0.950	1	-0.073	0.214	0.108	-0.267
	Sig. (2-tailed)	0.000		0.274	0.001	0.106	0.000
HRPt	Correlation	-0.116	0.073	1	0.122	0.113	-0.036
	Sig. (2-tailed)	0.081	0.274		0.066	0.887	0.600
age	Correlation	0.099	0.214	0.122	1	0.879	-0.129
	Sig. (2-tailed)	0.138	0.001	0.066		0.000	0.042
yrs service	Correlation	-0.169	0.108	0.113	0.879	1	-0.009
	Sig. (2-tailed)	0.001	0.106	0.887	0.000		0.887
VO2max	Correlation	-0.21	-0.267	-0.036	-0.129	-0.009	1
	Sig. (2-tailed)	0.001	0.000	0.600	0.042	0.887	

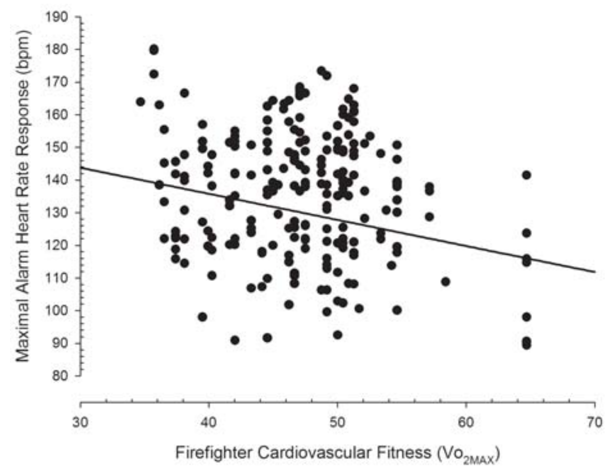
Graph 3.1: Effect of Firefighter experience on maximal alarm Heart Rate response.



HRmax = (Years of Service *0.4075) + 136.7064
R = 0.16875041, SEE = 0.1523

The measures of association in Table 3.2 suggest a cause and effect relationship between firefighter experience and fitness with firefighter heart arte response to alarm. Graph 3.1 indicates that as firefighters gain work experience, their heart rate response to alarm lessens.

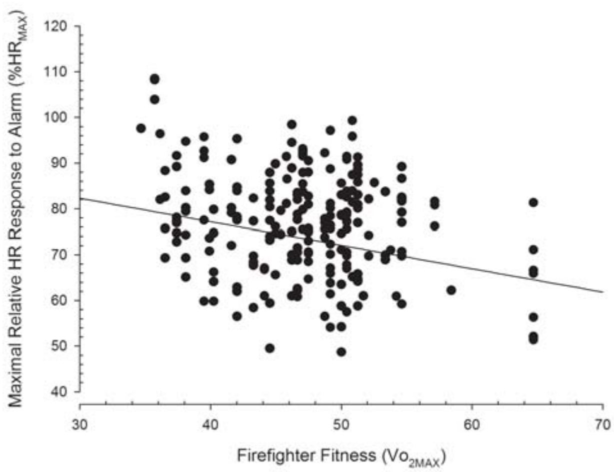
Graph 3.2: Firefighter fitness effects on maximal alarm heart rate response



HRmax = (Fitness * -0.7992) + 167.7577
R = 0.26, SEE= 0.1505

Graph 3.2 demonstrates the relationship between firefighter fitness and maximal alarm heart rate response. This data indicates that maximal heart rate response to the alarm declines as firefighter fitness improves.

Graph 3.3: Effects of Firefighter Fitness on relative maximal heart rate alarm response



%HRmax = (Vo_{2MAX} * -0.5105) + 97.59
R = 0.28, SEE = 0.1514

In addition, Graph 3.3 indicates that the relative heart rate response to alarm declines with improved firefighter cardiovascular fitness.

These findings differ from those reported earlier by Kuorinka & Korhonen (38). These authors found an positive relationship between firefighter fitness and heart rate response to alarm. In other words, the more fit firefighters in their study had greater heart rate increases in response to alarm. However this observation was based solely upon the observations of nine firefighters.

Responses to Alarm Types

To determine the effect of different alarm types on heart stress, heart rate responses were examined between Still and Box alarms. Table 3.3 illustrates heart rate responses induced by different alarm types. Table 3.4 contains the ANOVA F-table indicating no heart rate differences were detected between Still and Box alarms.

Table 3.1: Heart rate Responses to Alarm types

		Mean	STD	Min	Max
HRmax	STILL	135.0	18.89	89.4	179.6
	BOX	138.7	20.0	90.3	180.1
% HRmax	STILL	76.7	10.9	49.5	108.2
	BOX	77.9	11.5	51.9	108.5
HRP*t*	STILL	1.189	0.455	0.350	2
	BOX	1.174	0.472	0.280	1.98

Table 3.4: Alarm Type Differences F-Table

		SS	df	MS	F	sig
HRmax	B/n Grps	721.9	1	721.9	1.93	0.170
	W/n Grps	81.86	219	373.8		
	Total	82.58	220			
% HRmax	B/n Grps	74.59	1	74.59	0.597	0.440
	W/n Grps	27338.4	219	124.8		
	Total	27413.0	220			
HRP*t*	B/n Grps	0.012	1	0.002	0.056	0.812
	W/n Grps	46.8	219	0.214		
	Total	46.8	220			

Cardiovascular and Respiratory Responses to Fire Ground Ingress

Fire ground ingress was defined as the time period between exiting the station and arrival of an apparatus at the fire scene. Table 4.illustrates the effects of dispatch information on firefighter physiology during ingress. Table 4.2 shows the F-test of statistical significance between different types of dispatch information effecting firefighter physiology. With dispatch or during Ingress, firefighters may receive information about the fire scene. Some of this information has a measureable effect on firefighter physiology. Information provided to participating firefighters, was divided into three categories. Nothing refers to a situation where no additional information was provided during ingress. Entrapment refers to either the possibility or the confirmation of civilian entrapment at the fire scene. Other information refers to any information other than entrapment provided during ingress. This information commonly referenced security of the scene, road conditions, or possible threats to public safety personnel.

Table 4.1: Effect of Dispatch Information on Ingress Physiology

		N	Mean	Standard Deviation	Minimum	Maximum
VT	Nothing	180	1189.2	451.7	617.8	3099.3
	Entrapment	32	1299.9	303.4	738.6	1941.1
	Other	37	1159.4	341.3	711	1964.3
VE	Nothing	180	33.1	20.9	7.8	121.4
	Entrapment	32	37.9	12.9	16.9	63.5
	Other	37	33.7	17.4	12.7	79.2
Breaths/min	Nothing	180	36	7.7	14.5	57.2
	Entrapment	32	36	5.1	27.2	44
	Other	37	37.5	7	24	50
Heart Rate	Nothing	161	99.4	19.2	57.7	145.2
	Entrapment	31	112.6	14.4	85.8	136
	Other	34	100.4	19.6	69.3	131.7
% HR max	Nothing	161	56.4	10.7	32	85
	Entrapment	31	63.4	8.4	47	77
	Other	34	56.2	11.1	36	75

Table 4.2: Effect of Dispatch Information on Ingress Physiology

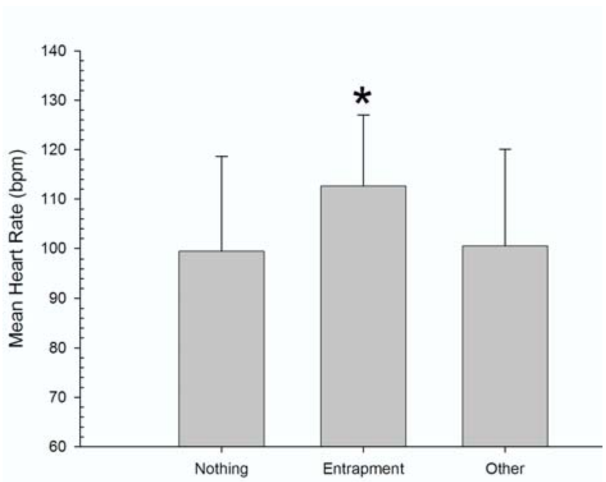
		Sums of Squares	df	Mean Square	F	Sig.
VeVol	Between Groups	4009808	2	200490.4	1.130	0.324
	Within Groups	43576365.4	246	177139.7		
Ventilation	Between Groups	612.4	2	306.2	0.800	0.450
	Within Groups	94029.5	246	382.2		
Breaths/min	Between Groups	73.9	2	37	0.690	0.502
	Within Groups	13155.5	246	53.5		
Heart Rate	Between Groups	4527.4	2	2263.7	6.5	0.002
	Within Groups	78081.6	223	350.1		
% HR max	Between Groups	1324.4	2	662.2	6	0.003
	Within Groups	24638.6	223	110.5		

Table 4.3: Tukey Post Hoc Comparison of Physiological Differences during Ingress

Dependent Variable	(I) Dispatch Info	(J) Dispatch Info	Mean Diff (I-J)	Stand Error	Sig
Heart Rate	Nothing	Entrapment	-13.1	3.670	0.001
		Other	-1.0	3.532	0.956
	Entrapment	Nothing	13.1	3.670	0.001
		Other	12.1	4.647	0.027
	Other	Nothing	1.0	3.532	0.955
		Entrapment	-12.1	4.647	0.026
% HR max	Nothing	Entrapment	-7.0	2.062	0.003
		Other	0.2	1.984	0.993
	Entrapment	Nothing	7.0	2.062	0.002
		Other	7.2	2.610	0.017
	Other	Nothing	-0.2	1.984	0.993
		Entrapment	-7.2	2.610	0.017

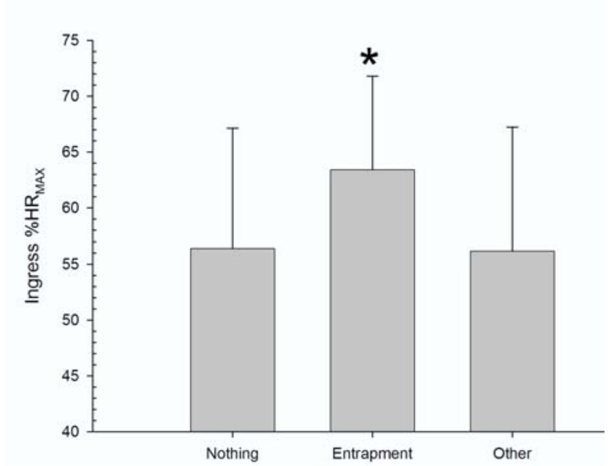
After significant differences were established, heart rate and relative heart rate differences were graphed to illustrate the observed differences. Graph 4.1 reflects differing Ingress heart rate responses observed as a function of dispatch information. These data indicate when entrapment is suspected, firefighters experience significant increases in cardiovascular stress prior to arrival at the fire scene. During Ingress firefighters are generally seated in an apparatus and little or no physical work is done. Therefore, the stress induced is an emotionally-driven sympathetic nervous system response (adrenaline outflow) to the information about entrapment.

Graph 4.1: Effect of Dispatch Information on Ingress Heart Rate



(*) Entrapment > Nothing, Entrapment > Other ($p < 0.05$)

Graph 4.1: Effect of Dispatch Information on Ingress %Heart Rate Max



(*) Entrapment > Nothing, Entrapment > Other ($p < 0.05$)

Tables 4.4 and 4.5 indicate that a significant relationship exists between the cardiovascular fitness of a firefighter (as indicated by Vo_{2MAX}) and the individual's heart rate during Ingress to the fire scene. The relationship is illustrated by graph 4.3.

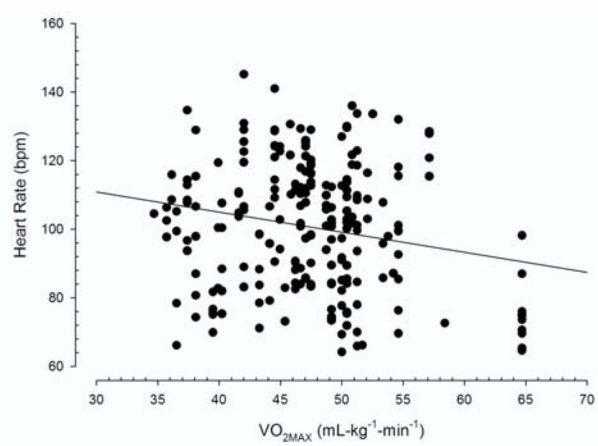
Table 4.4: Regression Vo_{2MAX} on HR

		ANOVA				
		SS	df	MS	F	sig
Model	Reg	3253.9	1	3253.9	9.2	0.003
	Resid	78546.4	222	353.8		
	Total	81800.4	223			

Table 4.5: Regression Coefficients Vo_{2MAX} vs HR

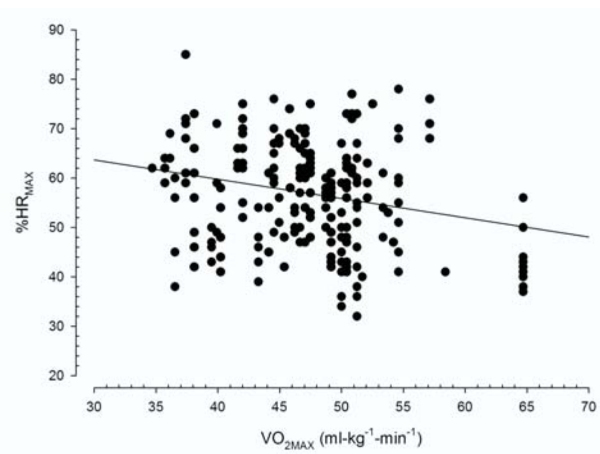
		Coefficients				
		Unstand Coef		Stand Coefs		
		B	Std	Beta	t	sig
Model	(Cons	129.5	9.4		13.7	0.000
	VO2m	-0.598	0.197	-0.199	-	0.003

Graph 4.4: Vo_{2MAX} regressed on Ingress Heart Rate



$HR = (-0.598 * Vo_{2MAX}) + 129.5$ $R = 0.199$, $R^2 = 0.040$

Graph 4.5: Vo_{2MAX} regressed on Ingress $\%HR_{MAX}$



$HR = (-0.399 * Vo_{2MAX}) + 76..04$ $R= 0.237$, $R^2 = 0.056$

Table 4.6 indicates that a relationship does not exist between firefighter fitness (as indicated by Vo_{2MAX}) and firefighter minute ventilation (V_E) during Ingress to a fire scene.

Table 4.6: Regression Vo_{2MAX} on Ingress V_E

ANOVA						
		SS	df	MS	F	sig
Model	Regr	55.7	1	55.7	0.147	0.702
	Resid	92830.2	245	378.9		
	Total	92885.9	246			

Cardiovascular and Respiratory Responses Suppression Operations

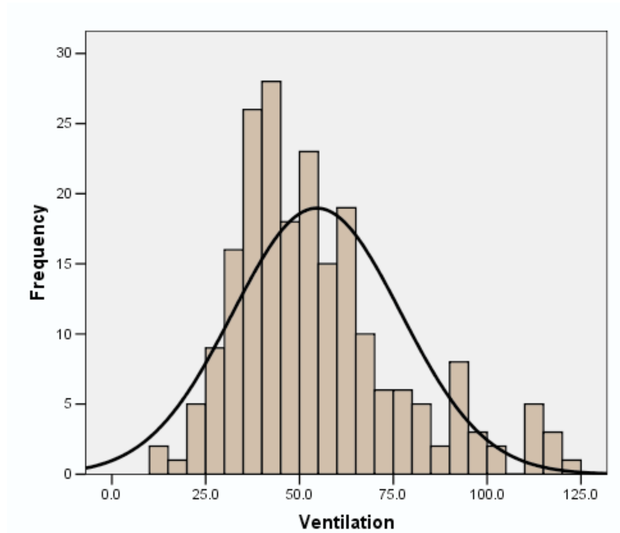
Physiological characteristics and duration of individual work phases of suppression operations were examined. Primary cardiovascular and respiratory physiological responses to each phase of suppression operations are outlined in Tables 5.1 through 5.4. Data presented in Table 5.1 represents overall responses to the fire scene across all work phases. The heart rate data illustrated here for overall suppression operations is similar to that described earlier (Sothmann, 1992 & Barnard, 1975).

Table 5.1: Overall Suppression Ops Physiology Descriptives

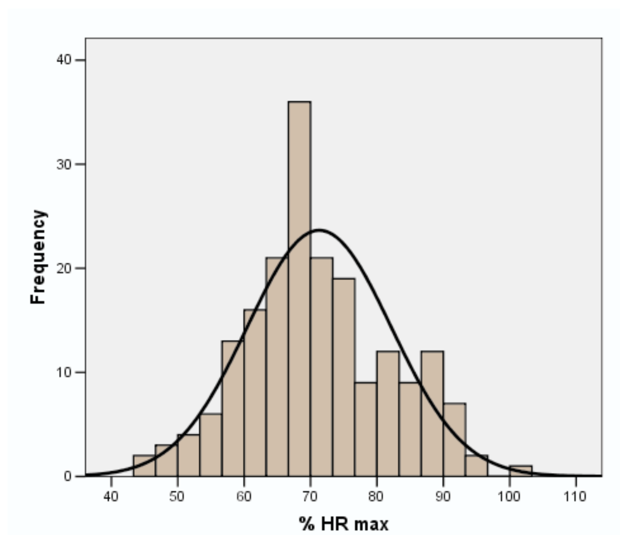
	Min	Max	Mean	STD
Duration	1.68	120.4	16.2	21.1
VeVol	699.8	3538.5	1569.0	523.0
VE	12.5	124.2	54.6	22.4
Brs/min	19.8	60.9	40.6	6.1
AccM	1.9	14.1	7.9	1.8
HR	81.9	170	126.2	19.8
%HR max	45	101	71.3	10.8

Graph 5.1 illustrates the frequency of ventilatory responses to fire suppression operations. Graph 5.2 illustrates the frequency with which levels of relative heart stress occurred during suppression operations. These data indicate that the typical firefighter response to fire ground operations is in excess of 70% of maximal heart rate and that on any given fire scene, nearly 70% of firefighters are working between 60% to 80% of their maximal heart rate. Similarly, the average firefighter is breathing at a minute ventilation of 50 L/min and 70% of firefighters are consuming between 28 and 78 L/min of SCBA air. Consuming air at these rates gave studied firefighters an average of approximately 28 minutes of air.

Graph 5.1: Frequency of Suppression Ops Minute Ventilation Responses



Graph 5.2: Frequency of Suppression Ops Relative Heart Rate Responses



Physiological responses were further explored by examining responses to individual Suppression operational work phases. Tables 5.2 contains data from individual suppression work phases, Fire Attack, Ventilation and Search respectively.

Table 5.6 is an F-statistic table showing significance of differences observed between suppression work phases. No differences were detected between suppression operations work phases with respect to duration or any measures of respiratory physiology. However, differences were detected between work phases with respect to raw heart rate and relative heart rate

Table 5.2: Suppression Operations Work Phase Physiological Responses

	Phase	Mean	STD	Min	Max
Duration	Attack	18.9	24.36	3.6	120.4
	Ventilation	16.9	25.47	1.8	120
	Search	12.2	9.51	1.7	45.3
VeVol	Attack	1596.1	582.74	829.4	3538.5
	Ventilation	1434.8	455.65	699.8	2619.3
	Search	1646.6	484.68	768.0	3155.8
Ventilation	Attack	56.2	23.91	24.2	119
	Ventilation	49.1	18.61	12.5	111.9
	Search	57.2	22.90	12.9	124.2
Breaths/min	Attack	41.4	5.65	30.8	60.9
	Ventilation	40.4	6.81	26.5	57.6
	Search	39.7	6.04	19.8	55.1
AccM	Attack	8.0	1.93	4.9	14.1
	Ventilation	7.4	1.62	2.3	10.7
	Search	8.0	1.68	1.9	12
Heart Rate	Attack	125.4	16.6	84.9	163.6
	Ventilation	117.1	20.20	81.9	156.3
	Search	134.6	19.61	84.4	170.0
%HRmax	Attack	71.4	9.09	49.0	92.0
	Ventilation	66.7	11.59	45.0	96.0
	Search	75.0	10.78	46.0	101.0

Table 5.3: Suppression Op work phase differences in Firefighter Physiological Response

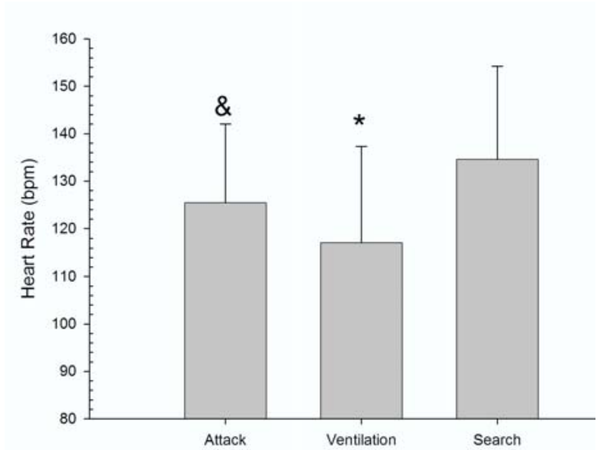
ANOVA						
		Sum of Squares	df	Mean Square	F	sig
Duration	Between Groups	1781.2	2	890.6	2.01	0.136
	Within Groups	94341.4	213	442.92		
	Total	96122.6	215			
VeVol	Between Groups	1533758.4	2	766879.21	2.85	0.060
	Within Groups	56463808.3	210	268875.28		
	Total	57997566.7	212			
Ventilation	Between Groups	2438.5	2	1219.24	2.46	.088
	Within Groups	103897.1	210	494.75		
	Total	106335.6	212			
Breaths/min	Between Groups	107.5	2	53.73	1.44	0.240
	Within Groups	7850.7	210	37.38		
	Total	7958.2	212			
AccM	Between Groups	16.7	2	8.36	2.66	0.072
	Within Groups	665.2	212	3.14		
	Total	681.9	214			
Heart Rate	Between Groups	9065.8	2	4532.92	12.98	0.000
	Within Groups	66333.1	190	349.12		
	Total	75398.9	192			
% HR max	Between Groups	2012.8	2	1006.40	9.29	0.000
	Within Groups	20589.8	190	108.37		
	Total	22602.6	192			

With differences detected among the physiological variables between work phases, a Tukey post-hoc analysis was performed to determine where differences exist between work phases. Table 5.7 outlines the results of the post-hoc analysis and Graphs 5.1 and 5.2 illustrate the detected differences in Heart rate and relative heart rate respectively.

Table 5.7: Post-Hoc Analysis of work phase physiological differences

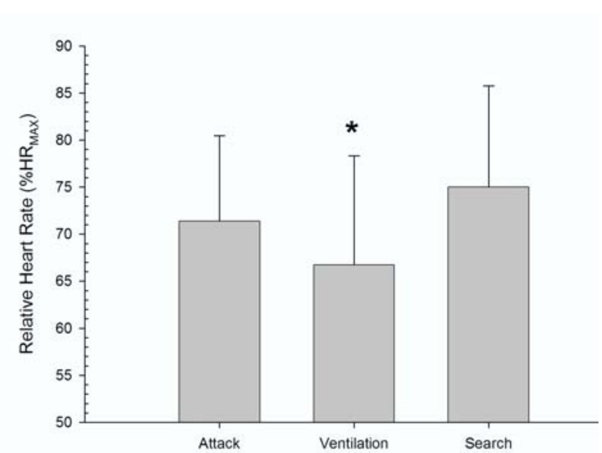
	(I) Phase	(J) Phase	Mean Difference (I-J)	Standard Error	Sig.
Heart Rate	Attack	Ventilation	8.3	3.34	3.70
		Search	-9.2	3.18	0.001
	Ventilation	Attack	-8.3	3.34	0.004
		Search	-17.5	3.44	0.000
	Search	Attack	9.2	3.18	0.012
		Ventilation	17.5	3.44	0.000
% HR max	Attack	Ventilation	4.6	1.86	0.036
		Search	-3.6	1.77	0.104
	Ventilation	Attack	-4.6	1.86	0.036
		Search	-8.2	1.92	0.000
	Search	Attack	3.6	1.77	0.104
		Ventilation	8.2	1.92	0.000

Graph 5.3: Suppression Ops differences in Heart Rate response



(*) Ventilation < Search, Ventilation < Attack
(&) Attack < Search

Graph 5.4: Suppression Ops differences in % Heart Rate Max response



(*) Ventilation < Search, Ventilation < Attack

Graphs 5.3 and 5.4 indicate search operations induce the highest heart rates during suppression operations. This high heart rate is most likely due to the physical stress of a fast-paced operation combined with the influence of the emotional stress of working in a dangerous environment. In the event search operations turn into a rescue operation, heart rate sky rockets. The highest heart rates observed during the study were in individuals involved in rescue of civilian victims. Some heart rates observed in rescue operations were in excess of 100% of predicted heart rate maximums and sustained for 20 to 40 minutes. Heart rates of this magnitude are extreme and may be responsible for triggering catastrophic cardiovascular events seen in firefighters possessing underlying heart disease.

Unfortunately, it appears nothing about the firefighter (Age, Experience, or Fitness level) is able to blunt or mitigate these responses. Data presented in Table 5.8indicate no relationship was detected between relative heart rate (%HRmax) and firefighter age, experience, or fitness level during suppression operations. On the surface, it may appear counter-intuitive to consider dissociation between fitness level and heart stress. However, it is important to note fitness here is an estimate of aerobic fitness. In fact, little if any of the work done during suppression operations is aerobic in nature. Therefore, a lack of association here between fitness level and cardiac stress during suppression ops is not surprising.

To discuss the work-induced stress placed upon the heart, blood pressure must also be considered. The product of heart rate and systolic blood pressure, known as the rate pressure product, is an indicator of work of the heart and the rate at which blood flow must be delivered to cardiac tissue. . Work that involves crawling and crouching body positions have the potential to drastically increase blood pressure as well as heart rate. This creates a hazardous situation for persons with underlying heart disease.

Physiology of Overhaul Operations

Overhaul operations were separated here from suppression operations. Overhaul operations are executed under different psychological and physiological stress environments compared to suppression operations. None the less, overhaul work represented a substantial physiological load to the firefighter. Table 6.1 outlines the physiological responses observed during overhaul work.

Table 6.1: Overhaul Descriptive Physiological

	Min	Max	Mean	STD
VeVol	681.9	3131.1	1321.0	427.8
Ventilation	12	114.9	43.0	19.8
Breaths/min	26.4	60.4	39.5	6.4
AccM	1.3	9.5	6.3	1.7
Heart Rate	65.1	153.9	116.9	15.0
% HR max	37	86	66.0	8.8

Overhaul responses were compared to suppression operations to detect differences in physiological demand. Table 6.2 contains the ANOVA F-table outlining these comparisons. Differences were detected between physiological variables during Overhaul and those of suppression operations work phases. The Post-Hoc analysis (Tables 6.3a and 6.3b) identified differences between Overhaul and suppression operations work phases.

Table 6.2: GLM analysis of Overhaul and Suppression Operations Phase Differences

Tests of Between-Subjects Effects						
Source	**Dependent Variable**	**SS**	**df**	**MS**	**F**	**sig**
Corrected Model	VeVol	6413920.62	3	2137973.54	8.80	0.000
	Ventilation	13406.95	3	4468.98	9.41	0.000
	Breaths/min	257.32	3	85.77	2.25	0.083
	AccM	206.26	3	68.75	23.44	0.000
	Heart Rate	15673.34	3	5224.45	17.28	0.000
	% HR max	4159.23	3	1386.41	14.33	0.000
Intercept	VeVol	657724263.47	1	657724263.46	2706.57	0.000
	Ventilation	781879.07	1	781879.07	1647.08	0.000
	Breaths/min	473680.55	1	473680.55	12423.30	0.000
	AccM	15987.46	1	15987.46	5450.51	0.000
	Heart Rate	4383100.27	1	4383100.28	14494.40	0.000
	% HR max	1400203.39	1	1400203.39	14477.45	0.000
phase	VeVol	6413920.62	3	2137973.54	8.80	0.000
	Ventilation	13406.95	3	4468.98	9.41	0.000
	Breaths/min	257.3	3	85.8	2.25	0.083
	AccM	206.3	3	68.7	23.44	0.000
	Heart Rate	15673.3	3	5224.4	17.28	0.000
	% HR max	4159.2	3	1386.4	14.33	0.000
Error	VeVol	75819202.2	312	243010.3		
	Ventilation	148108.2	312	474.7		
	Breaths/min	11896.1	312	38.1		
	AccM	915.2	312	2.9		
	Heart Rate	94348.7	312	302.4		
Total	VeVol	778318767.1	316			
	Ventilation	976042.7	316			
	Breaths/min	529233.8	316			
	AccM	17755.8	316			
	Heart Rate	485	316			
Corrected Total	VeVol	82233122.8	315			
	Ventilation	161515.2	315			
	Breaths/min	12153.4	315			
	AccM	1121.4	315			
	Heart Rate	110022.0	315			
	% HR max	34334.7	315			

Table 6.3a: GLM Post Hoc analysis of Overhaul and Suppression Op Phase Differences

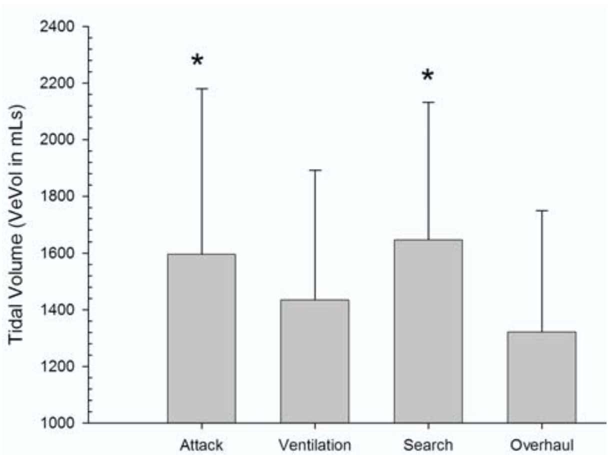
Dependent Variable	(I) Phase	(J) Phase	Mean Difference (I-J)	Std# Error	Sig#
VeVol	Attack	Ventilation	169.8	88.48	0.222
		Search	-68.7	84.07	0.846
		Overhaul	273.3	72.72	0.001
	Ventilation	Attack	-169.8	88.48	0.222
		Search	-238.5	90.77	0.044
		Overhaul	103.5	80.37	0.571
	Search	Attack	68.7	84.07	0.846
		Ventilation	238.5	90.77	0.044
		Overhaul	342.0	75.49	0.000
	Overhaul	Attack	-273.3	72.72	0.001
		Ventilation	-103.5	80.37	0.571
		Search	-342.0	75.49	0.000
Ventilation	Attack	Ventilation	7.6	3.91	0.212
		Search	-1.6	3.72	0.972
		Overhaul	13.4	3.21	0.000
	Ventilation	Attack	-7.6	3.91	0.212
		Search	-9.2	4.01	0.101
		Overhaul	5.8	3.55	0.354
	Search	Attack	1.6	3.71	0.972
		Ventilation	9.2	4.01	0.101
		Overhaul	15.1	3.34	0.000
	Overhaul	Attack	-13.4	3.21	0.000
		Ventilation	-5.8	3.55	0.354
		Search	-15.1	3.34	0.000
Breaths/min	Attack	Ventilation	1.3	1.11	0.632
		Search	1.8	1.05	0.297
		Overhaul	2.3	0.91	0.050
	Ventilation	Attack	-1.3	1.11	0.632
		Search	0.5	1.14	0.967
		Overhaul	1.0	1.01	0.754
	Ventilation	Attack	-7.6	3.91	0.212
		Search	-9.2	4.01	0.101
		Overhaul	5.8	3.55	0.354
	Search	Attack	1.6	3.71	0.972
		Ventilation	9.2	4.01	0.101
		Overhaul	15.1	3.34	0.000

Table 6.3b: GLM Post Hoc analysis of Overhaul and Suppression Op Phase Differences

Dependent Variable	(I) Phase	(J) Phase	Mean Difference (I-J)	Std# Error	Sig#
AccM	Attack	Ventilation	0.58	0.31	0.229
		Search	-0.12	0.29	0.975
		Overhaul	1.71	0.25	0.000
	Ventilation	Attack	-0.58	0.31	0.229
		Search	-0.71	0.31	0.115
		Overhaul	1.12	0.28	0.004
	Search	Attack	0.12	0.29	0.975
		Ventilation	0.71	0.31	0.115
		Overhaul	1.83	0.26	0.000
	Overhaul	Attack	-1.7	0.25	0.000
		Ventilation	-1.1	0.28	0.004
		Search	-1.8	0.26	0.000
Heart Rate	Attack	Ventilation	8.3	3.12	0.040
		Search	-9.1	2.96	1.229
		Overhaul	8.6	2.56	0.004
	Ventilation	Attack	-8.3	3.12	0.040
		Search	-17.5	3.20	0.000
		Overhaul	0.3	2.83	0.000
	Search	Attack	9.1	2.96	0.012
		Ventilation	17.5	3.20	0.000
		Overhaul	17.7	2.66	0.000
	Overhaul	Attack	-8.6	2.56	0.005
		Ventilation	-0.2	2.83	1.000
		Search	-17.7	2.66	0.000
% HR max	Attack	Ventilation	4.7	1.76	0.040
		Search	-3.5	1.68	0.150
		Overhaul	5.5	1.45	0.011
	Ventilation	Attack	-4.7	1.76	0.040
		Search	-8.2	1.81	0.000
		Overhaul	0.7	1.60	0.966
	Search	Attack	3.5	1.68	0.150
		Ventilation	8.2	1.81	0.000
		Overhaul	9.0	1.50	0.000
	Overhaul	Attack	-5.5	1.45	0.001
		Ventilation	-0.7	1.60	0.966
		Search	-9.0	1.50	0.000

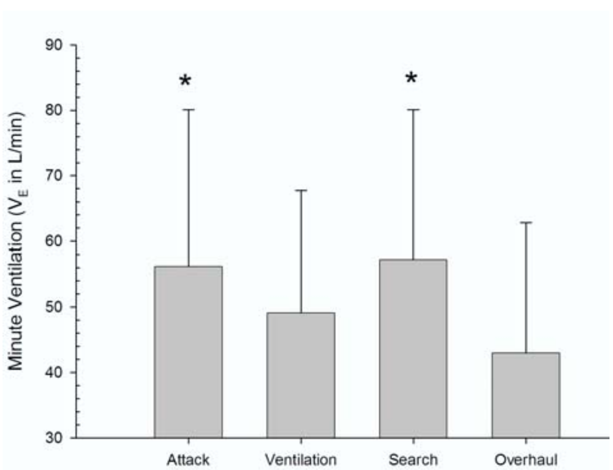
Graphs 6.1 through 6.5 illustrate differences in tidal volume, minute ventilation, physical activity (AccM, heart rate, and %heart rate maximum observed between Overhaul operations and suppression operations work phases. These physiological measures were all higher during suppression operations than during Overhaul.

Graph 6.1: Tidal Volume differences among Suppression and Overhaul Ops



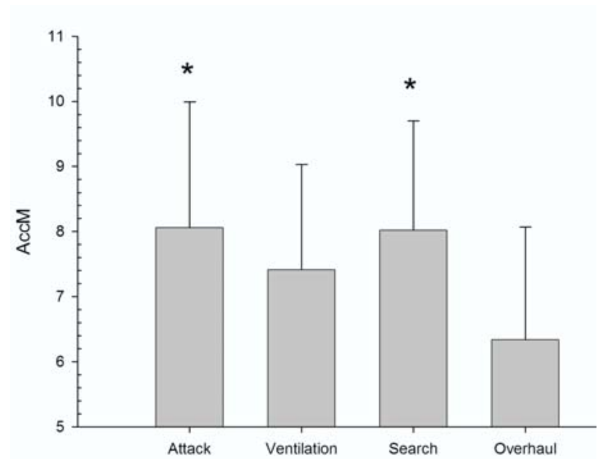
(*) Search VeVol > Overhaul, Attack VeVol > Overhaul

Graph 6.2: Minute Ventilation differences among Suppression and Overhaul Ops



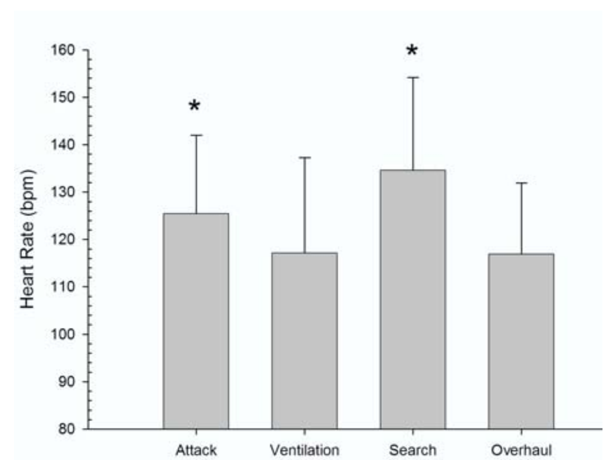
(*) Search V_E > Overhaul, Attack V_E > Overhaul

Graph 6.3: Physical Activity differences among Suppression and Overhaul Ops



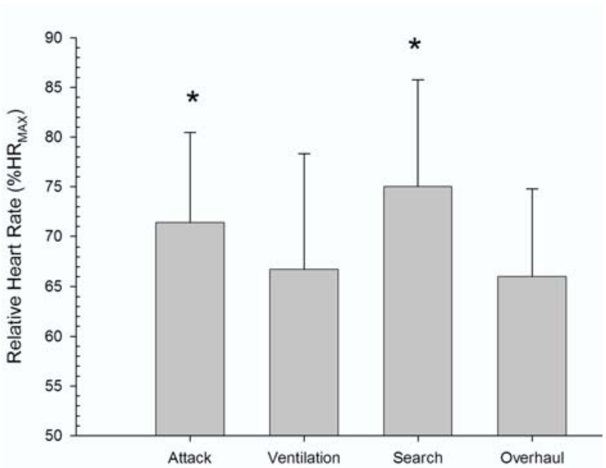
(*) Search AccM > Overhaul, Attack AccMl > Overhaul

Graph 6.4: Heart Rate differences among Suppression and Overhaul Ops



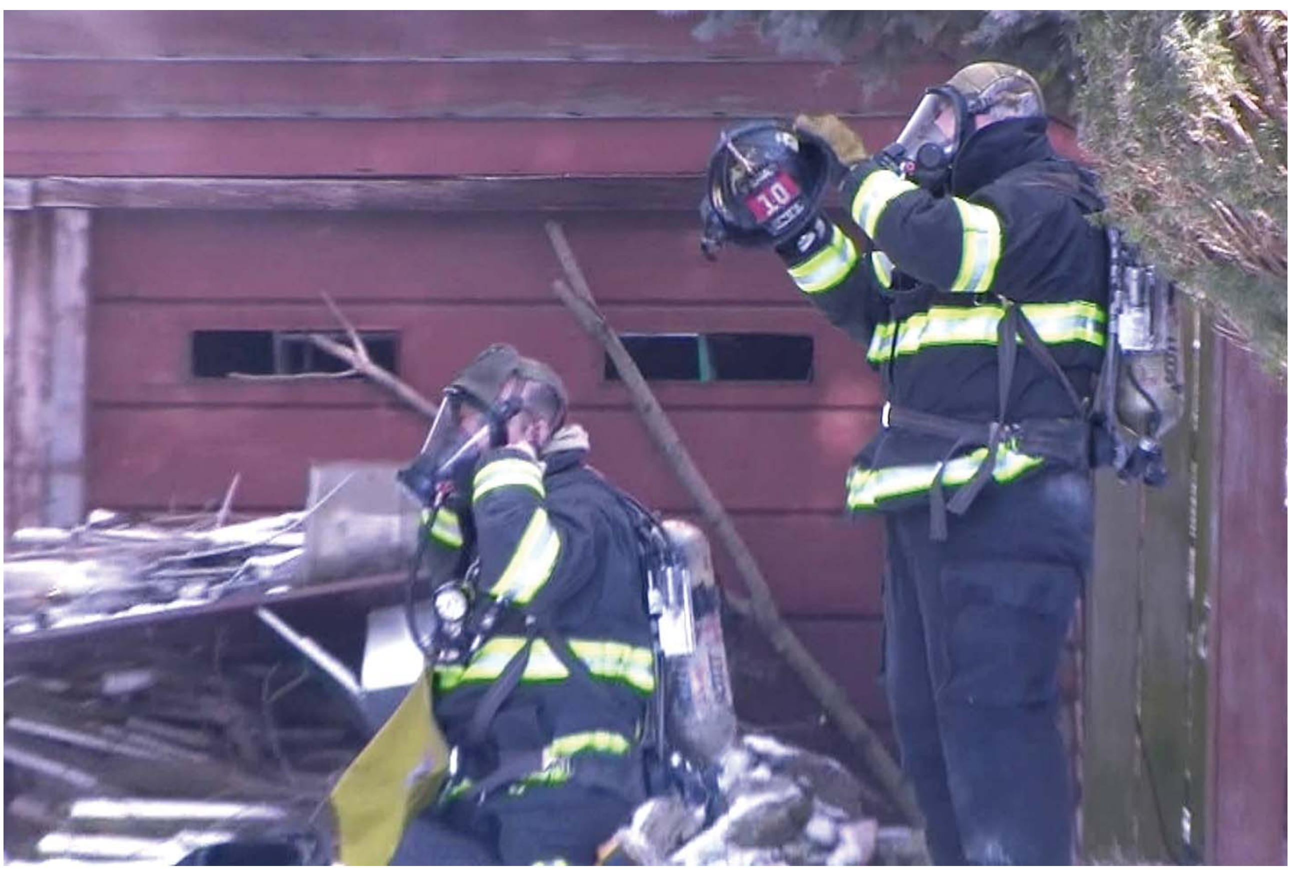
(*) Search HR > Overhaul, Attack HR > Overhaul

Graph 6.5: Relative HR differences among Suppression and Overhaul Ops



(*) Search %HRmax > Overhaul
Attack %HRmax > Overhaul

These data indicate that Overhaul operations imposed less cardiovascular and respiratory stress on studied firefighters than suppression operations. However, it is not possible to determine the relative contributions of psychological and physical stress that induce the observed responses. Overhaul can certainly be physically demanding work but it is generally executed in an environment of less psychological stress that suppression operations. Regardless of the stimulus (physical or emotional), increased heart rate generates cardiovascular stress.



Principle Components Analysis and Multiple Regression

A Principle Component Analysis was employed, to identify fire scene and subject characteristics having significant impact on firefighter physiology. Table 7.1 contains the component matrix extracted from the data set. This matrix was generated by pooling all fire scene and firefighter descriptive data and allowing the PCA analysis to group them into components. These components represent combinations of variables which explain the greatest variance in the cardiovascular physiology data.

The components listed in this matrix produced Eigenvalues above 1.0 as demonstrated by Graph 7.1. These Eigenvalues represent a weighting of variables with respect to their ability to explain variance in the dataA Principle Component Analysis was employed, to identify fire scene and subject characteristics having significant impact on firefighter physiology. Table 7.1 contains the component matrix extracted from the data set. The components listed in this matrix produced Eigen-

Table 7.1: PCA Component Matrix

	Component			
	1	2	3	4
Color	0.864	-0.105	0.029	.077
Involvement	0.830	-0.304	-0.053	0.155
Volume	0.805	-0.386	-0.026	.063
Situation	0.793	-0.394	0.074	-0.014
Heat Index	0.563	0.814	0.036	0.096
Temperature	0.573	0.808	0.038	0.088
% Body Fat	-0.121	-0.071	0.793	0.275
Age	-0.038	0.002	0.785	0.209
Footage	0.397	0.095	0.092	-0.653
VO2max	-0.056	0.016	-0.499	0.644

The Scree plot shown in Graph 7.1 indicates that only the first four solution components generated through PCA resulted in Eigenvalues greater than 1. Variables contained in the extracted components explain a total of 78% of observed physiology data variance and were therefore selected for Multiple Regression analysis

Graph 7.1: Eigenvalue Scree Plot

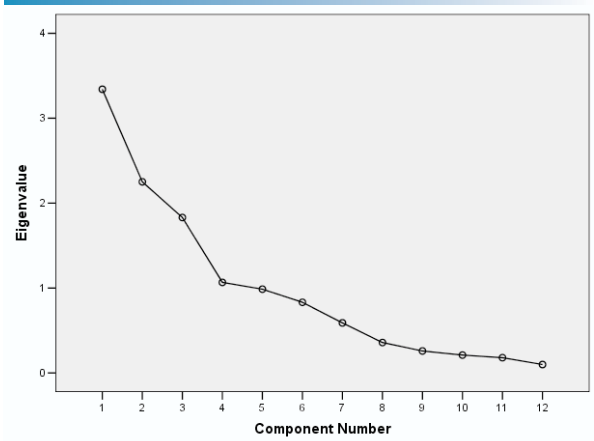


Table 7.2: Total Variance Explained

Total Variance Explained		
Component	**% Variance**	**Cumulative % of Variance**
1	35.3	35.3
2	17.4	52.7
3	15.1	67.8
4	10.1	77.9

Multiple Regression

Variables comprising the PCA-extracted components were regressed on a measure of cardiac stress (%HR_{MAX}). Table 7.3 contains the overall F-table for the regression and indicates a significant regression equation was produced.

Table 7.3: Multiple Regression F-table

ANOVA					
Model	**SS**	**df**	**MS**	**F**	**Sig**
Regression	7005.0	10	700.5	5.31	.000
Residual	67240.1	510	131.8		
Total	74245.2	520			

Examination of the coefficient table (Table 7.4) indicates five of the variables entered into the regression resulted in a significant regression equation.

Table 7.4: Standardized Regression Coefficients

		Beta Wt	**F**	**sig**
Model	(Constant)		4.58	0.000
	Age	0.218	1.38	0.007
	Yrs of Exp	-0.109	-0.68	0.252
	% Body Fat	-0.103	-1.24	0.003
	VO2max	.065	0.83	0.002
	Sq Footage	-0.078	-0.99	0.009
	Situation	0.132	1.12	0.264
	Involvement	0.139	1.06	0.002
	Color	0.133	1.10	0.105
	Volume	-0.075	-0.60	0.190
	Temperature	-0.006	-0.72	0.471

Table 7.5: Regression Model Summary

Model	R	R^2	Adj R^2	SEE
	0.317	0.100	0.048	10.44

Regression Equation

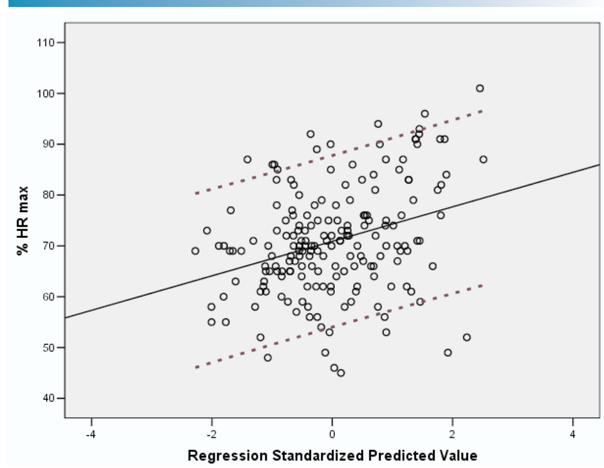
Significant variables from the coefficient table comprise the regression equation:

$$\%HR_{MAX} = 61.402 + (A * 2.335) - (B * 0.153) - (C * 0.310) - (D * 0.257) + (E * 0.000442)$$

A = % of Structure Involved in Fire
B = Firefighter Years of Service
C = Firefighter % Body Fat
D = Firefighter Vo_{2MAX}
E = Square Footage of Structure

The regression solution produced a predictive equation capable of estimating a firefighter's heart stress on a fire scene. The equation developed does not explain enough variance in the data set to be a practical predictive tool. However, the equation does identify and rank the fire scene and firefighter physiological variables that have the greatest impact on firefighter cardiovascular stress. Essentially a firefighter's age and fitness level combine with structure size and fire involvement to determine a fire scene's potential for inducing firefighter cardiovascular stress.

Graph 7.2: Regression Solution Estimating %HR_{MAX}



Qualitative Biomechanical Analysis

General Considerations

Thermal imaging and other video formats were utilized to observed firefighters during both real-world fire operations and during training. These video images were used to analyze the mechanics of firefighting skills. The physiological impact of these skills was interpreted to put the physiology recorded with LifeShirt into perspective. Personal Protective Equipment worn by firefighters is bulky and relatively heavy. In combination with the Self-Contained Breathing Apparatus (SCBA), hand tools, ladders, or hoses, the typical firefighter can carry as much as 70 pounds of gear onto the fire ground (Table 8.1). As a result, firefighters are almost immediately dependent upon glycolytic metabolism during suppression and overhaul operations.

In addition to the weight-bearing stress, firefighters also wear bulky gloves and ill-fitting boots which contribute to body instability. As a result, firefighters must exert greater than normal muscular

Table 8.1: Gear Weights

	N	Min	Max	Mean	STD
Weight (lb)	56	132.3	321.7	200.8	34.1
Wt w/gear (lbs)	56	203.7	434	272.5	38.8
Gear Wt (lbs)	56	49	112.3	71.7	14.6

Fire Attack Operations

Personnel involved in fire attack handle heavy, water-charge hose lines in an environment that typically requires them to assume a squatted or crawling body position. This body position and the forces required to move and manipulate the hose line results in large forces being generated, primarily by the body's core back, abdominal, and chest musculature. This type of movement and near-static force production typically results in elevated blood pressures due to a large magnitude of vascular compression.

Figure 8.1: Line Advance in Stairwell

Search & Rescue Operations

Search and rescue operations are generally conducted in low-visibility, high-heat conditions. The goal during primary search operations is to move as quickly as possible through the structure while still being thorough. In the effort, the firefighter carries a set of "Irons" weighing approximately 40 pounds in addition to their PPE and SCBA. Body positions assumed during search can be similar to that seen in Fire Attack. However, less force production is generally required to move through the structure. When search results in victim rescue, the firefighter must move the full body weight of a flaccid individual. This chore can be extremely difficult and require the generation of very large forces, primarily from the body's core musculature. Again, this force production and movement pattern can generate large insults to blood pressure due to vascular compression.

Figure 8.3: Laddering Up

External Ventilation Operations

Exterior ventilation operations often involve the use of ladders and tools to open windows or roofs to control heat and smoke movement within the structure. Firefighters typically carry chainsaws and other hand tools up ladders and then use them to cut holes through roofing material. Trying to maintain balance while operating a chainsaw off of a ladder lain across a steep roof, presents a significant challenge to the firefighter's agility. To maintain balance, it is necessary for the firefighter to have significant core body strength and endurance. Again, this type of near static work can cause significant increases in blood pressure. Figures 8.3 and 8.4 represent examples of exterior ventilation operations.

Figure 8.4: Opening a Roof

Overhaul Operations

Overhaul operations may involve work as strenuous as that of suppression and often more strenuous. The one overriding factor that reduces the cardiovascular stress during Overhaul is the reduced emotional drive (adrenaline) compared to suppression operations. The use of heavy tools and lifting make overhaul work similar to that seen in Ventilation. However, shoveling and lifting movement can cause substantial increases in blood pressure.

Figure 8.5: Overhaul

Discussion of Findings

DISCUSION OF FINDINGS

Despite considerable effort to reduce line of duty deaths due to heart attack, sudden cardiac death remains the leading cause of on-duty firefighter fatalities. A more telling fact is that an estimated 765 on-duty firefighters experienced heart attacks in 2005 (43); only 62 (8.1%) of which resulted in sudden death (2). These data indicate an alarming rate of adverse cardiovascular events among firefighters. Recently, Kales et al reported that nearly all working firefighters succumbing to heart attacks were determined to have underlying cardiovascular disease (5). In support of this opinion, several studies have reported the presence of risk factors for cardiovascular disease in firefighters (8-14). The presence of risk factors or even cardiovascular disease alone does not however, explain the extraordinary rate of heart attack death in firefighters. In addition, it is apparent that these fatal heart attacks are occurring in individuals younger in age than those in the general public experiencing the same fate (1). At the very least, firefighting presents a significant trigger for cardiovascular events. Several studies have suggested that strenuous physical activity on the fire ground may serve as this trigger (5-7). Although firefighting is intuitively a highly physical undertaken, there is little or no data illustrating the magnitude of its physical demand. This current study was undertaken to elucidate the magnitude of the cardiovascular and respiratory stress associated with structural firefighting.

Physiology of Structural Firefighting

Alarm Response

The cardiovascular and respiratory stress of fighting structural fires begins with a firefighter's response to the fire alarm. Increases in heart rate and minute ventilation in response to the alarm are induced by two primary mechanisms. First, a sympathetic- nervous-system-induced catecholamine (adrenaline) release results in increased ventilation and heart rate even before movement begins. Second, as the firefighter begins to move toward an apparatus, physical movement further increases heart rate and ventilation. We examined the first 90 seconds following alarm to determine the magnitude of this response. Heart rates typically rise to near 80% of predicted heart rate maximum and subsequently begin to decline when the firefighter has donned his PPE and mounted the apparatus. The magnitude of these responses indicate that the combination of physical and emotional effort result in substantial cardiovascular and respiratory stress. Some studies have found this instantaneous effort can induce ECG arrhythmias (18, 21) in addition to the heart rate and ventilatory stress. Fortunately, these responses can be modified. Our data indicate that older firefighters and firefighters who possess better physical fitness have lower heart rate responses to the alarm.

Fire Ground Ingress

During ingress to the typical fire scene, firefighter physical movement is substantially reduced resulting in a decline in heart rate and ventilation. If the firefighter has or receives information suggesting the fire scene involves entrapped victims, heart rate and ventilation remain high (or even increase). High heart rate and ventilation during this period of reduced physical activity indicate a strong emotional influence induced by sympathetic outflow (adrenaline release). Ingress physiological responses can also be mitigated by firefighter age and experience as well as fitness. Our data indicate that older, more experienced firefighter and those who possess better physical fitness have substantially lower heart rates during ingress regardless of the circumstance.

Suppression Operations

Once on scene, firefighter activity is primarily determined by the phase of suppression operations in which they are participating. Standard operating procedures of the Indianapolis Fire Department define three distinct phases of suppression operations, Fire Attack, Ventilation, and Search & Rescue.

Fire Attack Operations

As defined by this study, fire attack operations began when the first arriving engine company marked on scene. Just prior to arrival (end of Ingress), heart rate and minute ventilation begin to rise due to anticipation. This anticipation is generally induced when the firefighter gains site of the burning structure. It is proportional to the firefighter's perception of fire volume and intensity and is graded with respect to the firefighter's age, experience and level of fitness.

Heart rate and ventilation increase significantly as work begins. Increases to accommodate initial work tasks, pulling hose lines, donning SCBA and moving into a structure, are accompanied by a sympathetic outflow (adrenaline). A portion of this outflow is normally associated with the physical workload. However additional outflow is present as an emotional response to the situation. As the hose team enters the structure and assumes a squatted or even crawling body position, the hose line is charged and the line is advanced toward the fire. Advancing the line in a squatted or crawling position requires activation of a large mass of core body musculature in near static contraction. This large muscle mass compresses vasculature and induces an increase in systolic and diastolic blood pressures. Elevated blood pressure in conjunction with an increasing heart rate cause increases in work of the cardiac muscle and result in an increased demand for cardiac blood flow. This high level of demand for cardiac blood flow and the increased pressure load on the heart could serve as a trigger for MI in an at-risk heart.

Another source of cardiovascular stress is introduced here. As the firefighter enters a burning structure, ambient air temperatures are severely elevated. Although the firefighter is somewhat protected within the PPE, the PPE itself represents an uncompensible heat stress environment, in which it is virtually impossible to lose body heat. This thermal stress induces a hear rate increase in an attempt to rid the body of heat. Profuse sweating occurs within the PPE. If this heat stressed environment is endured long enough, loss of body water results in a reduced blood volume and a concomitant increase in heart rate. Although no association was detected between heart stress during fire attack and the level of firefighter aerobic fitness, it is well established that improved aerobic fitness improves cardiovascular performance in uncompensible heat stress environments (46).

Structure Ventilation Operations

Ventilation operations, as described here, involved the exterior ventilation of a burning structure. In accordance with IFD standard operation procedures, exterior ventilation is begun by the outside team of the first arriving ladder company. The physical demand of Vent operations vary greatly with the method of ventilation executed (vertical vs. horizontal ventilation etc), and the size and type of structure involved (residence vs. commercial structure, one vs. two story etc.). During the study, the most common situation involved vertical ventilation of a single story, wood framed residential structure. Firefighters executing vertical ventilation on these structures were required to scale ladders, and use hand tools and chain saws. When doing so, these individuals can typically carry 40-50 pounds of tools in addition to wearing their PPE. Scaling a ladder carrying hand tools and saws requires substantial power output. This level of power output is energetically supplied by oxygen-independent metabolic mechanisms (glycolysis, and creatine phosphate systems). This type of non-oxygen-dependent work indicates a need for firefighters to possess substantial anaerobic capacity in addition to aerobic capacity. During ladder ascent, especially with tools, large masses of core body musculature plus arm and leg muscle are activated. Here again, the activation of large muscle masses in near static contractions increase rate pressure product and work of the heart.

Search & Rescue Operations

Search operations *can be* the most physically and emotionally stressful job on the fire ground. The goal of primary search operations is to quickly survey the interior of a structure for the presence of victims. Execution of a search pattern requires the firefighter to crawl throughout an unfamiliar, burning structure without aid of visibility. While on their knees, searching firefighters use one hand to maintain contact with the structure floor as well as probe the floor area with a hand tool. The opposite hand is used to navigate the structure by maintaining contact with a wall. The intention is to investigate as much of the structure area as possible, as quickly as possible. This is a lifesaving operation and is usually the only hope of an entrapped civilian to survive their situation. Despite the similar body positions utilized in search operations and in fire attack (crawling, squatting etc), the physiological responses of the two movements are different. Of course, both are physically demanding and result in significant increases in heart rate and minute ventilation. However, the fast-pace character of search results in significantly higher heart rates and ventilation compared to the hose line operations of fire attack. Although activation of core and limb musculature is required during search, the contractions are less static in nature and should not result is much increase in rate pressure product as that seen during fire attack. In addition, the duration of search operations here tended to be less than the other phases of suppression operations.

With the discovery of a victim, search operations turn into rescue operations. Rescue operations elevated firefighter physiology to an entirely different plane. As discussed earlier, the suggestion of potential entrapment elevated heart rates and ventilation during ingress to the fire scene. Discovery of a victim and the subsequent removal of the victim resulted in the most severe level of stress observed during this study. Both the physical and emotional components of stress combine to drive heart rates to more than 100% of what would be predicted as a firefighter's maximum. The physical demand of moving an unconscious person is enormous. Near maximal effort from large muscle mass is required to move an unconscious adult victim. This effort is generally executed in a crawling or squatted body position and can result in large increases in blood pressures. In addition to the physical effort, a large, emotionally-driven sympathetic outflow of adrenaline is present which drives heart rates to extreme levels. Most impressive however, is this level of stress may be maintained throughout a 20-30 minute rescue operation. During one rescue operation recorded here, 4 firefighters rescued multiple victims from a second floor bedroom. All 4 firefighters worked at or above their maximum predicted heart rate for more than 25 continuous minutes. The workload placed upon the hearts of these firefighters was enormous. They ranged in age from 34 to 54 years of age. Fortunately, none of the participating firefighters experienced adverse physical damage as a result of the operation. It is important her to note that these individuals area all extremely fit, highly trained, and experienced firefighters. Another firefighter lacking any of these traits would not have been able to execute the rescue and may have even died in the attempt.

Overhaul Operations

Overhaul work was defined here as anything from pulling ceiling, searching for extension or hot spots to recovering tools and hose lines. In general, overhaul work can be physically demanding but it is not generally executed in a threatening environment. In addition, the firefighter does not wear the SCBA for a large portion of overhaul work. Heart rate and minute ventilation are generally elevated but not to the extremes seen during suppression operations. This is most likely die to the reduced sympathetic outflow stemming from emotional distress.

Primary Determinants of Physiological Response to the Fire Scene

Impact of Study Design

Many factors play a role in determining how a firefighter responds physiologically to a particular fire scene. Factors such as age, years of experience, health status and measures of physical fitness, are specific to the individual firefighter. Other factors, such as weather, characteristics of the structure, command strategies, and time of day are determined by the fire scene. By selecting a specific time of year, a single department (with consistent tactics), and a specific fire coverage area (as determined by station selection), we loosely controlled many of these determinants. The city of Indianapolis provided a moderate climate during which, winter months limit the impact of ambient heat stress. In addition, the Indianapolis Fire Department is a large, professional organization with a reputation of using aggressive interior attacks to protect life and property of the citizens of Indianapolis. IFD adheres to NFPA standards for medical oversight of firefighters (NFPA 1500), providing a subject population of generally healthy individuals. Lastly, the selection of specific IFD stations focused the study on approximately 25 square miles of primarily wood-framed residential structures of less than 3000 square feet.

Identifying Physiologically Important Variables

Using a Principle Components Analysis coupled with multivariate regression, five variables or "factors" were identified that have the greatest impact on firefighter cardiovascular performance on the fire scene. These factors can be grouped into two categories based upon the firefighter's ability to modify them. A factor that is modifiable may be manipulated to alter the firefighter's cardiovascular response to the fire scene. If a factor is non-modifiable, the firefighter has no opportunity to change the factor in order to alter their physiological response.

The non-modifiable factors identified as having primary importance to firefighter physiology on the fire ground include the firefighter's years of service, square footage of the burning structure, and the portion of the structure involved in fire. Again, these factors are beyond control of the individual firefighter. More importantly, they set the fire scene's level of physical demand. Modifiable factors important to physiology were firefighter body fat percentage and firefighter aerobic capacity. On the fire scene, these modifiable factors determine how the firefighter will respond to the physical demand required to perform successfully. Both of these factors are health-related components of physical fitness and can be directly affected by the firefighter. Oddly, the equation indicates a negative relationship between body fatness and cardiovascular stress. This indicates that, within the studied group, cardiovascular stress was reduced as body fatness increased. So, does being fatter reduce stress on the heart? Of course, the answer is no. Recalling that the group studied here was a healthy and fit group of firefighters, increased body fatness actually reduced the firefighter's ability to work hard. Essentially, the firefighters with the highest levels of body fatness were simply not able to push themselves (physically) as much as their leaner counterparts. This effect may be unique to the group of individuals studied here.

CONCLUSIONS

CONCLUSIONS

It is no surprise that heart rates, minute ventilation and blood pressures are elevated during firefighting activity. The physical work demand and the emotionally charged environment require these responses. However, prior to this study, the magnitude and duration of these responses were unclear.

Annual reports of firefighter deaths (1, 2, 3, 4) generally list the cause of on-duty heart attack deaths as "overexertion". However, overexertion is a relative term. Levels of work that produce overexertion in one individual might not do so in another, more fit individual. Therefore, several factors must be considered to put the data presented in to context. When we report means or averages of heart rates (70% of predicted HRmax) and levels of minute ventilation (50 L/min), some of the work does not seem all that strenuous. However, firefighters studied here were highly trained, medically supervised, healthy and relatively fit individuals. The same work in a less well trained and less fit group of firefighters would result in much higher levels of cardiovascular stress. In fact, work here that pushed studied firefighters to 100% of their maximal cardiovascular capacity could not be accomplished by some unhealthy and unfit firefighters. Even within this group, we see individuals with higher levels of body fat not being able to work as hard as their leaner peers. Another factor to consider is the fires themselves. We saw from the principle components analysis, the size of the structure and amount of fire involved have significant impact on the firefighter's response. Indeed, the average structure studied was a relatively small (2500 ft^2) residential structure. As structures grow larger and more complex, the physical response grows. Yet, even some of these small structures pushed firefighters to their maximal abilities. Lastly, we must consider the weather conditions. We chose to conduct the study in the absence of ambient environmental heat stress. Unfortunately, firefighters must fight fire in all weather conditions, including hot humid weather that imposes extreme heat stress conditions on the fire scene. The process of thermoregulation can impart severe cardiovascular stress on firefighters before they set foot on the fire ground. During a 2005 study of training related physiology, a study conducted at the Maryland Fire and Rescue Institute (36) saw many firefighters reporting for duty in a dehydrated state. Dehydration exacerbates the cardiovascular stress associated with thermoregulation and can debilitate even the most fit firefighter.

Fire Scene as a Trigger for Heart Attacks

So, how does the information presented here shed light on the extraordinary number of firefighter line of duty heart attacks? The answer lies in the magnitude of the physiological responses. Recently, a comprehensive examination of the LODD due to heart attack was completed by a group at Harvard University (5). The researchers found the primary cause of heart attack deaths associated with firefighting was overexertion in firefighters with existing cardiovascular disease. A 2006 review of research on cardiac deaths indicated that high levels of physical exertion as well as severe emotional stress are triggers for a heart attack (47). In the case of firefighters, both physical and emotional triggers are present. These researchers also concluded that periods of high physical or emotional stress essentially accelerate an inevitable cardiac event in persons with cardiovascular disease. This is an extremely important point with respect to firefighters. One of the most alarming facts with respect to on-duty firefighter heart attack fatality is the average age at the time of death is in the early 4^{th} decade of life.(1). If you are a person with cardiovascular disease, death due to heart attack or stroke is probably inevitable. However, if you are a firefighter with cardiovascular disease, that death due to heart attack or stroke is likely to come *much sooner*.

Another question asked about firefighter line of duty heart attack deaths is why so many occur *after* leaving the fire scene. As discussed earlier, there is an essential physical recovery period following any physical activity. The duration of the recovery period is determined by the duration and magnitude of the physical activity combined with the individual's level of aerobic fitness (all recovery is aerobic). This is because physical activity raises body temperature and causes the release of many hormones that enable us to do high levels of work. One of these hormones, adrenaline, is also released in response to emotional stimuli. Adrenaline raises the heart rate, blood pressure and increases minute ventilation. The higher the physical demand or emotional stress, the greater the rise in temperature as well as the amount of hormone released. These factors do not simply disappear with the cessation of physical activity or the removal of an emotional stimulus. Substantial time is required to metabolize hormones and to dissipate heat. As a result, stress effects tend to linger. One incident captured by the study involved the rescue of children entrapped on the second floor of a fully involved residence. The incident resulted in severe physical and emotional stress on the firefighters driving heart rates to levels in excess of 100% of their predicted maximum. Two hours after returning to station (some three hours following the completion of rescue operations), heart rates of individuals involved in the rescue remained in excess of 100 beats per minute. Essentially, the physical and emotional triggers for heart attack stay with the firefighter for some time after an incident. High levels of stress present long after an incident, is a potential trigger for cardiovascular events, especially in individuals with underlying cardiovascular disease.

Reducing Firefighter Deaths Due to Heart Attack

Unfortunately, many firefighters in the US are not only unfit for fire scene work but are generally unhealthy individuals. The discrepancy between the physical preparedness of firefighters and the high physical demand of firefighting stands at the center of fire service line of duty deaths. Simply to expect to survive fire ground operations, a firefighter needs, as a minimum, to be healthy (including the absence of cardiovascular disease). The goal of this research is to support a service-wide effort to reduce the number of firefighter line of duty deaths. Because heart attacks account for nearly half of these deaths, much attention is focused on elucidating and eliminating the cause of these events. Unfortunately, no substantial improvements in firefighter health have occurred in the last 25 or so years. As a result, firefighter death statistics (as a result of heart attack) remains virtually unchanged. With improved research funding we are beginning to better understand the etiology of these events and to develop plans that will change the death statistics. Currently, there appear to be two primary approaches to the problem.

Some researchers are working on the development of physiology monitoring systems in hope of detecting severely elevated cardiovascular or respiratory responses during fire ground operations. This in turn would allow affected firefighters to be relieved before a catastrophic event is triggered. Unfortunately, the data presented here suggest this approach would not be successful. It is apparent that, in some cases, extreme physiological responses are appropriate on the fire ground. Simply removing a firefighter because his or her heart rate is extremely high would stand in the way of getting the job done. It is much more important that firefighters be healthy and fit enough to turn the output of their cardiac pumps up (increase heart rate) enough to do what they are expected to do and not experience adverse effects because of it. This seems to negate the utility of a monitoring device that simply alerts to extreme level of heart rate or ventilation.

Programs such as the Wellness/Fitness initiative undertaken by IAFF and IAFC, and the US Fire Administration's Life Safety Summit have recognized the need for improving the health of firefighters as a preventative measure. The national fire prevention association has issued guidelines for oversight of firefighter health programs (31). These programs set the stage for improvement in firefighter health. If successful, they will certainly result in a reduction in firefighter deaths due to heart attack. It is important however, that firefighters take advantage of such programs, either voluntarily or as a requirement for service.

Although there remain unknown factors on the fire ground that may increase a firefighter's risk of developing heart disease, we know now that the vast majority of heart attack deaths occur in unhealthy, unfit firefighters. This study clearly demonstrates the magnitude of cardiovascular stress placed on working firefighters and indicates firefighting activity can be a trigger for a cardiac event. Essentially, firefighting is triggering a cardiac death that is inevitable in persons with cardiovascular disease. So how do we stem the tide of heart attack deaths in working firefighters? We must improve firefighter health and reduce their risk factors for heart disease. Whether the responsibility for that improvement lies with the firefighter, their department or their labor organizations is for the fire service to decide. The fire service is still asking why are firefighters dying of heart attacks and what can we do about it. Academic researchers have been demonstrating since the mid-seventies (6-11, 13, 15-24) that firefighting is a substantial trigger for heart attack and preventative physical training should be *required* of firefighters.

Implications for Firefighter Physical Training

Development of an effective physical training program begins with the identification of demand levels a job or event presents. Several studies have attempted to quantify the physical demand of firefighting by observation of training or simulated firefighting activity (6, 15-16, 18-27, 36, 38, 46). Unfortunately, laboratory measures tell us little about the physiology of real world structural firefighting. This was a primary reason the current study was undertaken. Adequate funding, appropriate technology, and an embedded relationship with a large metropolitan fire department enabled us to examine the physiology of real-world firefighting. With information about the cardiovascular and respiratory demands of structural firefighting, we are now able to make statements about how firefighters should be trained.

First, it is important to define what we refer to as physical fitness. The terms healthy and physically fit are not synonymous. Healthy refers to a state of well being and includes both physical and emotional aspects of life. Physical health includes not only the absence of disease but several functional physiological capabilities commonly referred to as health-related components of physical fitness. These components include aerobic capacity, body composition, muscular strength, muscular endurance and flexibility. Sound physical training programs designed for the general population address all of these components. Programs designed for individuals who regularly endure high levels of physical stress go beyond these health-related components and include some performance-related components of physical fitness. In addition, the goals for health-related components are substantially different for these individuals compared to the general public. Athletes and firefighters fall into this higher-demand category. Sometimes you will even hear firefighters referred to as occupational athletes.

The cardiac and respiratory stress data, in combination with the inferred blood pressure responses described by this study, elucidate the firefighter's need for a healthy cardiovascular system. The firefighter cardiovascular system will be stressed significantly, sometimes under high ambient heat stress conditions. In addition, the need to exert and maintain large muscular forces, usually from an awkward body position, indicates the need for significant muscular strength, muscular endurance, and joint flexibility compared to civilian counterparts. Accordingly, standardized guidelines for physical training NFPA 1583 (49), address these components for developing the firefighter's physical fitness. As fire scene work begins, firefighters typically carry 60-70 pounds of protective clothing, breathing apparatus, and tools. As a result, little of the work executed on the fire ground could be described as having a large aerobic component. Instead, the high levels of power output required on the fire ground places emphasis on non-oxidative (anaerobic) metabolic processes. This anaerobic capacity is not considered a health-related but a performance-related component of physical fitness. An improved anaerobic capacity can significantly reduce cardiovascular stress in individuals executing anaerobic work. Accordingly, firefighters would benefit from training that improves glycolytic and creatine phosphate metabolic system capacities.

Other performance-related components of physical fitness also play a role on the fire ground. Studies conducted by Dr. Denise Smith (50. 51) have shown the effects of firefighting activity on the balance and coordination of firefighters. Training protocols that include agility training would also benefit the firefighter and alleviate some of the risk of trips and falls on the fire ground, a substantial origin of firefighter injury.

Lastly, it is important (from a physiological standpoint) to recognize the wide range in numbers of fires worked between fire service organizations and the effect is has firefighter physical demand.

The physiological demand required to fight a structural fire is primarily determined by the structure. Essentially, the structure sets the demand level without regard to who is coming to fight the fire (career professional, volunteer, paid volunteer etc). As such, achieving similar goals on the fire ground places the similar physical stresses on *all* firefighters. However, a firefighter working in a busy company of a large metropolitan department may be required to fight multiple fires in a single shift. This lies in sharp contrast to the rural unpaid volunteer who may only work a handful of structural fires in a year. As observed in this study, the physical stress placed on the firefighter does not simply disappear when they leave the fire scene. Significant cardiovascular stress may be present for some time following an incident. Unfortunately, this places a substantial burden on firefighters who fight large numbers of fires. These firefighters do need to be held to a higher standard of physical preparedness in order for them to recover quickly and be able to meet the demands of the next incident. Achieving a level of physical preparedness that enables the firefighter to survive and function appropriately on a fire scene should be the *starting point* for firefighter physical training, not the goal!

As always, the healthier and more physically fit *any* firefighter is, the better. However, at a minimum, the firefighter needs to a healthy and physically fit *citizen*. With increasing physical stress (as determined by the number and character of fires they fight), higher fitness goals need to be set to ensure the firefighter is physically prepared. This would include increased levels of all health-related fitness components and the incorporation of performance-related components into physical training programs.

In conclusion, it appears that firefighting activity presents significant cardiovascular and respiratory stress. Recent evidence suggests that a majority of the cardiovascular-related line of duty deaths are caused by underlying heart disease. It is clear from the data collected here that fire scene work exposes the firefighter to a substantial potential for triggering cardiovascular events. Therefore, firefighters with pre-existing cardiovascular disease exposed to the physical and emotional stress of a fire scene are in extreme risk of a experiencing a myocardial infarction, stroke or other cardiovascular system collapse.

The fire scene is alive with many potential complicating exposure factors (toxic gases, particulates etc.) and it is certainly possible that working on a fire scene may contribute to the progression of the disease state. However, the best defense against the progression of the disease is a health monitoring plan coupled with a sound physical training program, and adequate operating procedures to lessen exposures. The National Fire Protection Association has issued guidelines for such programs and, in the case of physical training program, suggests they be made mandatory (49). Although this guideline meets with resistance from every faction of the fire service, departments, unions, and firefighters alike, it is a simple fact that sound physical training programs are the only way line of duty deaths due to heart attacks are going to be reduced.

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APPENDIX A:
TIMELINE OF PHYSIOLOGICAL RESPONSES

TIME	ELAPSED	EVENT	DESCRIPTION	SIGNIFICANT PHYSIOLOGICAL RESPONSES
0:30:00	0:00:00	Still Alarm	Report of a fire in a residence	Awaken HR and VE increase with increased physical activity and anticipation HR and VE are modified by fitness level and years of experience
0:31:20	:01:20	Exit & Ingress	No additional information	Initially,HR and VE decline with reduced physical activity Modified by firefighter experience and fitness Approaching scene, HR and VE increase with anticipation (adrenaline release
0:33:25	0:03:25	Arrive on Scene Size Up	Weather 8.3^{0}C (47^{0}F), 65% Relative Humidity Clear Sky, No Wind Double reidence Fire & heavy smoke showing from 1st floor 50% involvement, Gray smoke on arrival	Ingress companies: HR and VE Increase due to anticipation (adrenaline release)
0:33:25	0:03:25	Fire Attack Begins	Don SCBA & enter structure Advance hose line to fire	HR and VE increase exponentially as work begins HR increases to ~71% of predicted HRmax, VE increases to ~56 L.min In crouched position or kneeling with hose line, SBP and DBP increase RPP increases drastically as HR and SBP increase
0:33:25	0:03:25	Primary Search Begins	Don SCBA & enter structure Execute multi-room primary search	HR increases to ~75% HRmax and VE to ~57 L/min HR and VE may reach steady state and is maintained through search
0:33:25	0:03:25	Vertical Vent Begins	Retrieve tools approach structure Dom SCBA & Scale Ladder Vent Roof with chainsaw	HR and VE increase due to increased work level and adrenaline release HR increases to ~67%HRmax and VE increases to ~49 L/min If core body muscle is tensed to stabilize the body, blood pressure and HR increase drastically
0:45:37	0:15:37	Primary Search Ends	Exit Structure & change air bottle	HR and VE drops significantly
0:50:25	0:20:25	Vertical Vent Ends Exit	Roof prepare to deploy PPV fan	HR, VE and blood pressures decline to level appropriate to work load
0:52:25	0:22:25	Fire is Controlled		
0:52:25	0:22:25 Loss Stop	Overhaul Begins	Search for hot spots & extension	HR and VE increase proportionally to work load Overhead work increases HR and VE moderately, SBP & DBP increase significantly Shoveling and other heavy lifting can also increase blood pressure
1:12:00	0:42:00	Interior Overhaul Ends	Personnel exit structure Recovery of equipment and personnel	As heavy work ends, HR and VE decline to match workload
1:32:00	1:02:00	Exit Scene	Command Terminated	Physiological recovery begins; HR and VE decline as work load decreases
1:40:00	1:10:00	Return to Station		HR and VE remain elevated during recovery. EPOC is proportional to duration and level of exertion on fire scene Emotional stimuli may also contribute to elevation and delay return to pre-run levels

APPENDIX B:
INFORMED CONSENT STATEMENT

Study #: 07-12447

INDIANA UNIVERSITY – BLOOMINGTON
INFORMED CONSENT STATEMENT

EXAMINATION OF THE PHYSIOLOGICAL RESPONSES TO STRUCTURAL FIREFIGHTING AND PSYCHOLOGICAL RESPONSES TO GENERAL EMERGENCY CALL WORK SEEN IN PROFESSIONAL FIREFIGHTERS

You are invited to participate in a research study. The purpose of this study is to determine the physical and emotional responses of firefighters responding to emergency call and fighting structural fires. Sixty firefighters will be recruited for the study that will be conducted over 50 standard duty shifts (approximately 6 months).

STUDY INFORMATION

Medical History and Physical Assessment

To start the study, you will be asked to complete a demographic and medical history questionnaire that provides information about conditions that may affect your physical work performance. In addition, you will be asked to submit to a series of physical work tests to assess health-related aspects of your physical fitness.

Fitness Assessment

The first test, a Queen's College Step test, is designed to assess your cardiovascular fitness (condition of your heart and lung function). Before beginning the step test, you will be asked to put on a LifeShirt® device (described in detail below). This device will monitor and record your heart rate during the step test. Later, the research staff will use your heart rate during and after the test to evaluate your fitness level. To complete the test, you will stand at rest in front of an 18-inch tall box for two minutes. At the end of the rest period, you will be asked to step on to and off of the box for a period of three minutes. You will be provided with a cadence (rhythm) to step to during the test. At the end of the three-minute test period, you will again be asked to stand in front of the box for a period of two minutes to recover. Your pulse will be measured and recorded during the recovery period and used to estimate your cardiovascular fitness level.

.Subject Initials: ________

Next, you will be asked to do as many standard sit-ups as you can within a 2-minute period. This test is a field estimate of general muscular endurance. Third, you will be asked to do as many standard push-ups as possible within a one-minute period. This push up test is used as a general indicator of you muscular strength.

Physical Dimension and Body Composition

Your height and weight along with your waist and chest circumferences will be measured. To determine the amount of body fat you have, the thickness of skinfolds will be measured. Skinfolds are determined by measuring the thickness of a fold of skin pinched between the thumb and index finger. By measuring these thicknesses at specific body sites, the portion of your body that is fat can be estimated. Because all research team members will be males, females may refuse collection of body measurements that involve personal contact with a member of the research staff. Refusal will not prevent you from participating in the study.

<u>Physiology Monitoring</u>

During a period of fifty (50) consecutive duty shifts, you will be asked to wear a garment called LifeShirt® (Figure 1). This garment will continuously monitor your heart and breathing function as well as the movement of your body. The garment is a simple vest that zips up the front and contains two flexible wires to monitor breathing function. Three electrodes will be attached to your chest to record your Electrocardiogram (ECG or heart function). Prior to putting these electrodes in place, your skin will be prepared by wiping with an alcohol pad. A small disposable razor will be used to remove a small amount of hair at the attachment site if necessary.

With the vest in place, a single wire (called a data cable) that attaches to the ECG electrodes and the embedded wires will be attached to the front of the vest with Velcro®. The data cable connects to a small recording device you will carry in your pocket. Once the monitoring device is in place, it will be powered up and calibrated. You will be supplied with extra LifeShirt® vests and ECG electrodes so you may change when necessary. At the end of your duty shift, you will turn the recorder off and remove all monitoring equipment. You will then

.Subject Initials: ________

be provided a logbook in which you may record any information you feel important. LifeShirt® garments will be laundered by researchers and returned to you at the beginning of your next duty shift.

Figure 1: LifeShirt® system with recorder

Fire Scene Data Collection

A member of the research staff will be on duty during your duty shift and will be on-site at fire incidents to which you respond. At these fire scenes, researchers will observe and collect data that describes the environment in which you are working. This data collection may involve video recordings of you doing your job. This video data will be used to help researchers better understand and describe what you do. In addition, some video will be part of a final report given to the study's funding agency (US Homeland Security) as well as distributed to the fires service across the US.

Psychological Assessment

During a two-week period of the study, a randomly chosen group of 6 participants will be asked to provide additional information for the study. In addition to the physical data being collected, these individuals will be asked to fill out a short survey examining their emotional state at the beginning of their work shift and again after each emergency run (not just fire runs). At the same time the survey is filled out, you will be asked to provide a saliva sample by spitting into a sample tube. This saliva sample is used to measure your level of a stress-

.Subject Initials: ________

related hormone called Cortisol. If invited to participate in this phase of the study, you may refuse but remain in the primary study.

Data Analysis

Once all data is collected, researchers will use a statistical technique know as a principle components analysis to determine findings. This analysis allows researchers to determine the principle (most important) aspects (or components) of your job that determine how much physical stress you endure while fighting fires.

RISKS

Your participation in this study does not present any foreseeable risk to your health or safety. Some people have experienced slight discomfort when wearing the LifeShirt® garment due to skin sensitivities to fabrics or to electrode adhesives. Although these discomforts are rare and usually minor, it will be up to you to decide whether or not you wish continue in the study. The Queen's College Step test you will be asked to perform is a field test to determine your fitness level. Although less strenuous, it is intended to estimate the same information the doctor gets during your annual duty fitness stress test.

BENEFITS

As a result of your participation in the study, you will receive information from the research team about your physical fitness and body composition. At the end of the study, you will also receive copies of final study reports in both written and video format.

In a broader view, this project is a first of its kind study, which will provide researchers and the fire service with valuable information about the physical demands of your job. As a result, important advances may result which ultimately improve the health and safety of all first responders.

.Subject Initials: ________

CONFIDENTIALITY

It is important that you know how researchers deal with your personal information collected for the study. All information collected form you is strictly confidential and will not be disclosed to anyone outside the research team for any reason. Rather than using your name, you will be assigned a study identification number that will identify all data collected from you. Any paperwork that contains your name will be locked in a secure file cabinet for the duration of the study and destroyed after the study is completed. All data from individuals will be pooled (grouped) for analysis. As a result, it will not be possible for you or anyone else to identify your individual data in reports derived from the study.

At the end of the study (approximately May 2008), the code information that enables your identification will be destroyed. All the data (including video data) will remain in the possession of the researcher permanently.

COMPENSATION

As compensation your participation, you will receive $30.00 for each duty shift in which you are involved in the study. At the end of each duty shift, you will be asked to sign a log sheet. The log sheet will be counter-signed by a member of the research staff verifying your participation. Because you all live in different locations throughout the Indianapolis metro area, your local union office has volunteered to provide a secure and confidential drop box for your logs. You will need to deliver these logs to the local union office drop box in order to be paid for your participation. The research staff will collect these logs when it is time for payment to be made. Payment will be made to you twice, once at the study mid-point and once at the end of the study.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Dr. Joel Stager, at 1025 East 7th Street, Bloomington, IN 47405, 812-855-1637, and stagerj@indiana.edu .

.Subject Initials: ________

APPENDIX B: APPROVED INFORMED CONSENT STATEMENT

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the office for the Indiana University Bloomington Human Subjects Committee, Carmichael Center L03, 530 E. Kirkwood Ave., Bloomington, IN 47408, 812/855-3067, by e-mail at iub_hsc@indiana.edu.

PARTICIPATION

Your participation in this study is voluntary; you may refuse to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read this form and received a copy of it. I have had all my questions answered to my satisfaction. I agree to take part in this study.

Subject's signature______________________________ Date ___________________

Consent form date: September 18, 2007, Revised: September 28, 2007, Oct 3, 2007.

IRB Approved
Approval Date: OCT 0 4 2007
Expires: OCT 0 3 2008

Page 6 of 6

APPENDIX C:
INSTITUTIONAL REVIEW BOARD APPROVAL

RECEIVED
SEP 21 2007
HUMAN SUBJECTS COMMITTEE

INDIANA UNIVERSITY
BLOOMINGTON CAMPUS COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS

DOCUMENTATION OF REVIEW AND APPROVAL
of
Research Project Utilizing Human Subjects

Study # 07-12447

TITLE OF PROJECT: Examination of the Physiological Responses to Structural Firefighting Activity and the Psychological Responses to General Emergency Call Work Seen in Professional Firefighters

PROJECT DURATION - START DATE ~~09~~10/07/2007 END DATE 09/06/2008

PRIN. INVESTIGATOR Dr. Joel M. Stager, PhD SCHOOL/DEPARTMENT HPER / Kinesiology

ADDRESS 1025 East 7th Street, Bloomingotn, IN 47405 E-MAIL stagerj@indiana.edu PHONE 812-855-1637

RANK: Faculty ⊙ Res. Scientist ○ Post-Doc ○ Staff ○ Student: undergrad ○ masters ○ PhD/EdD ○

If PI's rank is OTHER than faculty, name of faculty overseeing the research (SPONSOR)

SPONSOR'S E-MAIL CAMPUS ADDR PHONE

FUNDING AGENCY and # US Department of Homeland Security, FIre Act Grant Application #: EMW -2006-FP-02258

As the principal investigator, my signature testifies that I pledge to conform to the following:

As one engaged in investigation utilizing human subjects, I acknowledge the rights and welfare of the human subject involved.

I acknowledge my responsibility as an investigator to secure the informed consent of the subject by explaining the procedures, in so far as possible, and by describing the risks as weighed against the potential benefits of the investigation.

I assure the Committee that all procedures performed under the project will be conducted in accordance with those Federal regulations and University policies which govern research involving human subjects. **Any deviation from the project (e.g., change in principal investigator, research methodology, subject recruitment procedures, etc.) will be submitted to the Committee in the form of an amendment for its approval prior to implementation.**

PRINCIPAL INVESTIGATOR:

Joel M. Stager (typed/printed name) — [signature] (signature) — Sept 21 2007 (date)

As the faculty sponsor, my signature testifies that I have reviewed this application and that I will oversee the research in its entirety, through the termination report.

FACULTY SPONSOR:

(typed/printed name) (signature) (date)

****

CAMPUS LEVEL REVIEW

This protocol for the use of human subjects has been reviewed and approved by the Indiana University/Bloomington Campus Committee for the Protection of Human Subjects.

_____ Exempt Review ¶#_____, _____ Exempt ¶# _____ with signed/documentation of consent,

✓ Expedited Review ¶# 3,4,6,7 Full Review, _____ Not Approved, _____ Withdrawn

[signature] Chairperson/Agent IUB Committee — 10/4/07 Date

logged in ts 9/21/06 approval logged ✓ copy to PI 10/4/07 rank code FT1 Col 3/13/07

test: PI 10/5/06 sponsor __________ co-PI __________

3/07

INDIANA UNIVERSITY
BLOOMINGTON
School of Health, Physical Education & Recreation
Department of Kinesiology