HEALTH AND SAFETY GUIDELINES FOR FIREFIGHTER TRAINING

UNIVERSITY OF MARYLAND

CENTER FOR FIREFIGHER SAFETY RESEARCH AND DEVELOPMENT

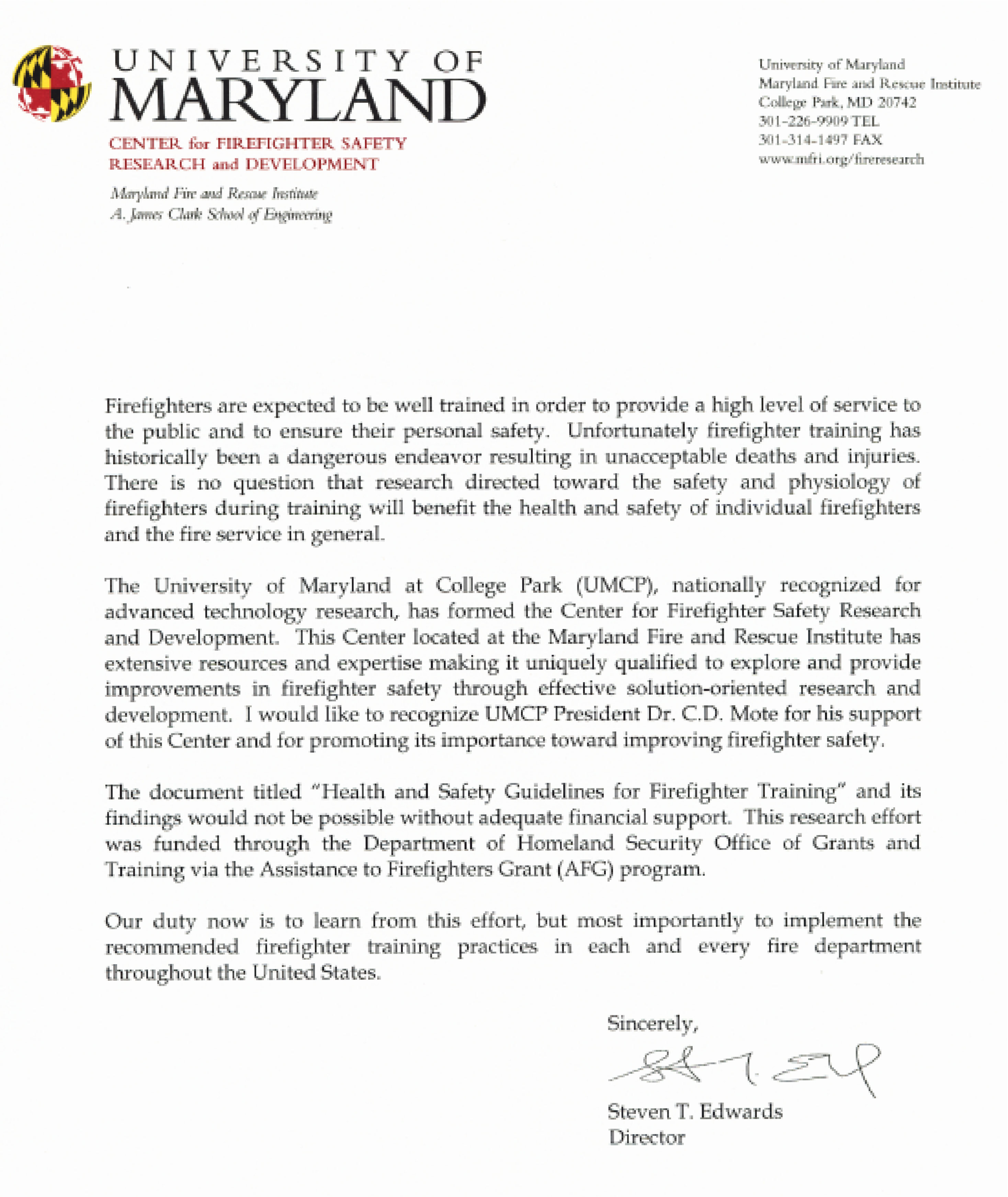
MARYLAND FIRE AND RESCUE INSTITUTE

COLLEGE PARK, MARYLAND

HEALTH AND SAFETY GUIDELINES FOR FIREFIGHTER TRAINING

Table of Contents


M.F.R.I.
M.F.R.I.



UNIVERSITY OF
MARYLAND
CENTER for FIREFIGHTER SAFETY
RESEARCH and DEVELOPMENT

Maryland Fire and Rescue Institute
A. James Clark School of Engineering

University of Maryland
Maryland Fire and Rescue Institute
College Park, MD 20742
301-226-9909 TEL
301-314-1497 FAX
www.mfri.org/fireresearch

Firefighters are expected to be well trained in order to provide a high level of service to the public and to ensure their personal safety. Unfortunately firefighter training has historically been a dangerous endeavor resulting in unacceptable deaths and injuries. There is no question that research directed toward the safety and physiology of firefighters during training will benefit the health and safety of individual firefighters and the fire service in general.

The University of Maryland at College Park (UMCP), nationally recognized for advanced technology research, has formed the Center for Firefighter Safety Research and Development. This Center located at the Maryland Fire and Rescue Institute has extensive resources and expertise making it uniquely qualified to explore and provide improvements in firefighter safety through effective solution-oriented research and development. I would like to recognize UMCP President Dr. C.D. Mote for his support of this Center and for promoting its importance toward improving firefighter safety.

The document titled "Health and Safety Guidelines for Firefighter Training" and its findings would not be possible without adequate financial support. This research effort was funded through the Department of Homeland Security Office of Grants and Training via the Assistance to Firefighters Grant (AFG) program.

Our duty now is to learn from this effort, but most importantly to implement the recommended firefighter training practices in each and every fire department throughout the United States.

Sincerely,

Steven T. Edwards
Director

photo courtesy of VivoMetrics, Inc.

ACKNOWLEDGEMENTS

Authors

Angela L. Bennett, MS, NREMTP is the Advanced Life Support Program Coordinator at the Maryland Fire and Rescue Institute and a doctoral student in exercise physiology at the University of Maryland at College Park.

James Brown, PhD is the director of the Human Performance Laboratory and a member of the department of Kinesiology faculty at the University of Indianapolis, Indianapolis, IN

Alex Derchak, PhD is the Principal Scientist and Vice President of Clinical Development for VivoMetrics Government Systems.

Marino di Marzo, PhD is the Chair of the Fire Protection Engineering Department located within the A. James Clark School of Engineering at the University of Maryland College Park.

Steven T. Edwards, M.G.A. is the Director of the Maryland Fire and Rescue Institute, retired chief of the Prince Georges County, Maryland Fire Department and a certified Fire Officer IV.

Reviewers

Richard Armstrong, BS
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Amr M. Baz, PhD
Mechanical Engineering, University of Maryland
College Park, MD

Paul O. Davis, PhD
First Responder Institute
Burtonsville, MD

James M. Hagberg, PhD
Department of Kinesiology, University of Maryland
College Park, MD

Martin J. LePore, MS, CFPS
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

The Center for Firefighter Safety Research and Development greatly appreciates the cooperation received from the following individuals and organizations throughout the study period and during the completion of this report.

Ashok K. Argawala, PhD
Institute for Advanced Computer Studies, University of Maryland
College Park, MD

Andrew Behar, President
VivoMetrics Government Systems
Ventura, CA

Ronald Hassan, MS, EFO
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Ramon E. Hodgson and the Logistical Support Section Staff
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Arthur T. Johnson, PhD
Biological Resources Engineering, University of Maryland
College Park, MD

Steve Kerber
National Institute for Safety and Technology
Beltsville, MD

Dan Madrzykowski, PE
National Institute for Safety and Technology
Beltsville, MD

Ana Melgarejo, Graphics Coordinator
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Lawrence Preston, MS
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Marc A. Rogers, PhD
Department of Kinesiology, University of Maryland
College Park, MD

Annette Ryburn, Institute Development
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

William H. Scott, PhD.
Biological Resources Engineering, ,University of Maryland
College Park, MD

Rebecca Spicer-Himes, M.G.A. and the Administrative Services Section Staff
Maryland Fire and Rescue Institute, University of Maryland
College Park, MD

Chief Fred Welsh and the College Park Volunteer Fire Department
College Park, MD

Maryland Fire and Rescue Institute instructors Steve Augustine, Jarod Blake, Donny Boyd, Paul Cusik, Tim Daly, Greg Dameron, Jeff Dickey, MarkFalkenhan, Rich Gilbert, Ann Guglik, Rick Harle, Tom Harman, Steve Heller, Robert Holmes, Richard Hopkins, Greg Johnston, Ernie Little, Jack Ludwig, J. Lynott, Dan McNeece, John McNeece, John Petrovick, Tom Ray, Bob Rose, John Rose, Mike Rutledge, Ed Sankbeil, Shawn Sebo, Dan Shaw, Dan Tuel, and Norman Wines.

The 208 study participants representing fire departments from Maryland, Virginia, the District of Columbia and the Department of Defense.

All photos contained in this report are from the MFRI Archive unless otherwise specified.

Duplication of this report in full or in part is not permitted. Additional copies may be obtained by contacting the Center for Firefighter Safety Research and Development at the Maryland Fire and Rescue Institute.

INTRODUCTION

Training lies at the very foundation of the fire service. The firefighting profession is fortunate in that its culture is one that encourages and strongly supports training and professional development throughout one's career. Firefighters are expected to be well trained in order to provide a high level of service to the public and to ensure their personal safety. This is critical in a profession that can be called upon to respond to any type of emergency at a moment's notice. Training is also very important in any occupation that has the potential for serious injury and death. Unfortunately, the history of the fire and rescue service is replete with the sacrifices made by firefighters in the line of duty. Proper training is one way to ensure safety and prevent these types of tragedies.

Few other public service professions spend as much of their on-duty time in training as the fire service. From the first day on the job, the firefighter recruit is constantly involved in training and developing the skills to meet the challenges that may present in the next response. There is no question that the specialization and technology available to today's firefighter or emergency medical technician require a higher level of knowledge and ability to operate than was required previously. Firefighters achieve certain milestones in training and as a result are certified to progressively higher levels, but the need for constant training and preparation never stops. There are many highly developed training academies, schools, and institutions devoted to the continuing education and professionalism of fire service personnel.

National, State and Local Fire Training Academies

There are numerous types and levels of training and educational programs available to firefighters throughout the United States. Each has a specific role in the training process at the local, state, or national level. Fire training programs can range from six hours to several hundred hours depending upon the course content. Fire departments that provide emergency medical services have additional training requirements which vary depending upon the level of service provided.

Local fire training academies operate at the city, county, or municipal level and generally provide training services to one fire department or to a specific geographical region. Most large city fire departments will have their own fire training academy that is designed to create situations that represent the emergencies that the firefighters of that jurisdiction will encounter. These training academies are staffed by experienced and professional fire service instructors who guide and manage the training programs to best serve their community.

Each state operates a state fire training program designed to provide training to a large number of firefighters in a larger geographical area. Many state fire training programs or state fire training academies are associated with universities or colleges. Others are a part of state government or are based under the auspices of a separate state-level board or commission. Each year the state fire training programs in the United States cumulatively train over 800,000 firefighters. To accommodate these large numbers of students, many state fire training academies have large training facilities and regional training systems.

In order to conduct realistic fire training programs, training centers and academies must have the appropriate training props and equipment. These specialized items allow for the simulation and replication of the actual emergencies to which the firefighter must respond. In essence, these training centers must construct a specially designed building that can be set on fire and burned several times each day. Structural burn buildings are constructed with materials that have been tested and proven to withstand the constant heating and rapid cooling that occurs during live-fire training evolutions. Special fire bricks, coatings, and high temperature tiles are used to protect the structural elements of the building and make these buildings very expensive to construct. Due to environmental concerns, these buildings can also be difficult to locate. To reduce some of the environmental concerns of burning petroleum-based fuels and Class A combustibles such as wood products many new fire training props use propane gas as the fuel.

Firefighter trainees need a place to learn how to lift and place ground ladders, use aerial ladder trucks that can reach up to 135 feet, rappel out of upper floors, practice high-angle rescues and advance hose lines. To accommodate these needs, fire training centers must have tall structures suitable for these exercises. These buildings are generally five to ten stories high and are designed to facilitate a large number of training scenarios. Buildings such as these are in constant use at any fire training academy.

Firefighters are often called upon to perform specialized rescues. To accommodate this need for training many fire training centers have elaborate props that can be used to simulate these situations.

The Maryland Fire and Rescue Institute Headquarters located on the campus of the University of Maryland, College Park

For example, many centers have confined space rescue props which are used to simulate rescues from below ground or tight spaces, props to simulate hazardous materials spills from tank trucks, and props that allow the simulation of building collapses. The grounds of the training academy can be used to simulate mass casualty incidents requiring a coordinated response and a host of other activities that are regularly created for training purposes. These innovative props and the ability to create a realistic training environment are critical to the success of the firefighter training program.

A structural firefighting building in use during a training evolution

In addition to all of the specialized structures and training props, fire training academies must have adequate classroom space to conduct didactic training sessions. While much of what firefighter trainees receive is hands-on training, significant classroom work is required as well. Firefighters, for example, must learn hydraulic theory to operate pumps and move water, the different phases of combustion, the proper method of assessing and managing an emergency medical patient and survival techniques. In general, before any training prop is used on the training ground the firefighters have already attended classroom sessions to learn the procedures and techniques required to handle such dangers in a safe manner.

Students receive classroom instruction prior to practical training evolutions

Fire service training is becoming more and more technologically advanced. Much of the coursework previously taught at the fire training academy is now available on-line in computer assisted or distance learning programs. Fire simulators that use computer graphics and programs to train command-level fire officers are used by many departments. Human patient simulators driven by computers and pneumatic systems are used in emergency medical training for firefighters and paramedics. Systems are being developed that will use virtual reality techniques to simulate fires so realistically that an actual fire will not even be necessary. As technology advances, so will the world of fire service training.

University of Maryland Center for Firefighter Safety Research and Development

The University of Maryland at College Park, nationally recognized for advanced technology research, has formed the Center for Firefighter Safety Research and Development. This Center is uniquely qualified to carry out the mission of improving firefighter safety through the research and development of improved communications systems, on-scene accountability, and firefighting equipment. There are extensive resources and expertise found within the Center for Firefighter Safety Research and Development. The close working relationships between key entities within the Center bring the potential for effective solutions in response to the need for vast improvement on this issue.

It is the mission of the Center for Firefighter Safety Research and Development to develop and support research that will improve firefighter safety by focusing the resources and specialized talents available at the University of Maryland toward advanced uses of technology in an effort to reduce firefighter deaths and injuries. It is the further mission of the Center to provide crossover technology and advancements to the nation’s Department of Homeland Security and other public safety agencies so that improved safety measures can benefit all first responders.

The Center for Firefighter Safety Research and Development consists of three principal departments within the University of Maryland.

Maryland Fire and Rescue Institute (MFRI)

> *The Maryland Fire and Rescue Institute is an internationally recognized emergency services training institute that is frequently involved in research and development projects. MFRI identifies specific firefighter safety requirements, determines project feasibilities, and directs project design parameters. Evaluations are conducted independ-*

ently through implementation in firefighter training programs. MFRI provides detailed feedback from end users to the research team. On an annual basis, MFRI conducts over 1,800 programs, training over 34,000 students.

Fire Protection Engineering Department (FPED)

The Fire Protection Engineering Department located within the A. James Clark School of Engineering is the national resource in undergraduate fire protection engineering education and the leading institution in graduate research and education. FPED regularly conducts research in areas such as fire dynamics, fire modeling, burn injuries, smoke movement and toxicity. The Center's expertise and resources are coordinated on a technical engineering level by FPED.

Small Smart System Center (SSSC)

The Small Smart System Center within the A. James Clark School of Engineering is dedicated to stimulating the growth of high quality research and education in the areas of design, fabrication, and physics of smart systems and devices integrated on a sub-millimeter scale. SSSC is versed in virtual reality modeling, instrumentation, and miniaturization. SSSC provides the Center's expertise in the areas of sensor development, data analysis, and virtual firefighting.

For the purposes of this research study, the University of Maryland Center for Firefighter Safety Research and Development is partnered with VivoMetrics Government Services (VGS) who established and oversaw the testing processes, data and biostatistical analysis and who provided scientific oversight. VGS also provided the high-resolution physiological monitoring devices, database record storage, and data analysis staff and facilities required for the tests conducted under this project.

VGS is a privately held company founded in 1999 that provides continuous ambulatory monitoring products and services for the collection, analysis, and reporting of subject-specific physiologic data. The LifeShirt (LS) System utilized in this study is an FDA-cleared, non-invasive, ambulatory monitoring system that continuously collects, records, and analyzes a broad range of cardiopulmonary parameters. The LS System has been used in over 12 clinical drug trials and pilot studies by large pharmaceutical companies such as GlaxoSmithKline, Pfizer, and Élan and is currently installed in 17 of the top 25 medical schools in the United States including Johns Hopkins, Yale, Stanford, Rush, and UCLA. The LS System is being used in many hospitals and clinics including the Mayo Clinic, Walter Reed Army Hospital, Henry Ford Institute, and the National Institutes of Health. As of August 2004, the LS System has been used in studies on 2,461 subjects for 7,513 data collection sessions, amounting to a total of 89,581 hours of data collection. The LS System has been reviewed and approved by over 85 human subject protection committees (IRBs) responsible for academic, industry, and pharmaceutical clinical research, and is a proven effective ambulatory monitoring device.

Status of Firefighter Training

This research project targets firefighters in training, a high-risk group based on historical evidence of death and injury rates. Firefighter recruits, firefighters participating in on-going training, and firefighters conducting training are identified by the United States Fire Administration (USFA) as especially vulnerable to death and injury. Reported training-related injuries totaled over 7,100 in 2003; however, the number of unreported injuries could be significant. More disturbing, between 1997 and 2003, an average of ten firefighters a year died in training-related incidents (Figure 1). These statistics are documented in USFA Special Report – May 2003, entitled *Trends and Hazards in Firefighter Training* (Thiel, et al. 2003).

Figure 1: Firefighter Fatalities 1997-2004 (USFA 2005)

	Fatalities During Training	Total Firefighter Fatalities
2004	13	107
2003	12	111
2002	11	100
2001	14	106 *(Plus 343 on 9/11)*
2000	13	103
1999	3	112
1998	12	91
1997	5	94

Rising injury rates for firefighter trainees and trainers occurred despite years of increasing emphasis on safety, more rigorous safety standards, and major investments in personal protective equipment (PPE), fire simulators, burn buildings and other training technology. Several relevant National Fire Protection Association (NFPA) standards directly apply to creating a safer environment for firefighter training. NFPA 1403 *Standard on Live Fire Training Evolutions in Structures* and NFPA 1500 *Standard on Fire Department Occupational Safety and Health Programs* are two of the most important. The purpose of the NFPA 1500 standard is to specify the minimum requirements for an occupational safety and health program for a fire department and to specify safety guidelines for those members involved in rescue, fire suppression, emergency medical services, hazardous materials operations, special operations, training, and related activities. NFPA 1403 details procedures to conduct safe fire training evolutions.

The USFA report also attributes many of the deaths and injuries during training to poor physical fitness and notes that heart attacks are the leading cause of death in training-related incidents. Firefighters who suffer a heart attack or stroke during training are more likely to die than survive, and those who survive tend to have long-term health problems. Ironically, the report also finds that a greater emphasis on physical training and exercise may be contributing to this trend as firefighters adjust to the stress of more rigorous fitness-training programs. Firefighter training faces a dilemma: more physically rigorous and realistic training is required to fully prepare firefighters for the dangers they face on the job, but those very requirements place trainees at significantly higher risk, especially when they are inexperienced and not yet at peak physical readiness.

In June of 2005, the National Fire Protection Association released its report titled *U.S. Firefighter Fatalities Due to Sudden Cardiac Death, 1995-2004.* This report included data collected during a ten-year period of on-duty firefighter deaths related to "sudden cardiac death," an umbrella term that included fatal heart attacks as well as other heart-related deaths. The analysis did not include strokes or aneurysms, though they also involve the cardiovascular system. This study produced the following conclusions:

- *During the study there were 1,006 on-duty firefighter fatalities of which 440 (43.7%) fell into the category of "sudden cardiac death."*

- *Autopsies or post mortem information was reported for 308 of the 440 victims of sudden cardiac death.*

- *Of the 308 firefighters, 134 (43.5%) had prior known heart-related conditions. These included previous heart attacks, bypass surgery or angioplasty/stent placement.*

- *An additional 97 firefighters had atherosclerotic heart disease defined as arterial occlusion of at least 50 percent.*

Firefighting activities and firefighter training are strenuous activities and often require that firefighters work at or near maximal heart rates, in many cases for extended periods. During the period of the NFPA study, 50 deaths occurred during firefighter training activities. This represented 11.4% of the total sudden cardiac deaths of firefighters during the study. Of the 50 deaths, 21 were engaged in physical fitness activities, 21 were involved in firefighting training evolutions, six occurred during classroom activities and two were not classified.

It is clear that insufficient data has been gathered on the physiological impact of real-time training scenarios on firefighters. Trainers and trainees in many cases do not even have baseline information about health and fitness that would help reduce many preventable injuries and death. Nor has it been possible to determine when continuous monitoring is an absolute requirement for safety during either training or emergency response.

In 2001, the NFPA conducted a study of the United States Fire Service. This study concluded that:

- *Seventy-three percent of firefighters worked in fire departments that did not have a program to maintain basic firefighter fitness and health as required in NFPA 1500.*

- *In rural communities (population under 2,500) 88 percent of firefighters did not have a firefighter fitness and health program.*

The key to resolving this dilemma is found in one of the "lessons learned" highlighted in the USFA report *Trends and Hazards in Firefighter Training*, (Thiel, et al., 2003), namely that "during training, a firefighter's physical stress level should be monitored continuously and departments should consider stronger physical screening programs…to reduce training-related heart attacks and strokes." Improved information is needed to develop more efficient safety procedures and practices, as well as to determine conditions during which ongoing physiological monitoring of firefighters should be required.

Physical Demands of Firefighting

Firefighters are sometimes called upon to push themselves to the limit. Efforts during emergencies by firefighters, rescue personnel, military personnel, and others sometimes require extreme physical exertions that test the line between life and death. Some attempts have been made to monitor the physical conditions of those exerting themselves severely (Lim and Yee, 2002), but these have often:

- *included only those variables most easily measured*

- *been limited to noninvasive measurements*

- *not included any interpretive algorithms for assessing the degree of danger for survival*

Life-threatening states include sudden cardiac failure, overheating, poisonous particulate and gas inhalation, electrolyte imbalance, sepsis (infection), and failure to maintain homeostasis. Lives can also be lost in dangerous situations when there is an inability to continue with the task at hand. Examples of causes include extreme fatigue, psychological imbalance, panic, uncoordinated movements, and inability to see, hear, or breathe.

Cardiac Failure

The most likely cause of firefighter fatalities is cardiac arrest (USFA, 2002). Severe exertion stresses the heart and requires it to deliver more blood to working skeletal muscles.

In order to produce physical work, the body requires oxygen to metabolize nutrient substrates (carbohydrates, fats, or proteins). Distributing oxygen from the atmosphere in the lungs throughout the body is the function of the cardiovascular system. The heart is the means to propel the blood.

There is a nearly linear relationship between heart rate and work rate. Heart rate increases from about 70 beats per minute (bpm) at rest to a maximum value during exertion.

Maximum heart rate is age dependent, roughly equal to:

$$\text{Predicted } HR_{max} = 220\text{-age in years}$$

Older individuals thus achieve lower maximal heart rates. As a result, older individuals cannot deliver as much oxygen to their working muscles as can younger people, so they do not have as great a work capacity. Physically active individuals at all ages generally have lower resting heart rates and greater physical work capacities than sedentary individuals.

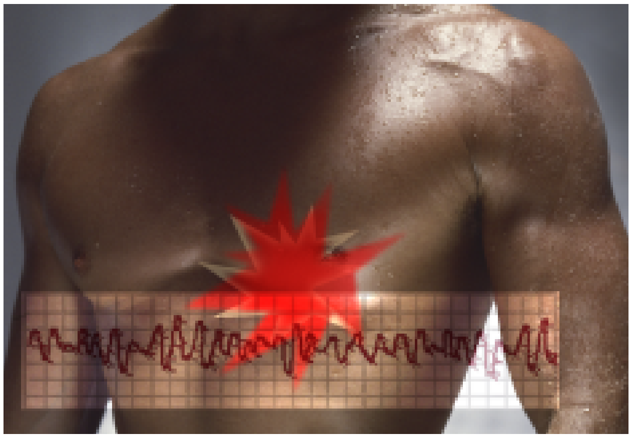
Stroke volume is the volume of blood delivered during each contraction of the heart. Stroke volume is about 70 mL at rest, and increases modestly to about 120 mL during moderate exercise. At more intense exercise rates, stroke volume does not increase further. During extremely intense exercise, stroke volume may actually decrease somewhat because the time to fill the heart becomes too short.

The volume of blood pumped throughout the system during one minute is called the cardiac output. Cardiac output is a function of heart rate and stroke volume. Cardiac output increases from about 5 L per minute at rest to 25 L per minute during heavy exercise. During extremely intense exercise, when stroke volume decreases, the cardiac output can decline and oxygen supply to the working muscles can become insufficient.

The heart muscle, or myocardium, requires oxygen to function properly. As oxygen demands of the body increase and greater cardiac outputs are required, the work of the heart also increases proportionally. If, for some reason, enough oxygen cannot be delivered to the myocardium, an oxygen lack (ischemia) develops. The result is sometimes pain emanating from the heart (angina). If the condition persists, heart muscle dies (necrosis), and the ability of the heart to supply sufficient cardiac output declines (infarction). A heart attack has occurred.

There are several contributing factors to heart attacks. The most important factor is the inability to deliver oxygen to the myocardium. Atherosclerosis, or a build-up of plaque along the walls of the blood vessels of the heart, impedes the flow of blood and slows the rate of oxygen delivery. If a piece of this plaque breaks off, or if a blood clot formed somewhere in the cardiovascular system flows to a coronary artery, blood can be completely choked off, and massive myocardial necrosis can occur. The same process, if it occurs in the brain, is called a stroke, and a clot in the pulmonary artery, called a pulmonary embolus, can be immediately fatal.

It is more likely that a heart attack will occur during episodes of high oxygen demand during strenuous exercise. It is also more likely in people who are not conditioned to physical exercise or who have other predisposing factors. Among these are high levels of blood cholesterol (lipids that form arterial plaque) and smoking (constricts arteries, causing lower possible flow rates). Stress and anxiety cause the release of various hormones into the blood stream, and these are normally meant to prepare the body for physical trauma, including the ability to staunch blood flow from injured tissue. They can, in addition, constrict arteries and promote blood clotting.



Blood can only perfuse cardiac vessels during the resting phase (diastole) of a heartbeat. During the contraction phase (systole), the contracting muscle squeezes myocardial vessels and blocks blood flow. As the heart beats faster and with more force, the time for blood flow and oxygen delivery to the myocardium becomes smaller and smaller.

Thermal stress can also add to cardiac demand. The working muscles are only about 20% efficient. About 80% of the chemical energy they use forms heat, and this heat must be released to the environment. Consequently, blood vessels in the skin dilate (cutaneous vasodilation), which raises the temperature of the skin. With higher skin temperatures, more heat can be dissipated to the atmosphere. In addition, venous blood, which during cold weather is routed through vessels deep within insulating tissues, returns to the heart through veins closer to the surface. Again, this promotes heat loss.

Blood flow necessary to remove heat does nothing to satisfy the oxygen demands of the working muscles. Thus, propelling this blood becomes an additional burden for the heart, adding to its workload, its own oxygen requirement, and the likelihood of a heart attack. There is often an initial rise of heart rate when exertion begins. Several minutes later there can be a secondary rise when body heat stores climb to levels that require heat removal. Cutaneous vasodilation then results in a secondary rise in heart rate.

Exposure to heat also results in sweating, and the liquid that forms sweat comes ultimately from blood plasma. Extreme sweating without fluid replacement thickens the blood (plasma shift) and makes the heart work harder, thus increasing its oxygen requirement. Diabetes can also starve the myocardium for energy and make it work harder to pump the same amount of blood.

Atherosclerosis can also cause high blood pressure (hypertension). There are other neural causes also. Each of these raises vascular resistance and elevated blood pressure is necessary to push blood through the vasculature. This, in turn, raises cardiac work rate. Over time, the heart muscle responds by thickening in order to produce greater contractile force (hypertrophy). However, contracting this larger muscle mass is less efficient than contracting a smaller muscle mass, so there is a double penalty paid: greater work to overcome hypertension and lower efficiency of contraction.

Congestive heart failure occurs when the heart is no longer able to contract with sufficient force. Venous return of the blood to the heart decreases, and higher venous blood pressure results. Interstitial fluid (fluid between body cells) is normally drawn into the blood and back into the heart by low venous return pressure (suction). When venous blood pressure increases, fluid is forced out through the walls of the veins rather than into the veins. The result is that the heart becomes surrounded by fluid, and this fluid acts to compress the heart. The extra work can cause the heart to fail.

Thermal Stress

Heat stroke is the most serious health problem associated with working in hot environments. Its onset takes place when the thermoregulatory system fails, sweating becomes inadequate, and the body's only effective means of removing excess heat is compromised with little warning to the victim.

Physical manifestation of heat stroke is typically discernible, as the victim's skin is hot, usually dry, red or spotted. Body temperature (core temperature as measured rectally) is usually 105°F or higher, and the victim is mentally confused, delirious, perhaps in convulsions, or unconscious. At this point, unless the victim receives quick and appropriate treatment, death can occur.

Heat stroke develops progressively and subjects may experience some of the intermediate conditions prior to the onset of heat stroke. Heat exhaustion includes several clinical disorders, and is typically considered as the direct precursor to heat stroke. It can have symptoms that may resemble the early symptoms of heat stroke. Heat exhaustion is brought about by the loss of large amounts of fluid by sweating, sometimes with excessive loss of salt (and other electrolytes). Someone affected by heat exhaustion still sweats, but also experiences extreme weakness or fatigue, nausea, or headache. Physical manifestations of heat exhaustion are somewhat different from heat stroke, as the skin is clammy and moist rather than hot and dry. The complexion is pale or flushed, and the body temperature is normal or only slightly elevated.

Heat cramps are painful spasms of the muscles that occur among those who sweat profusely in the heat and drink large quantities of water, but do not adequately replace the body's salt loss. As with heat exhaustion, salts and other electrolytes need replenishing, and drinking large quantities of water tends to dilute the body's fluids, while the body continues to lose salt. The low salt concentration in the muscles causes painful heat cramps. The cramps can affect any of the muscles, but fatigued muscles (those used in performing the work) are usually the ones most susceptible.

Heat edema occurs when cutaneous vasodilation and pooling of increased interstitial fluid in dependent extremities lead to swelling of the hands and feet. It is self-limited and rarely lasts more than a few weeks.

Heat syncope occurs as a result of volume depletion, peripheral vasodilation, and decreased vasomotor tone and occurs most commonly in elderly and poorly acclimatized individuals. Postural vital signs might or might not be demonstrable.

Someone who is not accustomed to hot environments and who stands erect and immobile in the heat may faint. The body attempts to lose excess heat by directing blood flow to the skin for direct heat loss, causing enlarged blood vessels in the skin and in the lower part of the body. However, blood may pool there rather than return to the heart to be pumped to the brain, causing fainting.

Heat rash, also known as prickly heat, is likely to occur in hot, humid environments where sweat is not easily removed from the surface of the skin by evaporation and the skin remains wet most of the time. Therefore, the sweat ducts become plugged and a skin rash soon appears. When the rash is extensive or when it is complicated by infection, prickly heat can be very uncomfortable and may reduce physical performance.

Transient heat fatigue refers to the temporary state of discomfort and mental or psychological strain arising from prolonged heat exposure. People not acclimated or accustomed to the heat are particularly susceptible and can suffer, to varying degrees, a decline in task performance, coordination, alertness, and vigilance.

Hyperthermia occurs when the hypothalamic temperature set point is normal but physiologic conditions are such that heat is being produced abnormally or cannot be dissipated. This is very similar to fever with the distinct difference that, during a fever, the hypothalamic set point is increased due to circulating signal chemicals. In effect, raising the body temperature is an immune response.

Endothermic organisms, such as mammals and birds, have a constant internal body temperature largely independent of environmental surroundings. Any type of increase or decrease in body temperature can have severe repercussions. The body's regulatory processes, organ systems, and signaling systems all function within a defined temperature range. Any deviation outside of this range can result in death.

Heat stroke has been a significant problem throughout the population, affecting the young, the middle aged, and the elderly. According to the Centers for Disease Control and Prevention (CDC), between the years 1979 and 1999 there were over 8000 deaths in the United States from excessive heat; 48% were due to weather conditions, 5% were due to man-made conditions (e.g., boiler room, furnace, or factory-generated extreme heat conditions), and the remaining 48% were of unspecified origin.

Firefighters exit the structural burn building during a training evolution

Although every age group is susceptible to heat stroke and heat-related illnesses, the elderly population is the most at-risk age group. In fact, it has been shown that heat-related deaths increase with age. Outside of these studies, however, it is very difficult to gather information on heat-related deaths, making the precise incidence of heat stroke unknown. The reported incidence of heat stroke varies in the United States because of three main reasons: First, in the United States, heat-related death is not a reportable condition in any state. Second, the definition of heat stroke varies, resulting in the under-reporting of heat stroke cases. Third, many heart-related illnesses and deaths are not recognized as heat-related at the time, and therefore are not reported. The actual reporting incidence ranges from 17.6 - 26.5 per 100,000 persons (Yeo, 2004). In places such as Saudi Arabia, where heat stroke is relatively common, the reporting rate is roughly 250 per 100,000 persons (Yeo, 2004).

Heat stroke is the cause of many life-threatening incidents. Mortality from heat stroke has approached 80% (Gathiram, et. al., 1987), although timely and aggressive therapy can reduce this significantly (Yaqub and Deeb, 1998, Costrini et al., 1979). Heat stroke is characterized by a nearly total loss of control of body chemical and thermal equilibrium. It is common for sweating to be interrupted; core body temperature rises to 106 - 110ºF (Costrini et al., 1979; Barrow and Clark, 1998) and wide swings in body temperature are common. Serum sodium and potassium levels fall; over time sodium returns to normal but potassium remains low. Over time, renal and hepatic failure is possible. Myocardial infarction damages the ability of the heart to function, and internal hemorrhage can lead to death (Knochel et al., 1961). One possible mechanism for all this to happen is that shifting of circulating blood from the splanchnic region to the skin to remove excess heat can make the intestine wall much more permeable to gram-negative bacteria living in the gut (Gathiram et al., 1987). If these bacteria invade the body, endotoxins they produce can produce septic shock with many of the symptoms of heat stroke.

Exertion-induced hyperthermia and exhaustion produce significantly higher incidence of cellular injury and death at lower core temperatures than hyperthermia alone (Hubbard et al., 1979). Depletion of muscle glycogen and hypoglycemia may be factors in the pathophysiology of heat stroke (Costrini et al., 1979). Dehydration may be an important factor in some cases.

This link between thermal conditions and exertion, and additional inability to compensate for heat stress with age, means that prediction of life-threatening conditions is relatively complex. Athletes may exhibit extremely elevated core temperature without developing heat stroke (Gathiram et al., 1987). Physical measurements alone may not be able to make required distinctions. Dangerous heat stroke is accompanied by disorientation or coma (Costrini, et al., 1979). Electrocardiographic abnormalities in the T wave and S-T interval (parts of the electrocardiogram) in heat stroke would indicate myocardial ischemia.

As a normal response to exertion, the body's core temperature rises. The thermoregulatory center is situated in the preoptic nucleus of the anterior hypothalamus in the brain, and stimulation of this nucleus following a rise in core temperature, due to a high environmental temperature or heat produced during exercise, results in autonomic nervous system-mediated vasodilation and sweating. Heat is then lost from the body through convection, radiation, and evaporation of sweat from the skin. However, heat loss is not always possible in certain environmental conditions.

Thermoregulation is vital to the body and its functions. Body heat is generated by normal metabolism and muscular action and is also absorbed from the environment. In order to maintain a stable body temperature, excess heat must have a means of dissipation in situations of heat generation. The three main routes of heat loss are via direct heat exchange with peripheral blood vessels, sweating, and through respiration. If any of these heat loss mechanisms are disrupted, then the body will not efficiently lose heat and can begin to show signs of heat stress.

Sweating is used by the body as a method of dissipating heat energy. Sweat ducts in the skin allow droplets of sweat to come through to the surface and evaporate. For each 1.7 mL of sweat, 1 kcal of heat is dissipated. On average, sweat production can remove up to 600 kcal of heat energy per hour (Yeo, 2004). Salt loss is a concomitant effect. Thus, it is imperative to replenish salts, as salt loss adversely affects thermoregulation. The next phase after generic thermoregulatory responses is the acute-phase response. This inflammatory response produces increased vascular permeability, leakage of intravascular fluid and activation of the coagulation pathway, resulting in multi-organ failure and disseminated intravascular coagulation typical of severe heat stroke. When thermoregulatory mechanisms become overwhelmed, cardiac output drops. Splanchnic (intestinal) and renal (kidney) vessels dilate, causing the core temperature to rise even further (Warfolk, 2000). The resulting high temperature leads to cerebrovascular congestion, cerebral edema, and increased intracranial pressure. This, in concert with decreased arterial pressure, reduces cerebral blood flow and causes central nervous system dysfunction (Kunihiro and Foster, 1998).

Exposure to high temperatures in combination with an elevation of body temperature prompts a number of changes in the cutaneous (skin) circulation. Specifically, blood flow increases from a baseline of approximately 250 mL per minute to about 6 to 8 L per minute (Lugo-Amador et al., 2004) through increased cardiac output and concomitant vasoconstriction of the renal and splanchnic circulation.

Although exposure to high temperatures can have fatal outcomes, some athletes and conditioned workers might reach and maintain body temperatures of 104°F (40°C) without substantial morbidity (ACSM, 1987). The process of acclimatization involves a number of physiologic and biochemical modifications that allow someone to undergo a level of heat stress that would possibly cause death in those not acclimated.

Physical conditioning improves cardiac performance, making substantial increases in skin blood flow readily possible without compromising oxygen delivery to critical tissues. Acclimation results in expansion of plasma volume, increased renal blood flow, and improvement of the body's ability to shunt blood away from noncritical circulatory beds. There is an improvement in the kidney's ability to withstand mild to moderate degrees of exertional destruction or degeneration of skeletal muscle tissue that is accompanied by the release of muscle cell contents into the bloodstream. This can result in hypovolemia (deficiency of the amount of blood in the body), hyperkalemia (high potassium concentration), and sometimes acute renal failure (Lugo-Amador et al., 2004). Acclimation also results in enhanced ability of the kidneys and sweat glands to retain sodium and prevent volume depletion. Sweat glands can also acclimate, secreting a greater volume of sweat with decreased tonicity. Hence, acclimatization is attained by constant or routine activity in heat, and is more easily achieved by people in good physical condition. It brings with it an increase in blood volume of up to 25%, an increased tendency toward earlier vasodilation during exercise, salt conservation, and an increase in sweat production (Johnson, 1991).

There are a number of factors that can put someone at an increased risk of heat stroke. Typically, people at the extremes of age are at a greater risk of heat stroke. Small children (younger than 12 years) lack sufficient body surface area to dissipate heat; they have a slower rate of sweating, and a slower rate of acclimation (Kunihiro and Foster, 2002). The older population (older than 65 years) is more likely to show failure of the heat-regulating system of the brain, thus improperly reacting to heat stress. Drug-associated heat stroke is a cause of some cases. A study done during a heat wave in New Orleans in 1998 revealed that the majority of the patients screened for drugs during heat stroke treatments were found to have residual levels of cocaine. Another, more common, recreational drug that was often found was ecstasy (Dancesafe, 2005). These were not purely overdose cases; the stimulant effect of a normal dose of the drug caused the body's basal temperature to rise.

Recreational drugs were not the only substances that increased susceptibility. Other drugs, such as diet pills, cause dehydration via diuresis. Ephedra-containing dietary supplements have been cited as the root cause of hyperthermia. However, the exact action of the drug is not known. It was postulated that the drug may produce a thermogenic effect by activation of dopamine receptors and by impairing heat dissipation through peripheral vasoconstriction (Oh and Henning, 2003).

Athletes may be at risk for heat stroke due to many different reasons. First, there are many African-American athletes with Sickle Cell Trait (SCT) involved in sports today. Roughly 8% of the African-American population suffers from SCT, and those athletes are at greater risk for developing heat stroke or exertional heat stroke (Yeo, 2004).

Another risk associated with athletes is hyponatremia (low blood sodium level), a condition resulting from excess water intake. In this case, the athlete, probably in an effort to avoid dehydration and cascading into heat stroke, consumes too much water and markedly dilutes the sodium concentration in the blood. This becomes physiologically significant when it results in a state of extracellular hypo-osmolarity, creating a tendency for free water to shift from the vascular space to the intracellular space. Although cellular edema is well tolerated by most tissues, it is not well tolerated within the rigid confines of the bony calvarium (skull). Therefore, clinical manifestations of hyponatremia are related primarily to cerebral edema (Kreider et al., 2003).

Athletes who play football are at a special risk because of the clothing involved and the time of year that practices begin. Evidence indicates that most of the heat-stroke occurrences were within the first two days of commencing practice. In other words, the athletes were out in the hot weather of August (possibly the hottest month of the year) layered with clothing and protective pads, and they had not been outside under these conditions prior to starting practice. These athletes were not acclimated to the weather and exposed to strenuous conditions, which caused fatalities attributed to heat stroke (Roberts, 2004).

The following is a list of risk factors for heat stroke:

- *Alcoholism*
- *Cardiovascular disease*
- *Dehydration*
- *Extremes of Age (<12 years, >65 years)*
- *Skin-altering conditions (psoriasis, eczema, burns)*
- *Lack of air conditioning in home during extreme temperatures*
- *Living in a multistory building in hot weather*
- *Low socioeconomic status*
- *Obesity*
- *Medications/drugs*
  - *Impair thermoregulation (diuretics, beta-blockers, anticholinergics, phenothiazines, alcohol, butyrophenones)*
  - *Increase metabolic heat production (benzotropine, trifluoperazine, ephedra-containing dietary supplements, diet pills, amphetamines, cocaine, ecstasy)*
- *Previous history of heat related illness can translate into a higher susceptibility to subsequent episodes of heat stroke or other various levels of heat illness. In some cases there could be a genetic predisposition that was the cause of the first episode, leading to an increased risk of future heat illness.*
- *Prolonged sun exposure: This is chiefly a problem because the body does not have a chance to cool down when temperatures are rising or have been steadily at or above 40ºC.*
- *Wearing heavy or excessive clothing affects the ability to exchange heat with the surroundings as well as trapping more sun energy in darker clothing, causing more heat to be transferred into the body.*

There are certain genes that regulate heat or that are involved in regulating heat adaptation. Thus, some people are more susceptible to heat than others are. The actual progression of heat stress (heat exhaustion) into heat stroke is due to a combination of events including thermoregulatory failure, exaggerated acute-phase response to heat, and alteration in the production of heat-shock proteins (Yeo, 2004).

Inhalation of Contaminants

Although firefighters are usually protected against inhalation of airborne contaminants by their Self-Contained Breathing Apparatus (SCBA), there are occasions where breathing of toxic substances does occur. During intervals when the SCBA is not used for one reason or another, gas, vapor, or smoke particulates present in many fires can cause injury or death.

Most toxic substances act to interfere with bodily metabolic processes, and, for that reason, have immediate and profound effects. It is universally true that compounds with smaller molecular weights are more toxic than those with higher molecular weights. Low molecular weight liquids are also more volatile than higher molecular weight liquids, so the vapors present are likely to be the most toxic also.

Particulates in the range of 5-10 microns or less are of particular concern because once inhaled they are not removed from the nether regions of the lung (the alveoli). This is called the respirable fraction of particulates. Smoke particulates are of special concern because soot, composed of small carbon particles, can act as a substrate for the adsorption of vapor molecules. Vapors might normally be expelled from the lungs during exhalation, but the tiny carbon particles trap them in the lung where they can continue to produce harm.

Carbon monoxide gas is especially dangerous because it binds very strongly to hemoglobin molecules in the blood. The affinity of hemoglobin for carbon monoxide is 200 times as strong as its affinity for oxygen. That means that any carbon monoxide inhaled will bind to hemoglobin in the red blood cells and will not be released under normal circumstances. Hemoglobin is the normal carrier for oxygen in the blood; hemoglobin transports about 100 times as much oxygen as is dissolved in the blood plasma. Thus, working muscles are very dependent on oxyhemoglobin to supply their oxygen needs. Hemoglobin also assists in the removal of carbon dioxide from the working muscles, and this function is also disrupted by carbon monoxide bound to hemoglobin.

When carbon monoxide occupies all sites on hemoglobin normally occupied by oxygen, the muscles are deprived of their normal oxygen supply. Muscle metabolism can continue anaerobically for up to 1-2 minutes, and then the muscles begin to die. This includes heart and lung muscles, causing death of the individual.

Modern treatment for carbon monoxide poisoning is hyperbaric exposure to 100% oxygen, driving carbon monoxide from its hemoglobin complex. This treatment, however, takes several days to complete, and must be started before carbon monoxide exposure is irreversible.

Effects of airborne contaminants are dose dependent, and dosage depends on many factors: alveolar ventilation rate, ambient concentration of contaminant, the respirable fraction of contaminant, protection factor of respiratory protection, if any, retention fraction of inhaled contaminant, and exposure time. Contaminant characteristics are well beyond the control of the firefighter, who has no indication of particle size or retention fraction. Therefore, exposure time must be minimized and respirator protection factor must be maximized.

The alveolar ventilation rate is the air flow rate reaching the effective gas-exchange portion of the lung, typically comprising 100 m^2 surface area. Alveolar ventilation rate increases to meet the demands of exertion, and is thus usually very high during the most intense portions of firefighting. Average alveolar ventilation rates may reach 100-150 L per minute, with peak flow rates up to 450 L per minute (Johnson et al., 2005). Ventilation for work above the anaerobic threshold is nonlinearly related to oxygen demand, so ventilation rates can climb very rapidly for heavy exertion. In addition, inhaled carbon dioxide acts as a respiratory stimulus, and thus can increase ventilation even further. Hence, exposure to toxic substances can be extreme under conditions encountered during firefighting.

Disorientation and Panic

Psychological factors can be important determinants of appropriate responses during severe exertion during firefighting. Morgan and Raven (1985) found that subjects who exhibited high anxiety were predisposed to respiratory distress while wearing a respirator. Low anxiety subjects had no such inclination. Johnson et al., (1995) demonstrated that anxious people performed work at a lower rate and for a shorter time than did non-anxious people, and the reduction in performance time was related to the degree of anxiety.

Firefighters can find themselves in unsafe situations if they make incorrect or unsound decisions. Several incident case histories appearing on www.firefighternearmiss.com involve confusion, incoherence, and poor judgment during training or live fires. Heat can cause degradations in cognitive ability, dexterity, and motor skills (Johnson et al., 1992). If ability at normal body temperature of 37°C is taken as the baseline, then nearly complete loss of each of these occurs when body temperature reaches 40°C. At this point, it would be expected that the firefighter could not act on a decision even if capable of making it. In fact, loss of mental coherence appears to be a strong indicator distinguishing between those who suffer heat stroke and survive and those who suffer heat stroke and do not (Johnson, etal., 1992).

Carbon dioxide can be abundantly produced in a fire. Carbon dioxide is a psychoactive gas that can cause perceptive changes at 3% if inhaled for 30 minutes or dizziness, stupor, and unconsciousness if inhaled at 10% for less than one minute (Johnson, 1991). Panic can ensue following carbon dioxide inhalation.

Communications can be affected by the state of mind. Impaired hearing or slurred speech results in misunderstanding leading to incorrect, and possibly fatal, responses. Sensory overload, wherein a person is presented with too much sensory information at once, can make matters much worse.

Related Studies

A number of life-threatening incidents have been reported on the web at www.firefighternearmiss.com. Each is instructive in its own way, but several point to the confusion that accompanies the threat to life and the way that lack of clear thinking can compound the seriousness of the situation. For example, one (Report Number 05-0000186) involved a fire training instructor whose air ran out as the fire was being ignited. Disorientation and indecisiveness almost cost this man his life. Another (Report Number 05-0000067) involved a firefighting crew ordered out of a building. One member of the crew became separated from the others, lost contact with the hose line, and headed in the wrong direction. A similar incident (Report Number 05-0000220) described a firefighter separated from his partner in a burning office building. He lost contact with his hand line, and was near panic when he found his way out just as he ran out of air.

Several emergency room physicians were interviewed (Albert, 2006) regarding heat stroke and heat illness. Vital signs, especially core temperature, were especially important. The higher the core temperature and the longer it was elevated, the worse the prognosis. Low blood pressure was a significant complication. An important predictor of heat illness severity was the patient's mental status. Confused, lethargic, unconscious, or comatose patients are in the most danger of dying. Patient self-reported symptoms as they began to suffer from significant heat illness included muscle cramps, headache, dizziness, nausea, and vomiting.

Thirteen male instructors were observed for changes in heart rate, temperature, and fluid loss during fire training sessions for which they were required to monitor and assist trainees during exposure to live fire situations (Elgin et al., 2004). Instructors performed minimal work during this exposure but were required to spend extended time exposed to hot conditions. Mean core temperature at the end of two fire exposures rose from normal body temperature (37°C) to 38.5°C; maximum core temperature response exceeded 39°C in eight instructors. Heart rates for several instructors corresponded to 90% of heart rate reserve, and reflected work climbing stairs or positioning training dummies. All instructors lost fluids during the exercises. One participant lost 3.2 L of fluids in 112 minutes and experienced dizziness and nausea. Three instructors felt that they would not be able to perform a rescue at the end of the exercise session. Two instructors displayed the dizziness and nausea associated with heat illness. This report indicated that instructors experienced considerable stress when participating in training sessions designed to monitor and assist firefighters in fire exposures.

An assessment of physiological and psychological responses was made on firefighters during training (Smith et al., 1997). A 16-minute ceiling overhaul task was simulated in neutral and hot thermal environments. The hot environment produced higher heart rates, tympanic temperatures, blood lactates, perceived exertions, and anxiety levels. These responses remained elevated during a ten-minute recovery in the hot environment. An additional study (Smith et al., 2001) showed similar cardiovascular stress and cognitive degradation during other simulated tasks.

Project Goals and Description

The primary goal of this project is to provide a tool to assist the fire service on a national level with reducing the number and seriousness of training-related injuries and death. Specifically, the Center set out to develop standardized guidelines for health management of firefighters during training activities.

Based on the previous discussions, physiological test data could contain important information related to firefighter safety. Because test subjects wore SCBA, contaminant exposure is not considered an important issue for study. Because exposure times for each of the tasks is relatively short, steady-state conditions are not likely to be reached.

Of importance are the following factors:

- *Subject health history*
- *Subject physical fitness (as indicated by the Harvard Step Test)*
- *Heart rate responses (rate of rise above resting level at the start of exertion and the rate of fall after exertion ceases)*
- *Ventilation rates (flow rates and volumes)*
- *Temperatures (deep body and skin, especially during intense exertion in hot environments)*
- *Subject related comments (especially about difficulties they experience)*

The Center for Firefighter Safety Research and Development conducted a physiological analysis of over 200 firefighters participating in strenuous training exercises, and has used the findings as the basis to publish the guidelines for monitoring and ensuring health safety during future training scenarios that are included in this report. This study focused on overexertion, heat stress, and recovery time after demanding training-related activity, assessing the physiologic effects of a variety of environmental conditions and the effects of operating in full personal protective equipment (PPE) during various activities. Simulated firefighting activity in the high temperature room of the structural burn buildings available at the Maryland Fire and Rescue Institute was also included in the study.

Gathering the necessary physiological measures was made possible using wireless, continuous ambulatory physiological monitoring technology. The LifeShirt gathered multiple measures including blood pressure, blood oxygen saturation, respiration, EEG/EOG, periodic leg movement, temperature, end tidal CO_2 and cough. These measures provide a dynamic cardiopulmonary profile that will allow us to track trainees' progress against baseline fitness readings while also providing an effective means of implementing the physical screening programs the USFA report recommends for reducing training-related heart attacks and strokes.

Fire service trainers will be able to use this manual during training sessions and/or actual incidents to assist in predicting the onset of overexertion and heat stress and optimizing recovery times. Based on a range of environmental conditions such as air temperature, fire temperature, and relative humidity as well as physical characteristics of each firefighter such as age, gender, height, weight, and fitness, the fire trainer will be able to determine the recommended duration that a firefighter should be allowed in a physically demanding work environment before taking a recovery period, and the recommended duration of a rehabilitation rest period before re-entry. In addition, better judgment will be possible regarding if and when a firefighter should be medically evaluated. The range of utilization and recovery times will vary based on how much work the firefighter has done within a given time, and will account for other factors such as hydration, environmental conditions, and individual characteristics.

The final project goal is to see a reduction in the number of training-related firefighter deaths and injuries in the United States. While all of the previous goals are easily measurable, the final goal is only measurable over the long term. The Center for Firefighter Safety Research and Development will continue to monitor firefighter-training safety over time.

REVIEW OF THE LITERATURE

According to the most recent estimates, there were 1,096,900 firefighters in the United States in 2003 (Karter, 2005). Just over 27%, 296,850, were career, and 800,050 (73%) were volunteer. Ninety-three percent of the volunteer firefighters serve communities of less than 25,000 residents and more than half of these serve rural communities of fewer than 2,500 residents. Of the career firefighters, 74% serve communities of 25,000 residents or more.

Reflecting a trend over the past ten years and including the two most recent years for which data are available, approximately 100 firefighters have died each year in the line of duty (NFPA, 2005). These totals include members of career and volunteer fire departments, seasonal and full-time employees of state and federal agencies with fire suppression responsibilities, prison inmates serving on firefighting crews, military personnel performing assigned fire suppression activities, civilian firefighters working at military installations, and members of industrial fire brigades. These deaths may have occurred at the scene of an alarm, whether a fire or non-fire incident; en route while responding to or returning from an alarm; while performing other assigned duties such as training, maintenance, public education, inspection, investigations, court testimony and fund raising; or while on call, under orders or on stand-by duty other than at home or at the individual's place of business. While including some data on training-related fatalities and injuries, the United States Fire Administration, the National Fire Protection Administration and other entities have focused considerable attention upon on-duty deaths attributable to fire suppression or emergency medical services operations.

The primary goal of this section is to review existing literature on the cause and nature of firefighter fatalities and injuries incurred through involvement in training activities, and integrate cardiorespiratory health and heat stress-related health findings associated with fire suppression activities. Many of these studies have employed live-fire training exercises. To the extent possible through existing reports, this review will consider both career and volunteer firefighter training injuries.

Methods

A tripartite approach was implemented to maximize the likelihood of identifying important peer-reviewed publications and accounts in the media, as well as reports of governmental and quasi-governmental organizations. The three elements are: 1) on-line search of biomedical and behavioral databases indexing peer-reviewed publications (e.g., Medline®, National Library of Medicine); 2) on-line search of news media databases (Lexis/Nexis® Academic); and 3) Google® searches of the Internet to identify public agencies and private organizations that might house or manage data of interest.

The search was conducted in two phases. In Phase 1, on-line searches were conducted to identify promising combinations of search terms, existing sources of on-line data in downloadable form (none were revealed), and public and private agencies and organizations that made their reports and other findings available on-line. The actual review of promising reports and peer-reviewed articles was accomplished in Phase 2.

The search terms employed across the different search engines comprised combinations of "firefighter", "fire service", "fire department", "injury", "fatality", "training", "health", "heat", "stress" and "exhaustion". Where it was possible to specify ranges of dates (e.g., Medline®), searches were conducted for reports dated from 1990 to the present.

Results

Systematic review of governmental and quasi-governmental Internet sites, supplemented by Google® searches, were successful in identifying potential and actual sources of firefighter injury and fatality data. Houser et al. (2004) identified a number of data sets of potential value for use in surveillance of first responder illness and injury. Table 1 relates the value of the data sets to the present review.

Table 1 Utility of Existing Archival Data Sets for the Current Review

Name	Maintained By	Included In Review	Reason
IAFF Death and Injury Survey	International Association of Firefighters	No	Career Personnel Only Raw Counts Unavailable
NFPA Firefighter Injury Reports	National Fire Protection Administration	Yes	Available in summary form
NFPA Firefighter Fatality Reports	National Fire Protection Administration	Yes	Available in summary form
USFA Firefighter Fatality Reports	United States Fire Administration	Yes	Available in summary form Includes narrative
Census of Fatal Occupational Requirements Injuries	Bureau of Labor Statistics (BLS)	No	Career Personnel Only Stringent Confidentiality
Survey of Occupational Injuries and Illnesses	Bureau of Labor Statistics (BLS)	No	Inconsistent state reporting

Though the Internet-based literature searches failed to reveal any studies that directly address firefighter injuries attributed to training, studies in a range of relevant areas were identified. This literature review includes general health findings, injury including exposure to heat, and cardiovascular and cardiorespiratory findings.

General Health Findings

Hodous et al.'s (2004) review of firefighter fatalities for 1998-2001 determined that 47% were non-traumatic, 18% motor vehicle related and 35% attributable to other traumatic causes. Of this latter group, almost half were associated with structure fires involving structural collapse, rapid fire progression and trapped firefighters. Using data from the National Fire Incident Reporting System, Fabio et al (2002) conducted an incident-level case-control study of the association between firefighter injury and incident characteristics. Risk factors for injury included five or more alarms, high-rise structures greater than three stories and at least one civilian injury.

Fangchao Ma et al. (2005) examined mortality in a cohort of Florida firefighters, noting increased risk of mortality for males from breast, bladder and thyroid cancers, and increased risk of cardiovascular disease mortality in female firefighters. Based upon an analysis of nine years of data from the National Health Interview Survey, Lee et al. (2004) reported that firefighters ages 30-39 face a significantly greater risk of hospitalization relative to other employed men in the same age group. Haas et al. (2003) reviewed 17 studies that reported calculated standardized mortality ratios (SMRs) for firefighters. These authors examined time-dependent mortality effects for all causes, coronary artery disease (CAD), cancer and respiratory deaths. In contrast to the Fangchao study, their time study failed to identify any increased mortality with increasing tenure for all-cause mortality or any specific cause. Further, the authors identified many causes of death for which firefighters' SMRs were less than one, indicating decreased mortality for those causes.

Coronary Artery Disease (CAD) and Cardiovascular Health

Campbell et al. (1998) assessed a group of 65 firefighters in a number of fitness areas including a submaximal bike test, 1RM bicep curl and upright row, push-ups, abdominal hold, grip strength, leg dynamometry, sit and reach and body composition. Anywhere from 45% to 68% of the participants failed to meet national benchmarks. Clark et al. (2002) applied World Health Organization (WHO) body mass index (BMI) categorization methods to a group of 218 active duty firefighters in six departments in North Central Texas undergoing duty fitness evaluations. Using the WHO classification, almost 81% of the subjects were classified as overweight, obese, or morbidly obese. Further, statistically significant correlations were found between BMI and systolic and diastolic blood pressure, maximal oxygen consumption (VO_2max), resting oxygen consumption (METS) and total cholesterol. These findings not only contribute to the understanding of overall cardiovascular fitness and its absence in firefighters but also that BMI may be an important tool to identify firefighters in need of health and fitness remediation activities.

Kales et al. (2003) published the results of a case-control study of firefighter on-duty deaths from coronary heart disease (CHD). They determined that most deaths occurred between noon and midnight. Compared to non-emergency duties, fire suppression, training, and alarm responses were significantly associated with risk for CHD death. Furthermore, relative to a comparison group of firefighters, those having died from CHD tended to be current smokers and diagnosed with high blood pressure and/or coronary artery disease.

Other studies are entirely consistent with Kales et al..'s (2003) findings. Metabolic syndrome as defined by the National Cholesterol Education Program Experts Panel (NCEP III) includes the presence of three or more of: waist circumference greater than 40 inches, HDL cholesterol less than 40 mg/dl, triglycerides greater than 150 mg/dl, blood glucose greater than 100 and resting blood pressure greater than 130/85 (NCEP Expert Panel, 2001). Womack et al. (2004) examined the data from an annual physical of 75 firefighters, finding that 23/75 were positive for metabolic syndrome. This incidence is well above that predicted for American males by NCEP III (30.7% versus 24%). Parker et al. (2005) analyzed CAD risk factor data for 41 firefighters and determined that the prevalence of metabolic syndrome increased significantly as aerobic fitness declined. Though a small sample, these findings are entirely consistent with Jurca et al..'s (2004) findings for a sample of almost 9000 men enrolled in the Aerobic Center Longitudinal Study and is also consistent with Lakka et al..'s (2003) study of Finnish men enrolled in a heart disease risk factor study. Byczek et al. (2004) found that in a sample of 200 firefighters, the prevalence of obesity, elevated total cholesterol, and elevated blood pressure exceeded Healthy People 2010 (DHHS, 2000) targets. In addition, the prevalence of obesity, low high-density lipoprotein (HDL), high low-density lipoprotein (LDL), and high total cholesterol levels were higher relative to the general population. In a more extensive analysis, Tonya et al. (2004) examined a ten-year time series of CAD risk factors for firefighters in Southern California, finding that as a group the total number of risk factors significantly increased over the ten-year period. Webster et al. (2005) findings of ischemic change in moderate-risk firefighters during maximum exertion in a graded exercise test are alarming and entirely consistent with the CAD risk factor findings that have been summarized above.

In a review, Sothmann (1992) emphasized the value of maximal oxygen consumption (VO$_2$max) as an important predictor of performance of firefighters when used in conjunction with task-specific testing. Several studies have examined the effectiveness of exercise programs of different lengths in improving aerobic performance of cadets, recruits and firefighters. The reports are mixed in their findings. Williford et al. (1998) reported that an 18-week firefighter training program significantly increased muscle strength and endurance, and improved body composition, but failed to produce changes in cardiovascular fitness and blood lipids. Harger et al. (1999) reported that 120 days of moderate aerobic activity significantly improved maximal oxygen consumption (VO$_2$max), lowered percent body fat and also improved performance on other measures of fitness in professional firefighters. Dempsey et al. (2002) reported that a mandatory physical fitness program for firefighters had a significant multivariate effect on physical fitness and medical indicators. Looking at hours lost for injury on the job, Stevens et al. (2002) reported that implementation of a wellness program resulted in a 47% reduction in injury-related absenteeism. The two-year program included warm-up exercises, a minimum of 20 minutes of cardiovascular exercise, strength training and stretching. Significant reductions in total cholesterol and systolic blood pressure and increases in push-ups were found to be the principal effects of the program. Babcock and Kirby (2004) measured the impact of a six-week comprehensive training program. At program start, 65% of fire recruits met expected aerobic capacity of 42 ml/kg/min; at program end, 89% met the criteria. Garfi et al. (1996) determined that a 16-week cross training program was effective in reducing the systolic blood pressure by 5.1 mmHg of a group of 42 male normotensive firefighter recruits. These authors state that this level of change is comparable to that achieved through endurance-only training programs. Blevins et al. (2005) reported that a one-year physical fitness program on- and off-duty significantly lowered systolic blood pressure, body mass index, percent body fat and several other measures. Previously, Blevins (2004) had reported baseline data for this group of career and volunteer firefighters, noting high rates of physical inactivity and other measures indicative of risk for CAD and cardiovascular events. Womack et al. (2005) studied the impacts of a one-year voluntary wellness program on CAD risk factors, demonstrating positive trends in CAD risk markers but failing to demonstrate a significant improvement over the one-year period. In a 1998 pilot study, Green found that a $100/month stipend failed to provide sufficient incentive for firefighers to participate in a standardized fitness program.

Soukup et al. (2005) analyzed maximal oxygen consumption (VO$_2$max) data for a sample of 363 professional firefighters of mixed rank and age. Controlling for age, the analysis failed to reveal significant differences in VO$_2$max across firefighter positions (captain, driver, firefighter, and administrator). Furthermore, these values were found to be above the minimal threshold shown to be associated with an increased risk of performance failure to fatigue. However, 22% of those tested did not meet minimum standards.

Roberts et al. (2002) examined respiratory parameters of firefighter recruits before and after a 16-week training program. These authors concluded that aerobic capacity was 20% below minimum standards for safe performance of suppression duties and that the training program improved aerobic capacity by 28% as well as decreased fat and increased lean muscle mass.

Myrhe et al. (1997) sought to determine the relationship between selected measures of physical fitness and performance of a standardized, strenuous firefighting training task. A regression model was derived which demonstrated that task performance could be predicted on the basis of percent body fat, strength and VO$_2$max. One other study evaluated the relationship between physical fitness and the performance of fire suppression activities (Williford et al.., 1999). A Physical Performance Assessment (PPA), consisting of multiple suppression tasks, was completed by 91 firefighters. Multiple regression analysis revealed that the best predictors of PPA were a 1.5-mile run, fat free weight and pull-ups. The authors suggest that these findings demonstrate the importance of physical fitness as it relates to the performance of fire suppression tasks. Rodriguez and Eldridge (2003) assessed the predictive value of aerobic capacity with regard to the probability of line-of-duty injury in firefighters. Maximum aerobic capacity and strength measures were measured annually over a five-year period and compared with injury records via logistic regression. A summary measure of strength variables and VO$_2$max was found to be a successful predictor of injury. Higher aerobic capacity and strength decreased the probability of injury. Mol et al. (2003) compared physical demands of actual and simulated firefighting. Though only means and standard deviations are offered for the activity measures, it is clear for several measures that simulated fire fighting evoked stronger physiological responses in several cases and for no measure did the data indicate that simulated firefighting was less strenuous that actual firefighting.

Cardiovascular Responses

D.L. Smith has published a series of studies on the physiological and psychological effects of live firefighting drills. Smith, Petruzzello et al. (1997) initially compared the impact of a neutral (13.7ºC/56.7ºF) vs. hot (89.6ºC/193.9ºF) environment on a simulated firefighting task. Under hot conditions, significant increases were seen for heart rate, tympanic temperature, blood lactate, Borg Ratings of Perceived Exertion (1974) and state anxiety (Spielberger et al.., 1983). Recovery was significantly slower after work was performed under hot conditions. Smith and Petruzzello (1998) studied the responses of firefighters engaged in strenuous live-fire drills while wearing either an NFPA 1500 (1987) standard configuration or a hip-boot configuration of firefighting gear. The results of this study indicated that wearing the NFPA 1500 gear resulted in longer performance time, greater thermal strain and greater perception of effort and thermal sensation. Smith, Petruzzello et al. (2005) examined selected hormonal and immunological responses to live-fire firefighting drills. Significant leukocytosis was noted immediately after firefighting activity and persisted through a 90-minute recovery period. Plasma ACTH (Adrenocorticotropic Hormone) and cortisol were significantly elevated after firefighting activity. The authors stated that elevated cortisol was related to feelings of reduced energy. The authors also stated that their data demonstrate the substantial magnitude of the physiological and psychological disruption following strenuous firefighting and that immune function may be impaired.

Campbell et al. (1999) monitored heart rate during a live burn as a means of determining the work/rest duty cycle. Their results indicated that suppression activities are interval in nature and that consequently interval type training, rather than endurance training, might better fit the needs of suppression personnel. Baker et al. (2000) conducted treadmill studies of firefighters wearing fire ensembles or sport ensembles. Ratings of Perceived Exertion (RPE), rectal temperature and heart rate were recorded. Interestingly, measures of RPE closely paralleled physiological parameters. Though these tests were not replicated for hot, humid conditions, the findings indicate that RPE may provide individuals with a valid measure of dangerous levels of perceived heat strain. Eglin et al. (2004) monitored maximum heart rate (HRmax) of a group of 44 firefighter instructors during live fire training exercises. Instructors' heart rates exceeded 90% of their HR reserve and four of the instructors doubted their ability to perform a rescue at the end of the exercise. The authors noted that the results obtained from some individuals gave cause for concern and signs of heat strain were seen in at least two of the instructors. Smith (2002) reported that relatively short bouts of firefighting in a live fire training situation led to significant changes in platelet number and antithrombin III activity. The author noted that further research is necessary to determine how these physiological changes might impact overall clotting ability or risk of blood clot development.

Responses to Heat

As an introduction to this section, it is appropriate to mention Frim and Romet's (1988) study which convincingly demonstrated in both field and laboratory settings that vapor barrier materials in protective clothing (such as neoprene) significantly contribute to higher thermal physiological strain, even at lower temperatures. These effects became more pronounced at higher temperatures and over extended periods of work. In addition, one of the more thorough analyses of environmental conditions experienced by firefighters in live-fire training has been measured and reported by Rossi (2003). Firefighters were typically exposed to radiant heat fluxes of between 5 and 10 kW/m^2, though a peak of 42 kW/m^2 was reached. The temperatures reached between 100 and 190ºC at one meter above the ground, reaching a maximum of 278ºC in one case. After 15 minutes in the heated room, the mean core temperature of firefighters rose by 0.6ºC. Sweat production varied from 0.7 to 2.1 L per hour. Most interestingly, during these exercises, a mean of 48ºC was measured between the firefighters' protective gear layer and normal uniform items worn underneath.

In a unique study, Hagan et al. (1996) compared the impact of two alternate shipboard firefighting water attack methods on the heat strain of firefighters. In the aggressive fog trial (versus direct straight stream), the fog pattern not only extinguished the flames significantly faster, but also resulted in lower measured body temperatures. Thus, fog attack reduced heat strain. Carter et al. (1999) assessed the value of cooling a firefighter with a high velocity fan during 10-minute rest breaks interspersed between 10-minute work periods during simulated firefighting. Two important findings emerged from this study: 1) ten minutes of exposure to heavy work in a hot and humid environment results in minimal heat stress; and 2) firefighting exposure in excess of 10 minutes without adequate rest and cooling may lead to a significant accumulation of heat stress and fatigue during subsequent firefighting activity, regardless of the fitness of the firefighter.

Ftaiti et al. (2001) studied the impact of different types of firefighter protective clothing on tympanic temperature and heart rate during treadmill runs. The heaviest jacket tested, a traditional French leather design, resulted in the highest temperature and heart rate and also greatest body mass loss. All lighter-weight textile jackets with and without membrane linings dampened these changes. The authors concluded that the magnitude of physiological responses facilitated by the textile jackets was correlated to jacket weight. Gavin et al. (2001) compared traditional cotton fabric and evaporation-promoting synthetic fabric exercise attire. Subjects ran on indoor treadmills according to prescribed regimens and a variety of subjective measures and physiological parameters were assessed. The authors concluded that the synthetic fabric did not provide any thermoregulatory, physiological or comfort advantage. McLellan and Selkirk (2003) compared the effect of short versus long pants worn under bunker pants, in full protective gear and self-contained breathing apparatus. They determined that during light exercise, wearing shorts reduces heat stress and extends exposure time by approximately 10 to 15%, but during heavy exercise of less than one hour duration, there was no benefit to short versus long pants.

Selkirk and McLellan (2004) examined the time to reach critical endpoints (representing potentially dangerous levels of heat exposure) at different levels of work effort and environmental temperature. The authors concluded that at lower metabolic rates and environmental temperature, work and rest schedules may be sufficient to extend work time. Most importantly, at higher ambient temperatures (35ºC), passive recovery may not be sufficient to reduce body core temperature back to or below baseline levels.

Smolander et al. (2004) examined the impacts of wearing a 1 kg. ice vest on physiological and subjective response during a treadmill task in a hot and dry environment. The ice vest reduced physiological and subjective strain responses. The authors suggested that this vest might increase efficient work time by 10%. Selkirk et al. (2004) compared the effectiveness of misting, forearm submersion and passive cooling on a group of firefighters engaged in heat-stress trials while wearing full turnout gear and SCBA. Forearm submersion not only significantly increased tolerance time and total work time but also significantly lowered heart rate and rectal temperature relative to misting.

In a study in the United Kingdom, Rayson et al. (2004), firefighters performed high-rise scenarios using Standard and Extended Duration Breathing Apparatus (SDBA and EDBA). Interestingly, the authors concluded that SDBA provided inadequate air to achieve the objectives of the scenario, while EDBA provided sufficient air, which contributed to high core temperatures and/or suspected exertional heat stress.

In a pilot study (N=7), Smith et al. (2001) studied recruit firefighters in a series of three trials in a live-fire scenario in a training structure. The findings were suggestive of increasing cognitive impairment across the three trials, but statistically significant differences were not detected. Snook et al. (2004) compared physiological and perceptual reports of heat strain in a simulated firefighting environment. In a series of three trials, both physiological (Moran et al.., 1998) and perceptual (Tikuisis et al.., 2002) heat strain measures increased across all trials. The authors concluded that even relatively brief bouts of simulated firefighting activity in the heat results in moderate to high levels of heat strain and that perceptual markers of heat strain were consistently higher than physiological markers across the three trials.

Johnson et al. (2005) studied possible remedies to noncompensable heat stress, which occurs when specially designed protective equipment, which features high thermal insulation and low permeability, reduces the potential for evaporative and conductive heat loss. Neither cooling vests soaked in ice water nor cooling vests soaked in ice water with an ice water-filled insert were found to be effective in alleviating heat stress.

The findings of a study published in 2004 by Fogarty et al.. tend to challenge conventional wisdom. This team sought specifically to examine the effects of firefighters' protective clothing on cardiovascular function. Subjects participated in a standardized, instrumented regimen utilizing a recumbent bicycle and wearing either heat protective clothing or shorts. Protective clothing increased cardiac output, but not stroke volume, indicating the differences were driven by heart rate. In the clothed trials, subjects experienced significantly shorter times to fatigue at lower peak work rates and with higher core and skin temperatures. Moreover, even though subjects in protective clothing experienced greater sweat loss, plasma volume did not change. The authors concluded that protective clothing reduced exercise tolerance but did not affect overall cardiovascular function at the point of volitional fatigue. Finally, the authors concluded that the incremental effect of clothing with regard to heat stress was negligible in comparison to that of the moderately heavy, semi-recumbent exercise under hot, dry conditions.

Studies of the Use of Self-Contained Breathing Apparatus (SCBA)

Johnson et al. (1999) examined the effect of respirator inspiratory resistance level on constant load treadmill performance. Their findings show that performance times decrease linearly with resistance level and that inspiratory resistance induces hypoventilation with lower minute volumes and lower oxygen consumption at higher resistances. Donovan and McConnell (1999) determined that rather than increase mean tidal volume while wearing SCBA, the firefighters in their study increased their breathing frequency. Wilson et al. (1999) examined the relationship between Trait Anxiety as measured by the State-Trait Anxiety Inventory Manual (STAI)(Spielberger et al..,1983) and respiratory distress while engaged in heavy physical exercise while using a full-face piece, air-line supplied, pressure-demand respirator. The study revealed that the STAI was effective in predicting the absence of respiratory distress while engaged in the task. The authors cautioned against sole reliance upon the STAI for screening, noting a combined false positive and false negative rate of 4 to10 percent. Eves et al. (2002) found that hyperoxia while wearing SCBA significantly increased maximal oxygen consumption (VO_2max) and maximal power output (POmax) by 3.8% and 7.1%, respectively. The authors believe that these findings could have significant implications for occupations that involve heavy work with SCBA. Campbell et al. (1994) assessed protection factors for positive-pressure versus negative-pressure SCBA. Their analytical model confirms the NIOSH assigned value of 50 to a negative-pressure full-face piece and a value of 10,000 for a positive-pressure SCBA. In a tangentially related study, Legg and Cruz (2004) examined the impact of single versus double strap backpacks, concluding that a backpack load of

6 kg produces a minor ventilatory impairment and that this effect is more pronounced for single as compared to double backpack straps. In another methodological note, Van Gelder et al. (2002) reported their use of a standard SCBA mask modified to perform pulse oximetry consisting of oximetry sensors added to the reflected rubber lining of the facepiece with wiring from the unit exiting near the attachment of the low pressure line which then connects to an electronics box attached to the base of the SCBA harness. These authors also reported the use of CoreTemp® capsules (Human Technologies, Inc), which are ingested by subjects and transmit temperature data to a pager-sized receiver/recorder worn on the belt.

Respiratory Exposure to Toxins

A now classic study by Treitman et al. (1980) measured air contaminants in a series of over 200 fires in Boston, Massachusetts. This study revealed dangerous levels of carbon monoxide and acrolein, as well as hazardous levels of hydrogen chloride, hydrogen cyanide, nitrogen dioxide and carbon dioxide. Benzene was also identified at most fires, but not at concentrations associated with acute injury. Feunekes et al. (1997) measured exposure of firefighter instructors to polycyclic aromatic hydrocarbons (PAH). Despite typical adherence to respiratory protection practices and short, intermittent exposures, tests revealed evidence of exposure and uptake. Although the levels found were lower than those associated with cancer risks, the possibility of longer-term health risks could not be ruled out. These PAH findings were later replicated by Caux et al. (2002). Bolstad-Johmson et al. (2000) conducted a comprehensive air monitoring study during the overhaul phase of 25 structure fires in Phoenix. She reported values for personal air samples that exceeded published safe maximum levels for acrolein (one site), CO (five sites), formaldehyde (22 sites) and glutaraldehyde (five sites). Furthermore, continuous air monitoring revealed unsafe short-term exposure values for benzene (two sites), NO_2 (two sites), and SO_2 (five sites). In their comprehensive review of benzene exposure, van Wijngaarden and Stewart (2003) expressed confidence in the validity of the Phoenix estimates for benzene and of the problem of chronic exposure of firefighters to benzene on the fireground.

Slaughter et al. (2004) examined firefighters' lung function at pre-, mid- and post-shift. Lung function did decrease from pre- to post-shift, but firefighters exposed to greater concentrations of respiratory irritants did not show correspondingly greater decrements in lung function.

Reinhardt and Ottmar (2004) conducted a comprehensive examination and analysis of smoke exposure among wildland firefighters (WLFFs). They determined that exposure to all pollutants was higher at prescribed burns than at wildfires and that smoke exposure reaches its highest levels among WLFFs maintaining fires within designated fire lines and performing direct attack of spot fires that cross fire lines. In a methodological study, Cone et al. (2005) recently validated the feasibility of fireground use of a handheld CO monitoring device that measures COHb (carboxyhemoglobin) levels via analysis of exhaled breath.

Burgess et al. (1999) reported the results of analysis of eight years of data on ventilatory capacity and single-breath diffusing capacity of carbon monoxide (DLCO) in firefighters. Though the ventilatory capacity data were consistent over time, the DLCO declined over time. The authors note that the DLCO findings pose a dilemma of reliability of the test versus the possibility of sensitive detection of early signs of the effects of smoke inhalation.

Miscellaneous Injury Reports

Mechem et al. (2002) conducted a retrospective review of occupational injury records from a large city fire department. Four percent of the 1,100 injury records involved assault by a patient. Firefighters were the subject of the injury report in about 1/5 of these records. Although their contribution to overall injury levels is rather low, this study nevertheless highlights an additional area for concern. Becker et al. (2003) examined firefighters' risk for fire apparatus crash injuries and fatalities. Unrestrained firefighters were especially at risk for fatality if involved in a crash. The centralized data sets used for this study preclude any possibility of distinguishing training-related injuries and fatalities from other categories.

The National Institute for Occupational Safety and Health has issued "Hazard ID" bulletins that explain the hazards to firefighters while working along roadways (NIOSH, 2002) and during tanker truck rollovers (NIOSH, 2002). The National Institute for Occupational Safety and Health has also addressed deaths and injuries resulting from live-fire training in acquired structures (NIOSH, 2004).

Blood Exposures

Deblina Datta et al. (2003) examined blood samples from three first responder populations in the United States for presence of antibody to Hepatitis C (anti- HCV; HCV). Prevalence ranged from 1.3% to 3.6%, which is consistent with appropriate referent groups in the U.S. population. HCV infection among first responders was not statistically associated with skin exposures to blood, but rather was statistically linked to non-occupational risk factors. Boal et al. (2005) have recently published concordant findings.

World Trade Center Rescuers

The unprecedented World Trade Center (WTC) rescue response encompassed over 5000 workers per day and continued for many months. A complete description of rescuer injury and illness injuries is well beyond the scope of this review. An analysis of rescuer visits to area emergency departments and Disaster Medical Assistance Team facilities revealed 5222 rescue worker visits in the month following the attacks. Musculoskeletal conditions ranked first (19%), followed by respiratory (16%) and eye (13%) disorders (Berrios-Torres et al.., 2003). A serious and debilitating syndrome, which came to be known as "World Trade Center Cough," was identified and studied by regional health officials in NYC (Prezant et al.., 2002). Feldman et al. (2004) conducted a stratified random cross-sectional study of 11,000 career firefighters who responded to the WTC. Based on a summary score of respirator use, 19% of respondents reported that they did not use a respirator and 50% reported using a respirator but wearing it rarely during work hours. These authors reported that the number of days of exposure (presence at the site) was the only significant predictor of respiratory and skin, ear, nose and throat symptomology. Furthermore, arrival time at the WTC, as a proxy measure for exposure intensity, was associated with increased symptom reporting and greater declines in pulmonary function. Just as the WTC terror incident was unprecedented, there are few comparable studies of other major fire events. Gallanter and Bozeman (2001) conducted an analysis of firefighter illnesses and injuries secondary to a series of wildfires in Florida. The injury and illness profile, as would be expected, hardly resembles the WTC complaints. Firefighters were most commonly seen for preventive, hygiene or environmental matters (33%) followed by foot-related complaints (15%) and rash-itch (14%).

Volunteer Firefighters and Rescuers

Magenetti et al. (1999) reported the results of their analysis of volunteer firefighter (VFF) injuries based on workers' compensation claims in West Virginia. Leading causes of reported injury were lacerations and contusions (28.9%), followed by strains and sprains (23.9%) and inhalation/respiratory complaints (13.7%). The authors noted that VFFs in this study had sustained falls at almost twice the national average reported by the NFPA for the comparable year. Morren et al. (2005) studied the health of volunteer firefighters three years after they were deployed in response to a major fireworks factory explosion. The most remarkable finding of this study is that compared to non-deployed volunteer firefighters, the research failed to identify any health status changes of the deployed volunteers. Several factors could explain these findings including selection bias (i.e., volunteers with changes in health status selectively did not return the survey to researchers) and recall bias associated with the three-year retrospective nature of the study.

Other Studies

Prezant et al. (1999) reported the results of health surveillance from 1985 to 1998 for sarcoidosis. The surveillance effort identified four prior cases and 21 new cases for the study period. Compared to EMS health-care workers whose annual incidence was zero, these firefighters showed increased annual incidence proportion and pint prevalence. Radiographic and physiological measurements demonstrated minimal impairment.

Wildland Firefighters

A considerable body of literature has focused upon activities and characteristics of wildland firefighters (WLFFs). Budd (2001) concluded that four key behavioral principles alleviate heat stress in experimental fires: 1) avoiding unnecessary heat; 2) encouragement of self-pacing; 3) facilitating evaporation of sweat; and 4) replacing sweat losses by drinking. Several methods of monitoring energy expenditure have been field tested including the use of 1) Heart rate monitoring and physical activity records (Burks, 1998; Tysk and Ruby, 1999); 2) CSA Activity Monitor (Metcalf et al., 2002) studies by Heil (2001) and Lankford et al. (2002); and 3) Doubly labeled water methodology (Ruby et al. 2002, 2003). Heil et al. (2004) have validated an algorithm for predicting energy expenditure based on the Actical (Mini Mitter Co., Inc.) and MTI (Manufacturing Technology, Inc.) monitors, mounted to a card, which was worn in the left chest pocket. Ruby et al.'s (2003) work indicated that WLFFs involved in prolonged strenuous work are at risk of a negative energy balance and loss of total body mass. Gaskill et al. (2003) reported seasonal changes in the aerobic fitness of a crew of WLFFs. Interestingly, the most aerobically fit WLFFs at baseline had detrained by mid-season while the least aerobically fit at baseline trained up to mid-season levels statistically indistinguishable from the most fit. Ferris et al.'s (2003) findings indicate that individuals with existing or borderline hypertension may display a more exaggerated increase in blood pressure during the United States Forest Service Pack Test than do normotensive individuals. Leadbetter et al. (2001) documented that WLFFs' field packs significantly impede ground travel during a forced evacuation, supporting a recommendation that packs be abandoned during emergency escape to a safety zone. Finally, Goodson et al. (2005) recently reported that performance on cognitive tests by WLFFs was not influenced by supplemental carbohydrate loading in the course of 12-hour shifts.

Media Reports

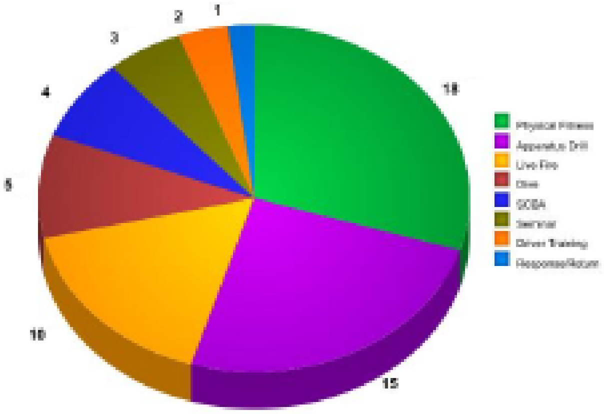
The Internet Lexis/Nexis® searches revealed anecdotal accounts of volunteer and career firefighter deaths occurring during training activities. Though the number of cases found is small relative to the total of known fatal incidents and the accounts are anecdotal, this sample of training injuries seems to reflect a representative range of training circumstances and causes of death and injury.

Recent USFA and NFPA Reports

In 1994, the NFPA released a review of firefighter training deaths dating back to 1984 (Anonymous, 1994). For that period, 89 deaths occured during training, accounting for eight percent of the firefighter deaths. Details of these deaths are displayed in Table 2. The NFPA reported that 49 of the deaths (55.1%) were attributable to heart attacks.

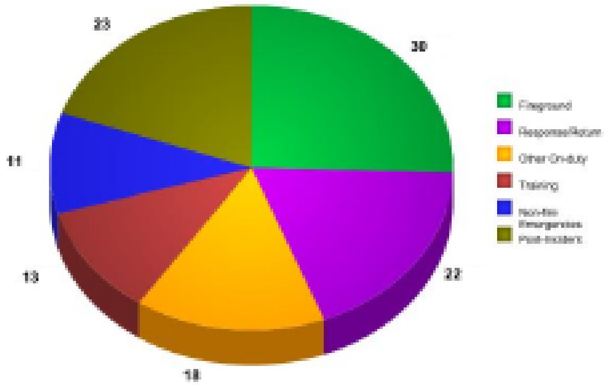
In its 2002 Report, the United States Fire Administration reported that that approximately 6% of firefighter fatalities occurred during training activities (USFA, 2002). According to the USFA the "leading nature" of fatal training injury was heart attack (54%), followed by trauma (31%). This report also revealed that compared to traumatic injuries, firefighters were more likely to experience a fatal heart attack while performing suppression support duties on the fireground, while in the fire station or during training exercises. Figure 2, derived from this report, shows a breakdown of leading types of training activities associated with training fatalities for 1990-2000.

Figure 2 - Training Fatalities by Type of Duty 1990-2000 (USFA 2002)



In a 2005 report the USFA reported 117 firefighter deaths for the year 2004 (USFA, 2005). Of the 117 deaths, 13 deaths (11%) were associated with training. More detail on the 2004 firefighter fatalities can be seen in Figure 3. Six of the thirteen training related deaths were cardiac in nature: two during wildland pack tests, two during physical fitness training and two more during fire suppression training exercises and class work. Of the remainder, one death was dive related, one was crash related and the other five involved fire apparatus or motor vehicles.

Figure 3 - Firefighter Fatalities by Type of Duty -2004 (USFA 2005)



In a 2004 report the NFPA released an analysis of on-duty firefighter injuries (Karter and Molis, 2004). Of 78,750 injuries, 7,100 (11%) occurred during training activities. Though details of the circumstances of the training injuries are not analyzed, details are available on the type of injury. The distribution of training injury types is displayed in Table 3.

In a special 2005 report, the National Fire Protection Association released an analysis of U.S. firefighter fatalities due to sudden cardiac death (Fahy, 2005). Of 1,006 total fatalities for the ten-year period, 440 were attributed to sudden cardiac death. Figure 4 shows the breakdown of these sudden deaths according to activity. For the training deaths whose circumstances are known 21/50 (42%) of the deaths occurred during physical fitness activities such as jogging, playing basketball, or undergoing endurance or agility activities, 21/50 (42%) were involved in emergency operations training evolutions including smoke drills, live fire training, and search and rescue, 6/50 (12%) were in meeting or classroom settings, and specific training activity details were not available for two of the cases.

In its annual 2005 report, the NFPA reported 103 firefighter fatalities for 2004 (LeBlanc and Fahy, 2005). The distribution of deaths by activity type is shown in Figure 5. Of the 12 training deaths, seven firefighters experienced sudden cardiac death, one firefighter became trapped under ice and drowned while testing dive equipment, one died in a plane crash, one fell from the back of a pick-up en route to training, one was struck and killed by a backing vehicle at the station and one died from a training exercise involving apparatus snow chains. This report also provided a breakdown of career and volunteer training injuries, though cross-tabulations by subcategories were not available. Of the subset of career and volunteer municipal firefighters, 3/29 volunteers (10%) and 7/63 career firefighters (11%) died from training-related activities.

Figure 4 - On-Duty Sudden Cardiac Death 1995-2004 (NFPA 2005)

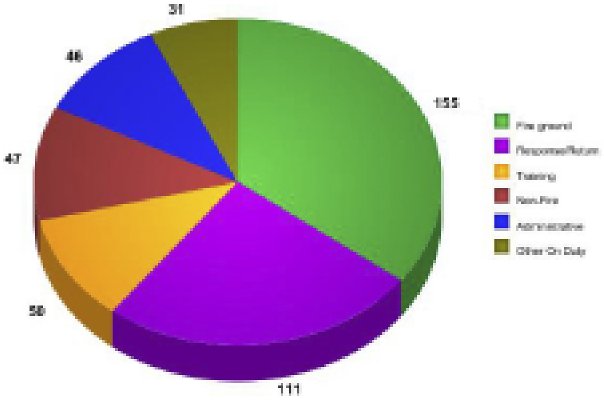


Figure 5 - Firefighter Fatalities by Type of Duty -2004 (NFPA 2005)

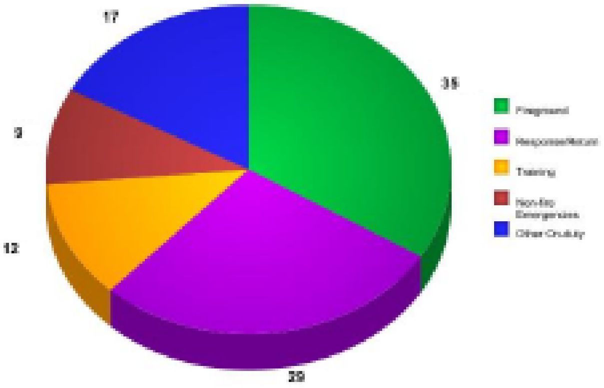


Table 2 - Firefighter Training Deaths by Activity, 1984-1993 (NFPA 1994)

Training Activity Type	Number (%)	Underlying Cause or Circumstance	Number
Company Drills	17 (19)	Heart Attack	12
		Stroke	2
		Falls and Trauma	3
Physical Fitness Training	13 (15)	Heart Attack	12
		Embolism	1
Live Fire Training	10 (11)	Smoke Inhalation	3
		Asphyxiation	2
		Heart Attack	3
		Trauma	2
Water Rescue	5 (6)	Drowning	2
		Heart Attack	1
		Stroke	1
		Heart Failure	1
Driver Training	5 (6)	Struck By	4
		Other Head Injury	1
Firefighter Competition	4 (4)	Falls	3
		Heart Attack	1
SCBA Training/Other	4 (4)	Heart Attack	4
Disaster Drills	3 (3)	Struck By	2
		Heart Attack	1
Structural Training	5 (6)	Heart Attack	2
		Falls	2
		Collapse	1
Vehicle Crashes	2 (2)	Trauma	2
Rappelling	2 (2)	Heart Attack	1
		Electrocution	1
Ladder Training	1 (1)	Electrocution	1
Other Training Sessions	6 (7)	Heart Attack	4
		Stroke	1
		Struck By	1
Unknown	12 (13)	-	12
Totals	89 (100)		

Table 3 - Training-related Firefighter Injuries in 2003 (NFPA 2004)

Category	*Burns*	*Smoke Inhalation*	*Other Respiratory*	*Burns & Smoke Inhalation*	*Wound, Cut, Bleeding, Bruise*	*Subtotal*
N	330	25	85	35	1185	1660
%	4.7	0.4	1.2	0.5	16.7	23.0

Category	*Dislocation, Fracture*	*Heart Attack or Stroke*	*Strain, Sprain*	*Thermal Stress*	*Other*	*Total*
N	340	70	4130	325	575	7,100
%	4.8	1.0	58.2	4.6	8.1	100

Discussion

One cannot begin discussing the state of the literature on firefighter health without bemoaning the almost complete absence of industry-wide studies beyond the injury and fatality data collected by the federal government or quasi-governmental agencies. This absence of industry-wide studies manifests itself, for example, in the conflicting findings regarding hospitalization and mortality data. In any case, it is perfectly clear that the apparent state of cardiovascular health of firefighters is at the best, shockingly suboptimal, and at worst, a national emergency preparedness catastrophe. It is equally clear that more research is necessary to identify promising approaches to improving the cardiovascular fitness of firefighters and the incentives necessary for these programs to succeed.

This review highlights a number of studies that adequately document the cardiovascular impacts of live-fire training activities. There is at least a suggestion in the literature that the distributions of cardiovascular stress generated by training activities and actual live fires are overlapping, even if only in the upper end of training activities and the lower end of live fire cardiovascular responses. The responses include increases in heart rate and core temperature as well as metabolites. The studies definitively indicate an increased cardiovascular risk. Some of the studies even suggest the possibility of short-term immunological compromise. Furthermore, the existing studies demonstrate the need for well-designed, appropriately instrumented, large-sample, multi-site studies to carefully study these issues.

This review of studies of responses to heat suggests that future studies carefully choose their measures of heat stress and underline the importance of investigating recovery as well as exertion. There is also some disagreement regarding the actual impact of protective clothing on exertional heat stress. Some studies indicate that clothing increases heat stress, but at least one study suggests that the marginal impact of clothing on heat stress may be negligible.

Two unrelated areas of the literature stand out. The studies of firefighters' exposure to respiratory toxins form a coherent picture of increased levels of risk from some environmental toxins commonly associated with firefighting. It also appears that wildland firefighters have been studied in relative depth and breadth.

Though annual counts and tabular analyses and some peer-reviewed literature accounts are available, firefighter training injuries remain under-studied. Much of the research has been focused on the study of fireground and especially structural firefighting fatalities and injuries. The most useful and almost only available data on training fatalities and injuries are those available from government agencies such as the United States Fire Administration and the quasi-governmental National Fire Protection Administration. Existing analyses of firefighter training fatalities and injuries are insufficient for anything more than general discussions of causality. The available analyses indicate that cardiovascular events are a substantial contributor to many of the fatal events, with trauma related to motor vehicles and falls a second broadly identifiable area.

As the circumstances of training fatalities, rather than injuries, have been better documented and analyzed, the discussion will focus on these data. Firefighter training fatalities have hovered in the 8% to 11% of total firefighter deaths range for most of the past 20 years. It would also appear that training injuries have remained at or above 10% for most of the past 10 years. Training fatalities have typically placed third in rank behind fireground and response/return injuries.

Though terminology has changed over time, it is apparent that cardiac-related events are the single largest identifiable cause of training fatalities. In contrast, cardiac-related events do not play nearly as dominant a role as causes of non-fatal training injuries, where musculoskeletal injuries dominate all other categories. Regrettably, without access to the actual data sets, it is not possible to assess whether cardiac related-deaths are clustered in older cohorts of firefighters or distributed more generally across age groups. Qualitatively, published reports of firefighter deaths from apparent cardiac arrest identify victims of various ages, not merely in the older age bands. Trauma related deaths account for the next largest identifiable cause of fatalities, largely attributable to motor vehicle crashes, pedestrian injuries and falls. It is notable that cardiac events and motor vehicle related events are also substantial contributors to non-training firefighter fatalities. Based on existing analyses and as might be expected, cardiac-related fatalities are linked to strenuous structural fire training activities. Finally and even more alarming is the association of cardiac-related fatalities to

METHODOLOGY

Two hundred firefighters between 21 and 55 years of age were recruited by the Maryland Fire and Rescue Institute for inclusion in the study. Subjects were required to possess a minimum of three years' experience as a firefighter and hold a Firefighter II certification as defined by the National Fire Protection Association (NFPA 1001, 1992).

Testing was conducted at the Maryland Fire and Rescue Institute on twenty dates between August 3, 2005 and October 14, 2005. Upon arrival at MFRI on the assigned date, subjects received an introduction to the study and provided informed written consent to participate in accordance with University of Maryland policy. The study was approved by the Institutional Review Board for human subjects.

Core body temperature was monitored with a CoreTemp™ core body temperature monitoring system (HQ Inc. Palmetto, FL). The CoreTemp™ system utilizes an ingestible (pill-form) radio-transmitting thermometer to provide core body temperature at ten-second intervals throughout digestive tract transit. Data from the CoreTemp™ sensor was transmitted to an external monitoring and recording device mounted on the subject's hip. Immediately after providing informed consent, subjects were asked to swallow the core body-temperature-monitoring pill and provide a urine sample for the determination of urine specific gravity (USG). Urine specific gravity was determined using a MISCO Model 301 digital refractometer for the purposes of evaluating the hydration status of each participant. Subjects with a urine specific gravity greater than 1.02 were considered euhydrated and those with a urine specific gravity less than 1.02 were considered dehydrated.

Subsequently, subjects were randomly assigned to one of three four-person hose teams and asked to complete a demographic and basic health history questionnaire. The time required for completion of the questionnaire allowed determination of resting systolic and diastolic blood pressures. All subjects were cross trained as emergency medical personnel with a minimum certification of Emergency Medical Technician-Basic (EMT-B) and were thus able to measure blood pressure on one another throughout the study using the sphygmomanometers and stethoscopes provided by MFRI.

The LifeShirt System

The LifeShirt System is an innovative, ambulatory, multi-sensor, continuous monitoring system for collecting, analyzing and reporting health data. A monitoring method called respiratory inductive plethysmography (RIP) enables researchers to capture a highly accurate view of subjects' breathing. RIP has been cited in over 1600 peer reviewed articles and has been the gold standard for bedside respiratory monitoring in intensive care units for over 20 years. The LifeShirt device gives this technology ambulatory capability because the garment's design provides an elegant solution to the problem of respiratory bands shifting out of place on the subject during activity and changes in posture. The LifeShirt System is able to collect reliable objective physiologic data through various sensors, including RIP bands, which measure pulmonary function (tidal volume, respiratory rate, etc.), electrical activity of the myocardium via a standard modified lead II electrocardiogram (ECG) and activity/posture via a tri-axial accelerometer. Other peripheral diagnostic devices with digital output may be used as components of the LS System for special purposes. For the current study, accessory devices enabled the monitoring of blood oxygen saturation (SaO_2) and skin surface temperature. An on-board PDA continuously encrypts and stores the patient's physiologic data on a compact flash memory card. Posture and activity information are also tracked and recorded.

Study participants obtain baseline blood pressure measurements

A MFRI instructor attaches the Nonin X-Pod pulse oximeter ear lobe sensor to a study participant.

The sensor array of the LS System is embedded in a sleeveless undergarment, made of washable material that fits snugly and can be worn comfortably for extended periods. RIP sensors are embedded in this shirt ensuring correct and durable placement and allowing multi-channel recording. The RIP sensors consist of a sinusoidal arrangement of electrical wires that are excited through an extremely low current, electrical oscillator circuit. One sensor is sewn into the shirt at the level of the rib cage (fourth intercostal space) and one at the level of the abdomen (umbilicus). From these signals, a variety of calibrated respiratory pattern measures are extracted such as minute ventilation, tidal volume, respiratory rate, fractional inspiratory ratio, and peak inspiratory flow.

An electrocardiogram is recorded by means of three electrodes placed directly onto the skin on the upper chest and on the lateral surface of the abdomen. This standard configuration provides a single lead for heart rate and ECG waveform determinations. R-spikes in the ECG are detected, and the R-R intervals are converted to instantaneous heart rate. Respiratory sinus arrhythmia (RSA) is measured using the peak-to-trough method: for each breathing cycle, the shortest R-R interval during inspiration is subtracted from the longest R-R interval during expiration.

For measurement of body posture (angle deviation from horizontal) a two-axis accelerometer is placed onto the shirt over the sternum. The rectified and integrated accelerometer signal is used to detect periods of physical activity and rest. This signal permits focusing on portions of the tracing in which motion artifacts might be present.

A study participant dons the LifeShirt System

Blood oxygen saturation (SaO_2) is monitored using a Nonin™ X-Pod pulse oximeter and a model 8000Q ear-lobe sensor (Nonin Medical Inc., Plymouth, MN). The X-Pod device detects SaO_2 in the range of 70-100 ± 2-3 % for ambulatory adults. Skin temperature is measured using an ExaconTM D-S18 thermistor (Exacon A/S, Roskilde, Denmark) mounted to the subject's torso. Both the SaO_2 and skin temperature devices interface with the LifeShirt Model 200 recording device through a serial connection allowing continuous ambulatory monitoring. Core body temperature was monitored with a CoreTemp™ core body temperature monitoring system as described above.

VivoLogic™, a proprietary PC-based software, decrypts and processes recorded data, and provides viewing and reporting features for researchers and clinicians to view the full-disclosure, high-resolution waveforms or look at trends over time. Summary reports can be generated that present processed data in concise, graphical and numeric formats. Data can also be exported in ASCII format for analysis in other software programs.

Subjects were next fitted with a LifeShirt ambulatory monitoring system (VivoMetrics Government Services, Ventura, CA) according to the manufacturer's specifications. Respiratory inductive plethysmograph function of the LS System was subsequently calibrated by asking each subject to re-breath from an 800 ml fixed-volume bag (provided by the manufacturer). After LS calibration, subject body weights were measured using a Scale Tronix® electronic scale (Scale-Tronix Inc., White Plains, NY). Subject height was also measured at this time.

After fitting the LS system and determination of a baseline body weight, subjects were asked to execute the testing and training evolutions, each followed by a minimum of 20 minutes of recovery time. Subject systolic and diastolic blood pressures were measured during the final five minutes of the recovery periods. Real-time telemetry data was monitored during evolutions to allow immediate restoration of function in the event of electrode displacement or equipment damage.

Calibration of the respiratory inductive plethysmograph function of the LifeShirt System

Study participants complete the Harvard Step Test

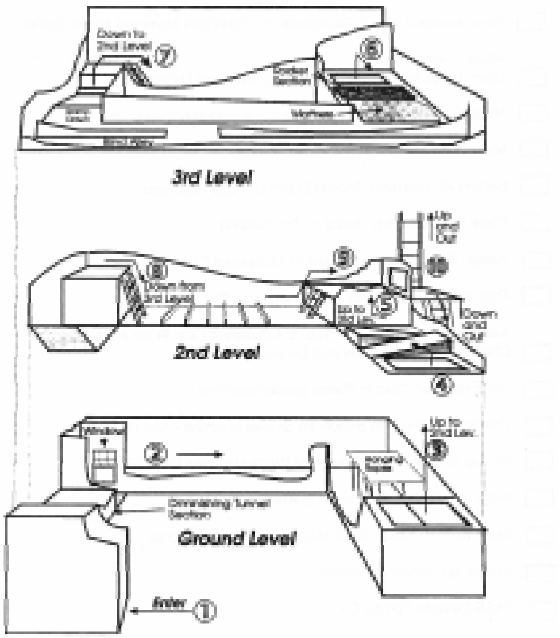
Harvard Step Test

With the LS System employed, subjects were assigned a station for execution of the Harvard Step Test for estimation of aerobic capacity. This test was conducted in a classroom at MFRI with ambient temperature near 78°F. Subjects were instructed to stand quietly in front of the 50.8 cm (20 inch) step box for a two-minute period to establish baseline cardiovascular function. On verbal command, subjects stepped on and off of the step box at a 30 step-cycle per minute pace for a five minute period or until exhaustion. Exhaustion was defined as when the subject could not maintain the stepping rate for 15 seconds. Upon completion of the test, subjects were instructed to sit quietly on the step box for a four-minute period to obtain heart rate recovery data.

Training Evolutions

The Maryland Fire and Rescue Institute strictly adheres to NFPA 1403 as the basis of its firefighter training programs. For example, Chapter 5 of the standard lists the Job Performance Requirements (JPRs) for Firefighter I, the first of two levels of firefighters. MFRI's curriculum and testing for Firefighter I meet, and even exceed, the JPRs listed in Chapter 5. Some of the practical skills stressed in the MFRI curriculum are the use of personal protective equipment and self-contained breathing apparatus and live firefighting. PPE and SCBA training are covered in Sessions 11 and 12 and culminate in the application of these practical skills in the Institute's Breathing Apparatus Training Obstacle Course (Maze). Many times in real-life situations firefighters are called upon to perform duties in hazardous conditions in unfamiliar locations. The ability to effectively operate under such conditions is a key to the health and safety of the firefighter and the overall success of mitigation efforts on the emergency scene. The Maze simulates operating in an unknown environment while wearing full PPE and SCBA so that students become accustomed to operating in these conditions.

Figure 6: Breathing Apparatus Training Obstacle Course (Maze)



Maze Evolution

The Maze evolution used in this study was conducted as a standard firefighter maze training evolution. MFRI's Breathing Apparatus Training Obstacle Course (Maze) building is a three-story facility featuring diminishing clearances, drop-offs, windows, crawl spaces, stairs, and ladders (Figure 6). Although maintained in near total darkness, the facility is designed to simulate a hazardous, low-visibility fireground environment. For training and safety purposes, the facility is equipped with a central monitoring corridor where subjects may be observed continuously. Subjects were staged at the entrance to the Maze wearing PPE and SCBA. Before entering the Maze each subject verified that he/she had sufficient air to complete the evolution. Subjects entered the Maze on command of the safety officer. Subjects then traversed the Maze at their own pace utilizing standard procedures for such an environment. The time required for each subject to traverse the Maze was recorded to the nearest second.

Burn Evolutions

MFRI also maintains a three-story structural firefighting building (Figure 7). The construction of MFRI's burn building has evolved as technology and building materials have progressed. The basic construction is concrete block walls and concrete floors and roof.

Additionally, there are two types of fire resistance provided within the MFRI burn structure. First, a sprayed-on fire resistive material is provided in the burn rooms on the first and second floor. This lining, known as Pre-Krete G-8 (Pocono Fabricators), is a hydraulic calcium aluminate cement that when applied provides thermal protection to the structure. Another type of fire resistance is provided by lining the interior walls of the burn rooms on the third floor with a high temperature protective lining. These protective tiles are manufactured by High Temperature Linings (HTC) and are composed of interlocking refractory tile and encapsulating material. It is designed to withstand repeated high temperature and extreme thermal shock created during fire extinguishment evolutions without spalling, cracking, splintering or other degradation. Evolutions conducted on the first floor are focused on search and rescue while evolutions on the third floor focus on high temperature fire situations.

Operation of hose lines for interior structural attack of fires is presented in Sessions 7, 8, 9 and 10 in the Firefighter I curriculum. Opportunities to apply these practical skills in actual fire conditions are presented in Sessions 18, 31 and 32 of the MFRI Firefighter I curriculum. These sessions are conducted in MFRI's structural fire building. The physical layout of the building enables instructional staff to simulate fires in a countless number of scenarios. However, the specific scenarios for Firefighter I are detailed in the curriculum.

In addition to NFPA 1001, NFPA publishes a host of other standards and recommended practices that affect firefighter training. In the interests of safety and providing state-of-the-art training MFRI's programs and all of the evolutions used during this study are presented in compliance with these standards and recommended practices. Among the applicable standards and recommended practices are:

- *NFPA 1402, Guide to Building Fire Service Training Centers, that contains the minimum requirements for training fire suppression personnel engaged in firefighting operations under live conditions*
- *NFPA 1403, Standard on Live Fire Training Evolutions, that contains the minimum requirements for training fire suppression personnel engaged in firefighting operations under live fire conditions*
- *NFPA 1404, Standard for Fire Service Respiratory Protection Training, that contains the minimum requirements for training fire suppression personnel engaged in firefighting operations under live fire conditions*
- *NFPA 1584, Recommended Practice on the Rehabilitation of Members Operating at Incident Scene Operations and Training Exercises, that contains the minimum level criteria for developing and implementing a rehabilitation process for fire department members at incident scene operations and training exercises*

Study participants pull a hose line from the fire engine

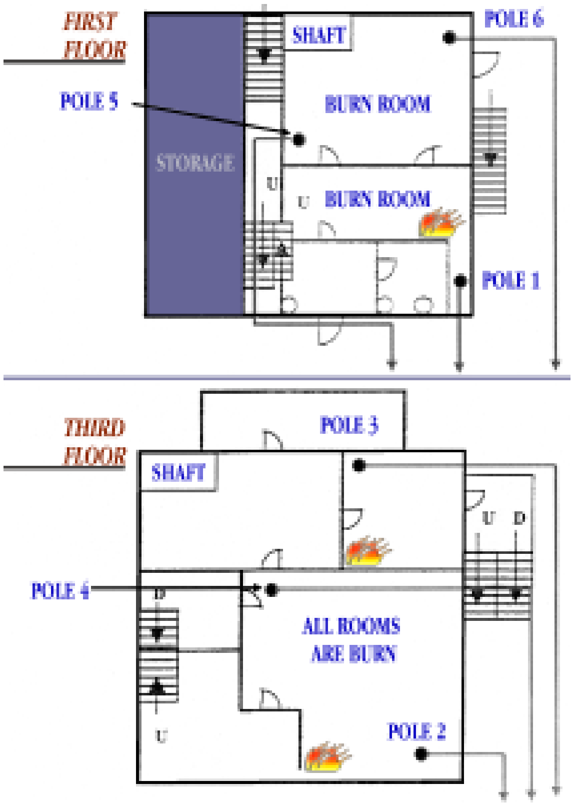
Each burn evolution consisted of two four-person hose teams in full personal protective equipment and wearing self-contained breathing apparatus advancing hose lines to, and extinguishing fires on both the third and first floor of the burn building. Each hose team consisted of a nozzle person controlling water flow from the hose, an officer in command of the hose team, and a backup person and control person to aid in advancing the hose line and executing search and rescue operations. All firefighting activity within evolutions started with hose teams staged at the back of a fire engine positioned approximately fifty feet from the north side of the burn building.

A MFRI instructor prepares the wooden pallets and excelsior wood fibers for the burn evolutions.

Three wooden pallets and 1/2 bale of Excelsior Wood Fibers fueled fires used in burn evolutions. Wooden pallets are made of untreated, uncontaminated wood. Each pallet is 48x40x5 inches. The mean weight of the three pallet combination was 47kg. The range of weights was 41 kg. - 54 kg. The range of moisture content was 8% to 11%. The Excelsior Wood Fibers are composed of uncontaminated wood fibers that are biodegradable. These are obtained from the Stark Company. One bale measures 18x14x36 inches; therefore the 1/2 bales used in this study were 18x14x18 inches. The average weight of product used in each burn was 31 kg. All fires in the study were extinguished applying a 30-degree fog pattern to the ceiling area, rotating the pattern clockwise onto the burning material until fire was extinguished using 1.5 inch Elkhart Brass, Chief, variable fog nozzles (model# 4000-24).

Burn evolutions started with the third-floor burn. The fire was located in the small room identified in Figure 7. Auxiliary fires located adjacent to the fire room were used to generate smoke and to insure limited visibility inside the structure. The location of these auxiliary fires is also identified in Figure 7.

Figure 7: Structural Firefighting Building



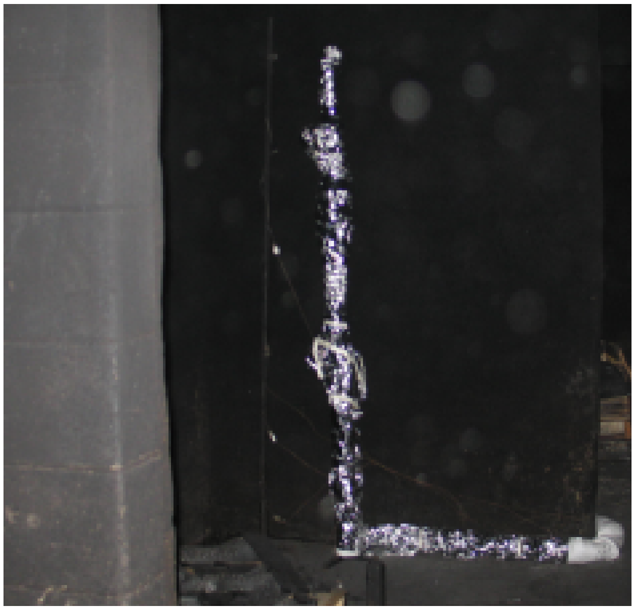

A study participant advances the hose line up stairwell

Hose teams pulled and extended a 200-foot hose line from the engine and advanced the line up an exterior stairwell to a second-floor door. Once the hose team was positioned at the door (and on command from the safety officer), the hose line was charged (filled with water) and the team entered the burn building. The hose line was then advanced up an interior stairwell to gain access to the third floor. Once staged on the third floor, the team advanced the hose line to the burn room. The nozzle person and officer entered the burn room and took up positions approximately five feet and ten feet respectively from the fire. The backup team member remained at the burn room doorway while the control individual took up a position in the room adjacent to the burn room. After establishing their positions, team members were asked to maintain position for a period of four minutes to provide a period of heat exposure. At the end of the heat exposure period, team members extinguished the fire and exited the burn room, and finally the burn building.

Immediately after the third-floor hose team exited the building, the first-floor hose evolution began. Hose teams pulled and


Study participants prepare to enter the first-floor burn evolution

extended a 150-foot hose from the engine and advanced the line to a first-floor exterior door of the burn building. Once the hose team was in position (and on command from the safety officer), the hose team entered the burn building and advanced the line toward the burn room. After staging in an adjacent room, the hose team entered the burn room and extinguished the fire. Subsequently, backup and control individuals entered the burn room and began a search and rescue operation to locate a simulated victim. The rescue mannikin, Rescue Randy (Laerdal), is 60 inches tall and weighs 145 lbs. Once the mannikin was located, it was dragged from the burn room and out of the burn building. The team then exited the burn room and finally the burn building.



Flux gauges in the third floor burn room

The third hose team (of each burn evolution) served as a Rapid Intervention Team (RIT) for the operation. RIT teams remained outside the burn building in full turnout gear and wearing breathing apparatus. In addition to its safety function, this team served as an experimental control measure. Each hose team rotated through third-floor and first-floor burns. A burn evolution was complete when the last member of the first-floor hose team exited the burn building.

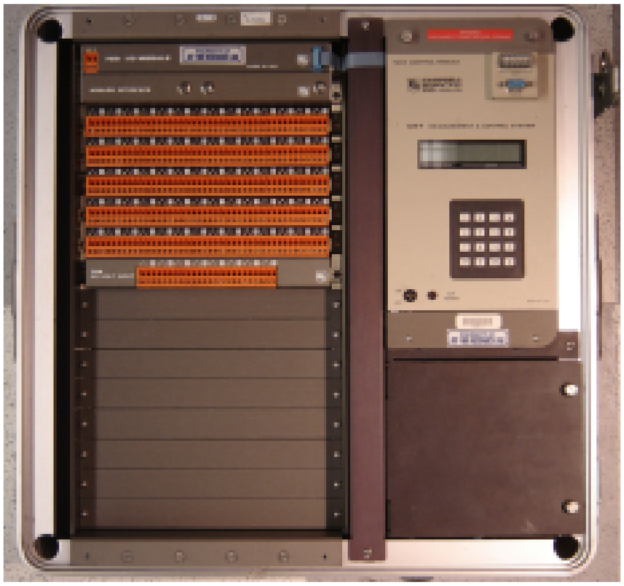
Ambient environmental conditions outside the burn building including air temperature, relative humidity, and heat index were measured prior to each evolution of the day. The Maryland Fire and Rescue Institute Policy and Procedure for weather conditions was used to determine the safety of conducting testing each day.

Instrumentation Layout

The instrumentation of the structural burn building consists of temperature sensors at various locations and flux sensors in the burn room on the third floor. The temperature was monitored at three different locations on the first and third floors as shown in Figure 7. At each location a six-sensor rake is mounted on a post to provide a vertical temperature distribution at that location. The sensors were distributed along the height of the post from the floor to the ceiling. The temperature sensors used were K thermocouples manufactured by OMEGA.

Two flux gauges were supplied and installed by the National Institute of Science and Technology (NIST) in the third- floor burn room. A separate post holding the flux gauges was installed. The two gauges were aimed horizontally at the fire at elevations of one and two feet from the floor. The gauges were water-cooled and were protected with insulation and aluminum foil except for the sensing surface.

The thirty-six thermocouples and the two flux gauges were connected to a data acquisition system. The system, manufactured by Campbell Scientific, Inc (Logan, Utah), was provided to the Fire Protection Engineering Department by the Fire Laboratory of Alcohol, Tobacco and Firearms (ATF) located in Greenbelt, MD.



Data Logger CR-7 Campbell Scientific, Inc., Logan, Utah (photo courtesy of ATF)

RESULTS AND DISCUSSION

This study has generated an unprecedented data-set describing the physiology of firefighters undergoing standardized training activities, in full gear, while operating as part of a team. The initial analysis of the data has been intended to describe the subject population, the response of the participants to the various training evolutions, and the relationships among the measurements. The primary objective of this analysis is the generation of an easily managed set of guidelines to assist field fire service management in identifying those team members who may warrant attention in on-site resource management.

Overview

This study was conduced to achieve the primary objective of providing the fire service with more and better data regarding the physiologic stress experienced by firefighters during their work. The manifestation of this data will be a better understanding of the normal ranges of physiologic response than has previously been available. From this knowledge it will be possible for on-site field managers to identify team members who are displaying physiologic responses that are outside of the normal range and actively attend to their status. The result of this study is a set of guidelines for monitoring firefighters during training activities. With time and experience, this set of general guidelines can be modified to reflect individual differences among members of a fire crew, resulting in a personalized file for each individual that can direct firefighter utilization and rest schedules as well as providing insights into training and hydration needs for each individual. Utilizing detailed, real-time physiologic monitoring and management of firefighters during training will provide a basis for utilizing this sort of information for decision making on the fireground. The combination of these various factors – guided monitoring, indicators of fitness, and indicators of hydration status provide field fire team management an unprecedented opportunity to effectively manage available resources for performance and safety.

Study Summary

Data were collected during standardized assessments and real training exercises conducted at the Maryland Fire and Rescue Institute. Standardized assessments were an analysis of urine specific gravity to provide an objective indication of hydration status and the Harvard Step Test which is a commonly used sub-maximal estimation of fitness level. Fire training involved one situational rest period where the resting team waited quietly in full turnout gear (including self contained breathing apparatus) as a rapid intervention team, and three working evolutions (Maze and first-and third-floor burn evolutions). During the testing subjects wore the LifeShirt System, an ambulatory physiologic monitor that collects respiratory, cardiac, and activity data via sensors embedded in a comfortable garment, and for this study also included a skin temperature sensor and a receiver unit to pick up signals sent from an ingestible core temperature probe. Data were written to removable flash memory in high resolution waveforms and subsequently analyzed and reduced to provide the results reported presently.

Subjects reported a positive experience while wearing the LifeShirt and the data quality was quite good overall. There was some ECG data loss due to electrode detachment due to sweat, and it was, at times, difficult to acquire a stable signal from the ingested core temperature or pulse oximetry sensors. The temperature sensor data was likely impacted by the orientation of the sensor's radio transmitter that changed as the sensor made transit through the gut of the subject. There was minimal equipment damage associated with the data collection, and this happened almost entirely during the maze evolution and was the result of extreme pressure on cable connection points as subjects navigated "squeeze points" and wall crossings.

Subjects

Age and Morphometry

A total of 208 subjects participated in this study. The subjects ranged in age from 21 to 55 years of age with an overall mean age of 31 years. The age distribution was normal if slightly skewed towards the younger segment of the population (Figure 8). Over half of the subject pool were between 20 and 30 years old (54.5%), 30.7% were between 31 and 40 years old, and the balance were over 40 years old (Figure 9). Male subjects comprised 93.2% of the subject group.

Figure 8: Age Distribution Histogram

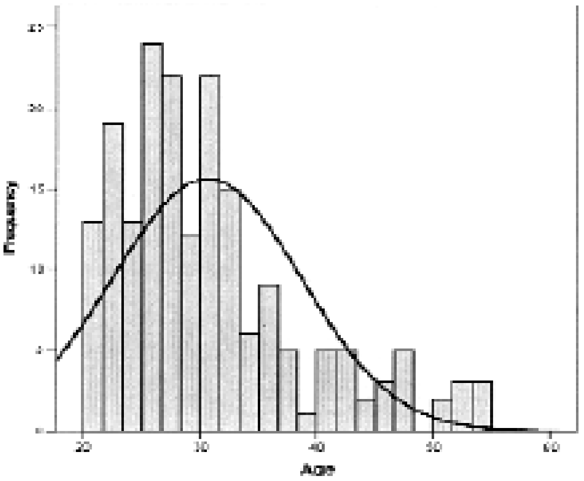
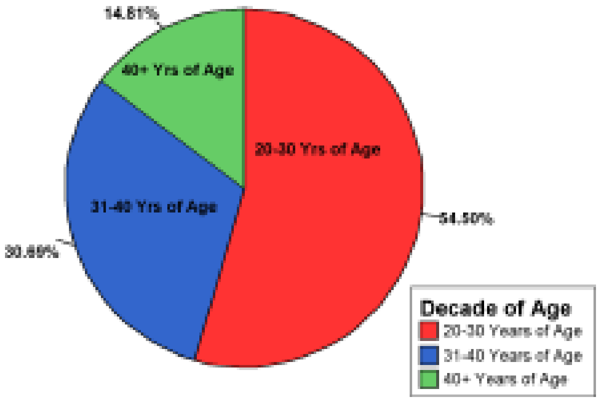


Figure 9: Age Distribution as Portion of Studied Population



Subjects were morphometrically similar to the standard US population for age and gender matched individuals (McDowell, et al., 2005). Male firefighters tended to be heavier with slightly higher BMI compared to the standard US population. However, this trend was reversed for female firefighters, who tended to weigh slightly less with similar BMI.

Table 4: Population Morphometry

Descriptor	N	Studied Firefighter Group *(mean ± S.D.)*
Age (yrs)	190	31.0 ± 8.0
Height (in)	190	70.0 ± 3.0
Weight (lbs)	190	198.6 ± 34.5
BMI	190	28.0 ± 4.7
Years of Service	190	10.0 ±8.0

Table 5: Male Firefighters 20 – 29 years of age

Descriptor	N	Studied Group *(mean ± S.D.)*	U.S. Male Population *(mean ± S.D.*
Height (in)	94	70.6 ± 3.0	69.6 ± 0.11
Weight (lbs)	94	198.5 ± 34.0	183.8 ± 1.55
BMI	94	27.7 ± 5.3	26.6 ± 0.19
Years of Service	94	6.6 ± 3.3	N/A

Table 6: Male Firefighters 30 – 39 years of age

Descriptor	N	Studied Group *(mean ± S.D.)*	U.S. Male Population *(mean ± S.D.*
Height (in)	54	70.3 ± 3.3	69.5 ± 10.0
Weight (lbs)	54	202.1 ± 35.3	189.5 ± 1.99
BMI	54	28.7 ± 3.98	27.5 ± 0.26
Years of Service	54	11.9 ± 5.0	N/A

Table 7: Male Firefighters 40+ years of age

Descriptor	N	Studied Group *(mean ± S.D.)*	U.S. Male Population *(mean ± S.D.*
Height (in)	27	70.8 ± 3.1	69.6 ± 0.13
Weight (lbs)	27	211.5 ± 26.3	196.1 ± 1.84
BMI	27	29.8 ± 3.6	28.5 ± 0.26
Years of Service	27	20.7 ± 11.7	N/A

Table 8: Female Firefighters 20 – 29 years of age

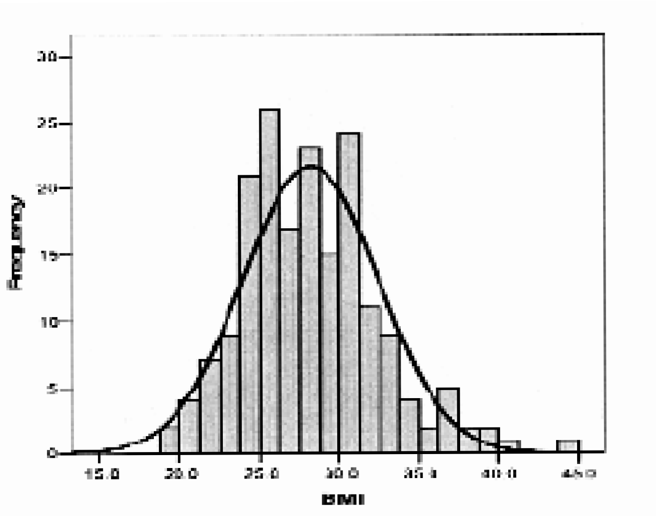
Descriptor	N	Studied Group *(mean ± S.D.)*	U.S. Female Population *(mean ± S.D.*
Height (in)	8	68.6 ± 2.5	64.1 ± 0.64
Weight (lbs)	8	153.8 ± 18.2	156.8 ± 1.98
BMI	8	23.1 ± 3.5	26.8 ± 0.29
Years of Service	8	5.8 ± 3.4	N/A

Table 9: Female Firefighters 30+ years of age

Descriptor	N	Studied Group *(mean ± S.D.)*	U.S. Female Population *(mean ± S.D.*
Height (in)	5	64.9 ± 0.9	64.2 ± 0.11
Weight (lbs)	5	161.4 ± 16.7	163.4 ± 2.0
BMI	5	27.0 ± 2.9	27.9 ± 0.33
Years of Service	5	10.0 ± 2.9	N/A

The implication of the weight and BMI differences is not clear. There are at least two viable explanation: male firefighters tend to be slightly less fit/more obese than the general population or more muscular, resulting in a larger weight-to-height ratio and thus a larger BMI. For women, it is most likely the case that the women are more fit than their non-firefighter counterparts are and this fitness is manifested in a leaner physique. Overall BMI is relatively high for the studied population (Figure 10). Although there were a number of subjects who were very muscular, many were carrying excess body fat. This may account for the high mean values for BMI.

Figure 10: BMI Histogram



Career vs. Volunteer Service

Approximately 60% of the subject pool were classified as career firefighters versus volunteer. Career and volunteer firefighters were similar in age, height, and years of experience while volunteers tended to have higher body weights and body mass index (BMI) values compared to career firefighters (Table 10 and 11).

Table 10: Career Firefighters

Descriptor	N	Mean	Standard Deviation
Age (yrs)	114	31.0	7.0
Height (in)	114	70.0	3.0
Weight (lbs)	114	193.1	30.3
BMI	114	27.6	4.4
Years of Service	114	11.0	7.0

Table 11: Volunteer Firefighters

Descriptor	N	Mean	Standard Deviation
Age (yrs)	67	30.0	10.0
Height (in)	67	71.0	3.0
Weight (lbs)	67	206.5	39.5
BMI	67	28.8	5.1
Years of Service	67	10.0	7.0

Fitness Level Determination

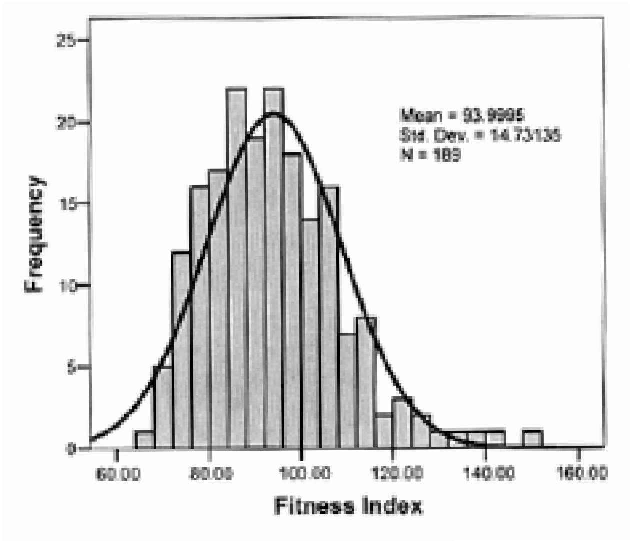
A fitness level (index) was determined for each studied subject using the Harvard Step Test (Brouha, 1942). Heart rate data is recorded for 3.5 minutes after the completion of the test. Recovery heart rate data is used in the following equation to determine the Fitness Index (FI):

$$\text{F.I.} = \frac{(\text{Duration of Exercise x } 100)}{(2 \text{ x Sum Recovery Heart Beats})}$$

Where: Sum Recovery Heart Beats = (heart beats 1-1.5 minutes of recovery) + (heart beats 2-2.5 minutes of recovery) + (heart beats 3-3.5 minutes of recovery)

The fitness index of the subject group as quantified with the Harvard Step Test was normally distributed around a mean of 94.0±14.7 (Figure 11). The original Harvard Step Test study (Brouha, 1942) indicates that a fitness index less than 55 is indicative of poor physical fitness, an index between 55 and 64 low-average fitness, an index between 65 and 79 high-average fitness, an index between 80 and 89 good fitness , and an index above 90 of excellent physical fitness.

Figure 11: Fitness Index Histogram



This index value for the study population indicates that the participants were in excellent fitness. This result from the Harvard Step Test is in contrast to the observations of the research team who noted that many subjects appeared to be relatively unfit.

Previous published criticism of the Harvard Step Test have reported an overestimation of fitness, especially in young men (Davies, 1968, Bonen, 1975, Francis, & Brasher, 1992). Therefore, it is not reasonable to consider the fitness level determined by application of Brouha's scale accurate. Regardless of the accuracy of individually determined fitness levels, the differences in these indices are representative of differences in fitness among studied individuals.

For the purposes of analysis, the Harvard Step Test results were treated as an indicator of relative fitness within the study cohort, but not an accurate estimate of actual VO_2max. It would be a reasonable expectation for the firefighter population to be significantly more fit than the general population given the strenuous nature of the occupation and the inherent risks associated with fatigue during work. The severe potential penalties associated with a lack of sufficient fitness to respond to the objective challenges of fighting fires should serve as motivation for individuals and firefighting teams to develop and maintain the highest level of fitness possible. Subsequent analyses of the data collected as part of this study will be intended to provide guidance into the nature of training most appropriate for the stress of fighting fires.

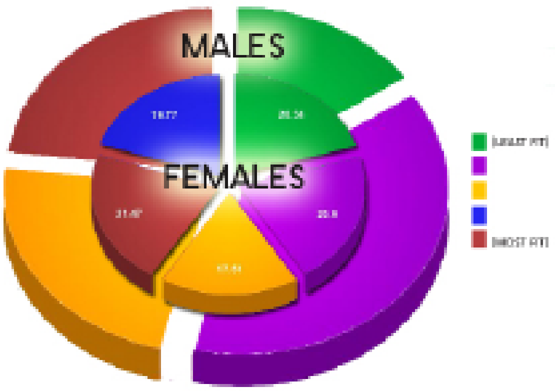
Fitness index was distributed normally within male (mean = 94.2 ± 14.2) and female (mean = 90.8 ± 21.6) subjects. The male mean is slightly higher compared to the females. However, this should be interpreted cautiously considering the substantial difference in group size. Given the small number of female subjects within the population and the similar fitness index across genders, the subject group was analyzed in its entirety, i.e. not separated based on gender.

Figure 12 indicates that a quintile distribution of subjects results includes a single quintile (#3) devoid of male subjects. This distribution anomaly was generated as a result of the similarity of fitness within a small female subject group. However, the small group of female subjects did not permit subsequent analysis within gender populations. Therefore, all subjects were included in fitness-associated analysis regardless of gender.

Table 12: Generation of Fitness Index Quintile

N	Valid Missing	189 1
Mean		93.9995
Std. Deviation		14.73135
Minimum		67.90
Maximum		148.40
Percentiles	20	81.3000
	40	89.3000
	60	95.7000
	80	105.6000

Figure 12: Fitness Quintile Distribution by Gender



Hydration Status

Urine specific gravity (USG) has been shown to be a valid measure of hydration status. USG values reflect the concentration of salts and other non-water elements of urine and can be used to validly infer the relative volume of water in the plasma and intracellular compartment. While USG typically ranges from approximately 1.002 to 1.030, a value of 1.010 is indicative of a euhydrated state while values less than 1.020 indicate adequate hydration (Armstrong, et al., 1994). In practice, athletes demonstrating USG measures greater than 1.020 are considered to be dehydrated. If applied to the studied firefighter group, only hydration group 1 was optimally hydrated (euhydrated) with portions of group 2 being adequately hydrated.

Being sufficiently hydrated is widely recognized as an important requirement for optimal physical performance during exercise and sport. It was therefore somewhat surprising to find that less than 10% of the participants (n = 31) were euhydrated as indicated by a urine specific gravity of 1.02 or less. The balance of subjects for whom hydration status was determined (n = 152) were dehydrated prior to beginning their training day. It is worth noting that the majority of this testing took place during the mid-to-late summer in Maryland, an environment that is known to be extremely hot and humid. Common sense dictates that firefighters should not be performing their job duties involving significant physical stress in high-heat, high-humidity macro- and micro-environments when dehydrated. The metabolic work and environmental stressors associated with firefighting make dehydration, heat stress, and heat injury a very real possibility and firefighters should make every effort to ensure that they are sufficiently hydrated at all times to provide the greatest "fluid-bank" to support sweating and cardiovascular function during extreme situations.

The physiologic responses observed relative to hydration suggest a threshold-like effect, wherein subjects were sufficiently hydrated or not. Those subjects who were euhydrated had more measured physiologic responses to work than subjects who were dehydrated.

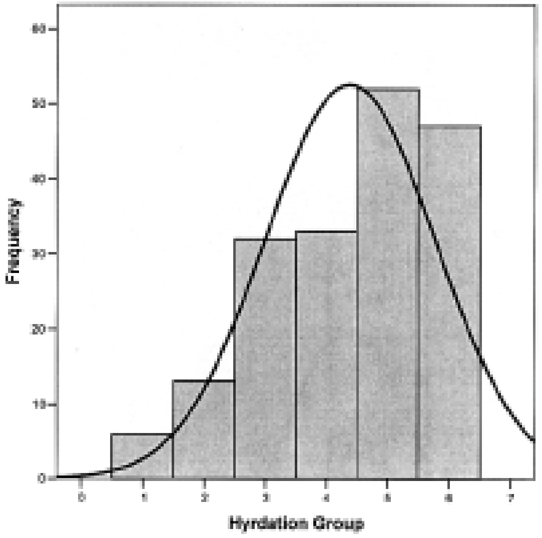
However, within the dehydrated subject population the most dehydrated subjects were not necessarily more taxed than the least dehydrated. There are several possible explanations for this observation. It is possible that the physiologic responses appeared similar because the most dehydrated subjects were limited in their capacity for work and the physiologic responses reflected effectively maximal responses across subjects. An alternate explanation is that there is a cardiovascular threshold that marks a switch point in fluid management and physiologic response to work. Finally, given the relatively small number of subjects in the dehydration subgroups it is possible that there is, in fact, a "dose-response" to dehydration level that this study was simply underpowered to reveal.

A frequency distribution analysis of USG values established six distinct groups of hydration levels within the studied population as shown in Table 13.

Table 13: Urine Specific Gravity

N	Valid	183
	Missing	7
Mean		1.02497
Std. Deviation		.007157
Minimum		1.004
Maximum		1.038
Percentiles	16.67	1.01700
	33.33	1.02200
	50	1.02600
	66.67	1.02900
	83.33	1.03200

Figure 13: Hydration Groups Distribution Histogram



Training Evolutions

This data-set provides an opportunity to evaluate the relative physiologic stresses associated with the standard evolutions used in training firefighters. It is interesting to note that in terms of physiologic stress, the working evolutions were very similar. It may have been reasonable to assume a-priori that the third floor burn would have required the greatest physiological output because of the stair-climb with hose and heat exposure. However, when the working evolutions are compared to one another, the maze evolution was associated with greater amounts of movement and a number of larger respiratory responses than were observed during the burn evolutions. There was no difference among the working evolutions in measures of heart rate or relative heart rate suggesting that the physiologic stresses were similar in all three evolutions. The disorientation, near blindness, and physical challenges associated with the maze evolution may have resulted in anxiety and emotional stress in the subjects. This sort of stress manifests in altered breathing patterns characterized by rapid shallow breathing and may have caused the increased ventilatory volumes observed during the maze evolution. This observation is supported by the fact that those subjects in the oldest age group displayed the smallest ventilatory volumes in all evolutions. It is reasonable to infer that the oldest subject group also had the most experience would have had the capacity to remain the most "calm" under the stresses of the evolutions in general, and particularly during the disorientation and confusion associated with the maze.

Overall Descriptive Statistics

Tukey Post-Hoc Test were utilized to determine differences among evolutions for each variable. For all measured variables, values were significantly lower during the RIT evolution as compared to all three working evolutions.

When considered in units of rest (as a function of RIT stress level), the maze evolution appears to have been more physically demanding than either of the two burn evolutions. All physiologic values were significantly higher during the maze evolution compared to the first-floor burn, but when compared to the third-floor burn the differences did not reach statistical significance (Figure 14-19).

Figure 14: Physical Movement/RIT

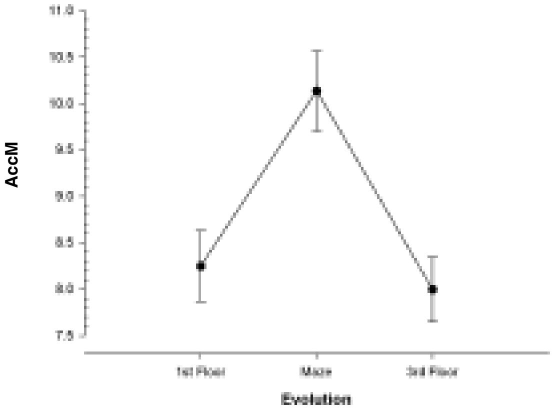


Figure 15: Tidal Volume/RIT

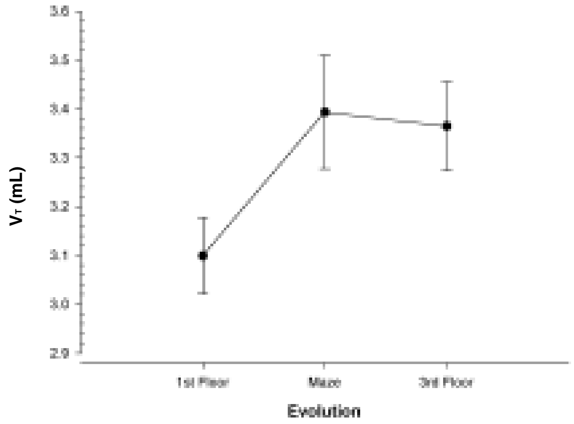


Figure 16: Minute Ventilation/RIT

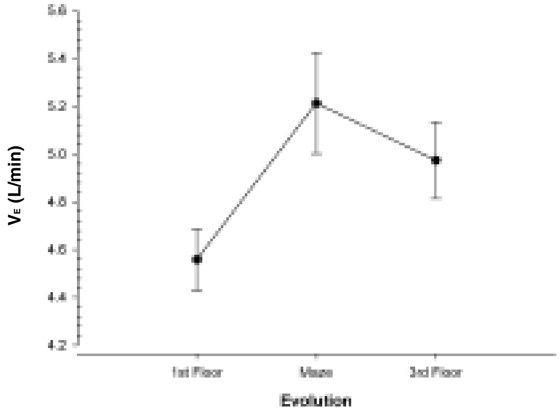


Figure 17: Breathing Frequency/RIT

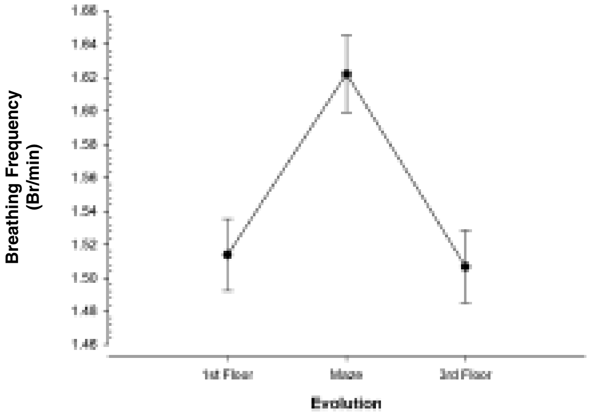


Figure 18: Inspired Air Flow/RIT

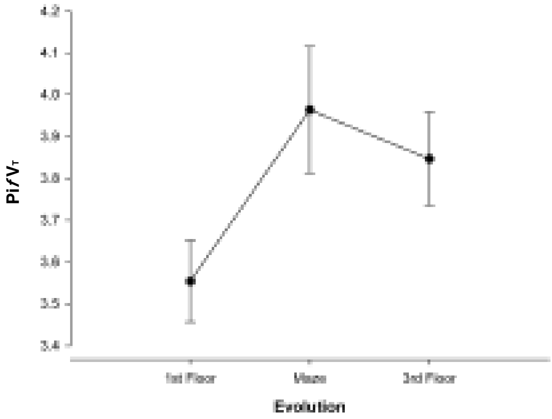
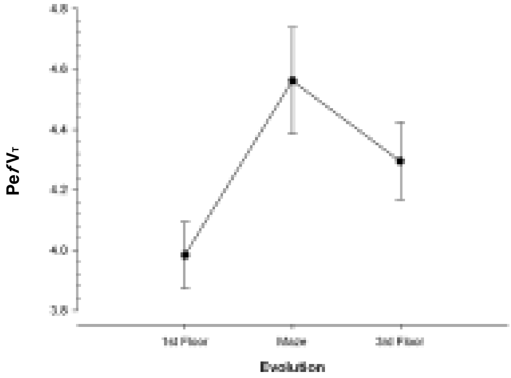


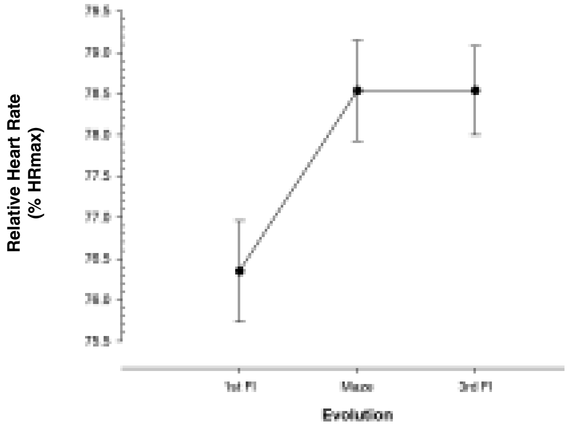
Figure 19: Expired Air Flow/RIT



Removing the RIT values from the statistical analysis allows the comparison of the working evolutions without the variance associated with including a categorically different evolution in the analysis.

Differences in relative heart rate (percentage of age-predicted maximal heart rate) between the first-floor evolution and the third-floor evolution were not detected with the RIT evolution included. When RIT was removed, it is apparent that the maze and third-floor burn evolutions required a higher relative heart rate than the first-floor burn (Figure 20).

Figure 20: Relative Heart Rate

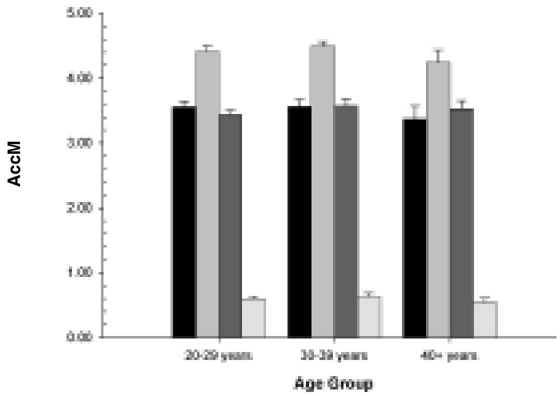


Effects of Age on Physical Performance

• *Physical Activity*

Physical Activity determined from the sum of movement in all three accelerometer axes (AccM) was significantly lower during the RIT evolution compared to all three working evolutions in all age groups. Physical activity was higher in the maze evolution compared to all other evolutions in all age groups. Physical activity did not differ significantly between the two burn evolutions (Figure 21).

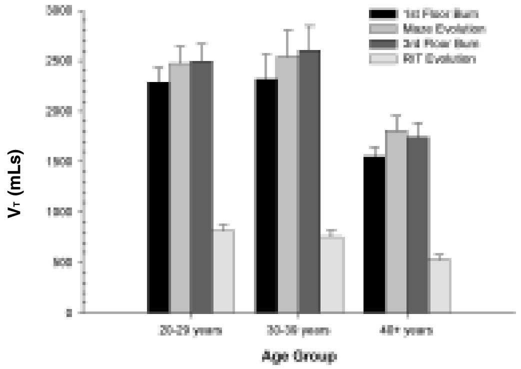
Figure 21: Physical Activity



• *Tidal Volume*

Tidal Volume (V_T) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Tidal Volume did not differ significantly among the three working evolutions (Figure 22).

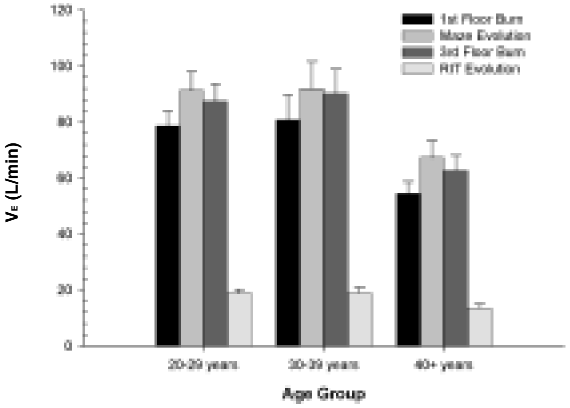
Figure 22: Tidal Volume



• *Minute Ventilation*

Minute Ventilation (V_E) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Minute Ventilation did not differ significantly among the three working evolutions (Figure 23).

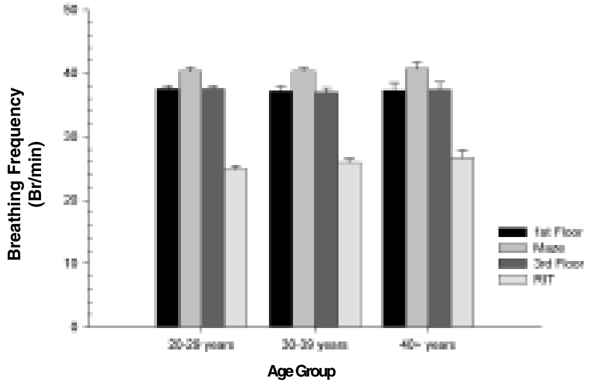
Figure 23: Minute Ventilation



• *Breathing Frequency*

Breathing frequency (Br/M) was significantly lower during the RIT evolution compared to all three working evolutions in all age groups. Breathing Frequency did not significantly differ among the three working evolutions.(Figure 24).

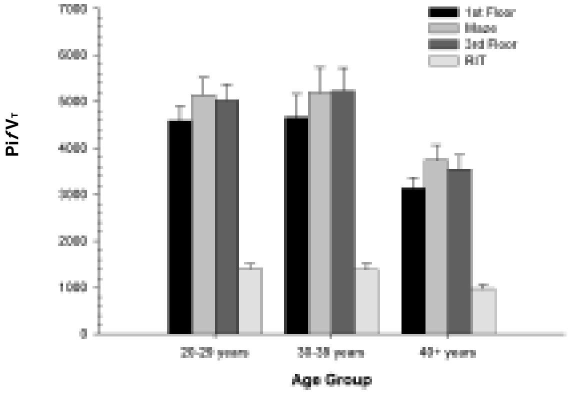
Figure 24: Breathing Frequency



• *Inspired Air Flow*

Inspired air flow ($PifV_T$) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Inspired air flow did not significantly differ among the three working evolutions.(Figure 25).

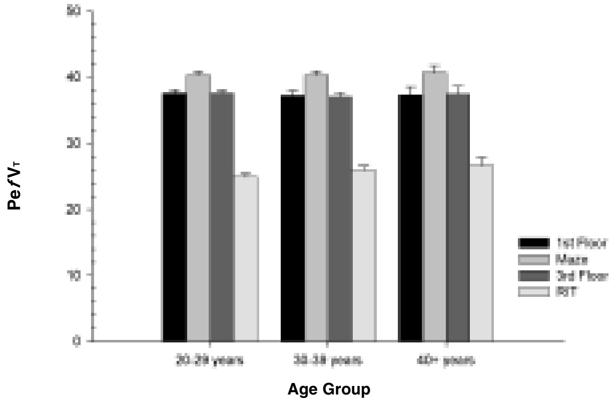
Figure 25: Inspired Air Flow



•Expired Air Flow

Expired air flow ($PefV_T$) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Expired air flow did not significantly differ among the three working evolutions (Figure 26).

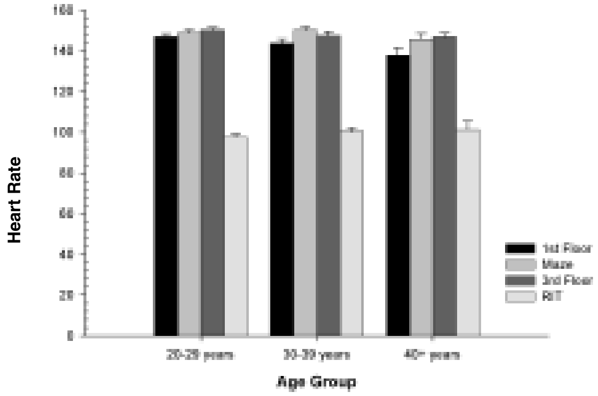
Figure 26: Expired Air Flow



• Heart Rate

Heart rate (HR) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Heart rate did not significantly differ among the three working evolutions (Figure 27).

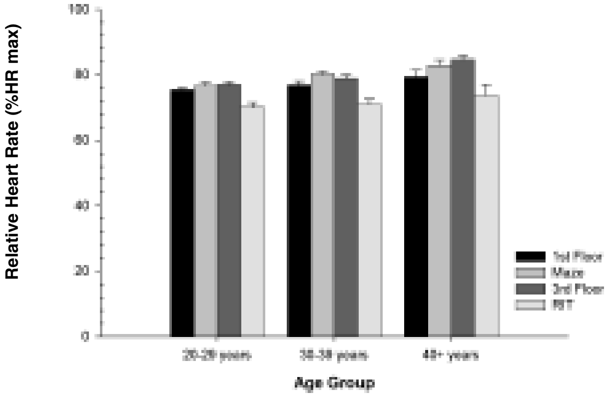
Figure 27: Heart Rate



• Relative Heart Rate

Relative heart rate (percentage of age-predicted maximal heart rate) was significantly lower during the RIT evolution compared to all three working evolutions for all age groups. Relative heart rate did not significantly differ among the three working evolutions (Figure 28).

Figure 28: Relative Heart Rate

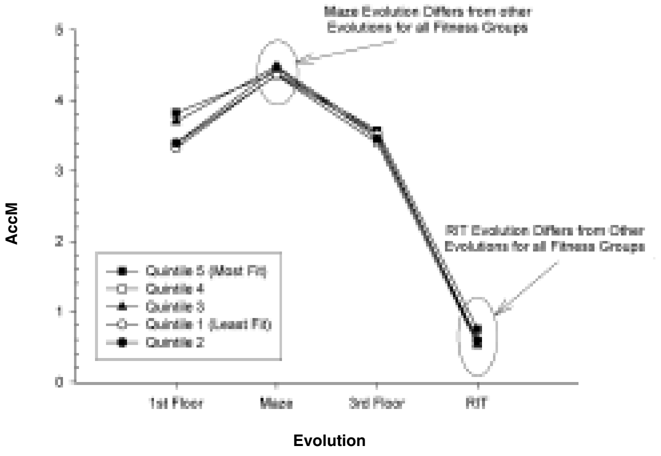


Effects of Fitness Level on Physical Performance

• Physical Activity

The maze evolution required the greatest amount of physical activity among all working evolutions across all fitness quintiles. Physical activity was significantly lower during the RIT evolution compared to all other evolutions (Figure 29).

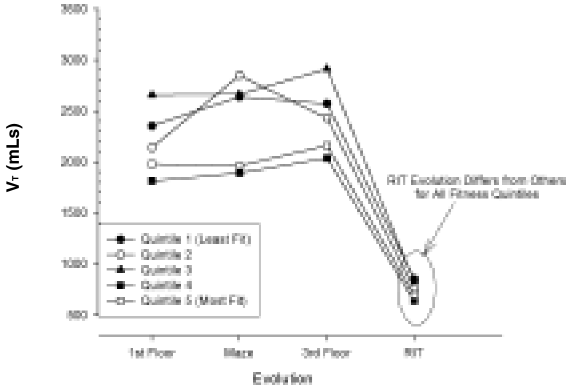
Figure 29: Physical Activity



• *Tidal Volume*

Tidal volume (V_T) was significantly lower during the RIT evolution compared to all working evolutions across all fitness groups (Figure 30).

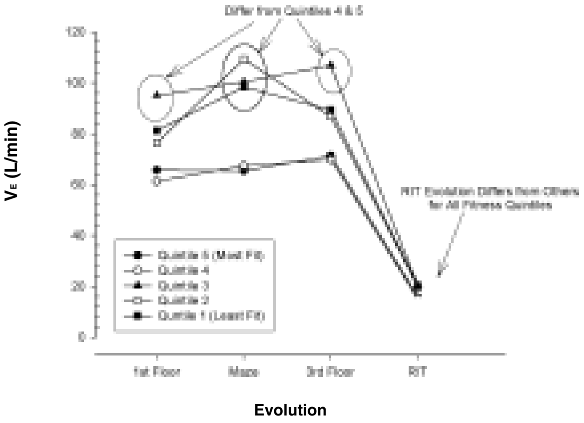
Figure 30: Tidal Volume



• *Minute Ventilation*

Minute Ventilation (V_E) was significantly lower during the RIT evolution compared to all working evolutions across all fitness quintiles. During all working evolutions, lower levels of minute ventilation were observed in the most-fit individuals (Quintiles 4 and 5) compared to all other fitness groups (Figure 31).

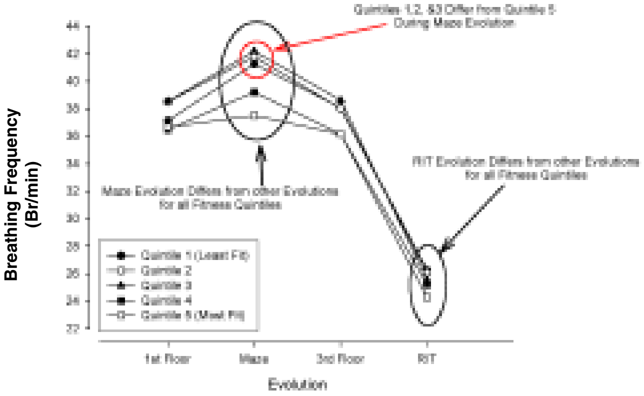
Figure 31: Minute Ventilation



• *Breathing Frequency*

Breathing frequency (Br/M) was significantly higher during the maze evolution compared to all working evolutions across all fitness groups. Breathing frequency was significantly lower during the RIT evolution compared to all three working evolutions. Breathing frequency was significantly lower in Fitness Quintile 5 compared to Quintiles 1, 2 and 3 during the maze evolution (Figure 32).

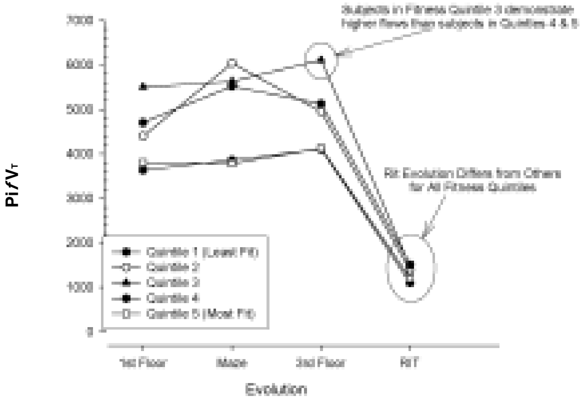
Figure 32: Breathing Frequency



• *Inspired Air Flow*

Inspired air flow (PifV_T) was significantly lower during thr RIT evolution compared to all working evolutions across all fitness groups. Although inspired air flow rates appear lower for the more fit groups, only Quintile 3 demonstrated a significantly higher inspired air flow during the third floor evolution compared to other fitness groups (Figure 33). It should be noted that Quintile 3 contained only female subjects.

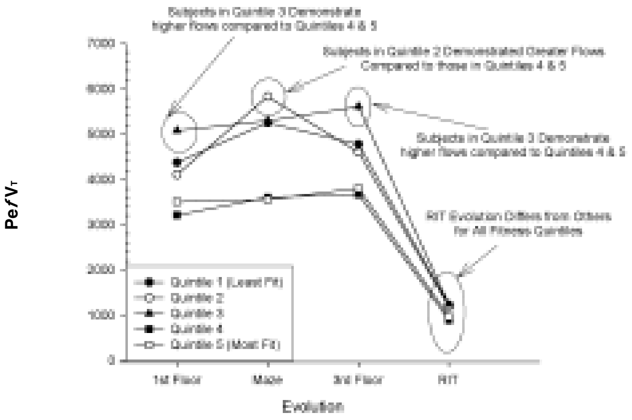
Figure 33: Inspired Air Flow



- ***Expired Air Flow***

Expiratory air flow (PefV_T) was significantly lower during the RIT evolution compared to all working evolutions for all fitness groups. Fitness Quintiles 2 and 3 demonstrated higher expired air flow compared to the more fit groups (Quintiles 4 and 5) during all working evolutions (Figure 34).

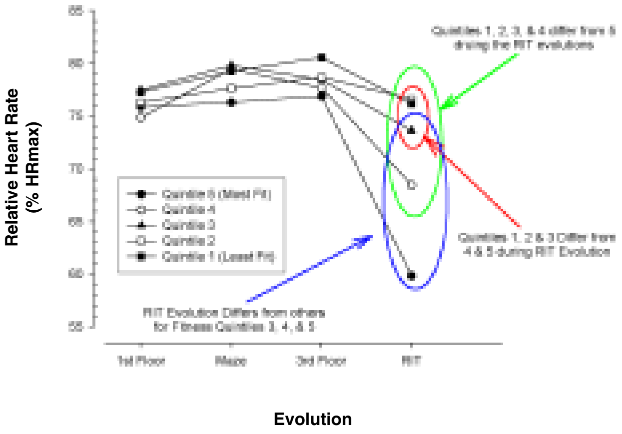
Figure 34: Expired Air Flow



- ***Relative Heart Rate***

Relative heart rate was significantly lower during the RIT evolution compared to all working evolutions within Fitness Quintiles 3, 4, and 5 (Figure 35). Relative heart rate was significantly lower in the most fit individuals (Quintiles 4 and 5) compared to all other fitness groups during the RIT evolution.

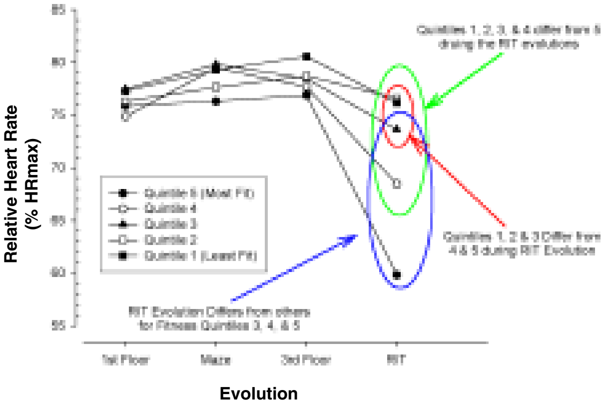
Figure 35: Relative Heart Rate



Effects of Hydration on Physiological Performance

Following the Tukey post-hoc analysis, Hydration Group 1 had a significantly lower relative heart rate response (% HRmax) to both burn evolutions compared to all other hydration groups. Relative heart rate did not differ significantly among the other hydration groups (Figure 36).

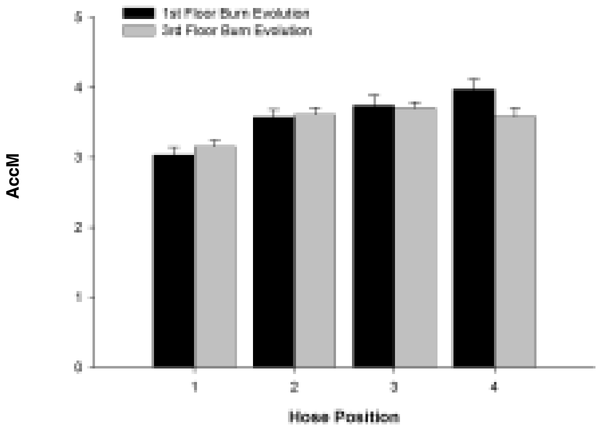
Figure 36: Relative Heart Rate



Effects of Hose Line Position on Physiological Performance

Physical Activity (AccM) was significantly lower for the firefighter controlling the hose nozzle (Hose Position 1) compared to all other positions on the hose line (Figure 37).

Figure 37: Physical Activity



Ambient Environmental Data

Time of Day

During each day of testing, ambient air temperature and heat index rose steadily through the final hour of testing (Figures 38-40). Heat stress was fairly constant during the first 7 to 9 days of testing. Peak heat stress occurred on day 11 while the lowest heat stress occurred during the final week of testing (days 16 through 19). The weather on days 16 through 19 was overcast and rainy (Figure 41).

Figure 38: Air Temperature

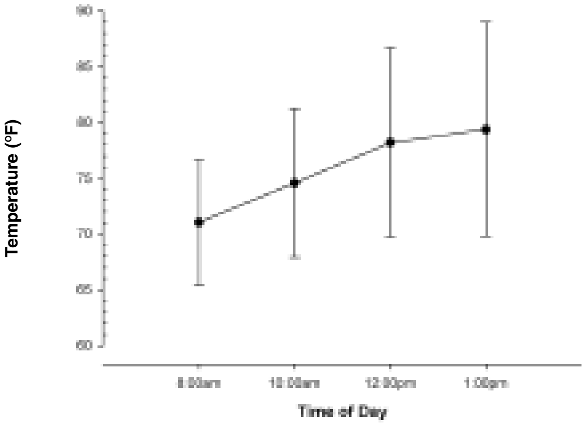


Figure 39: Relative Humidity

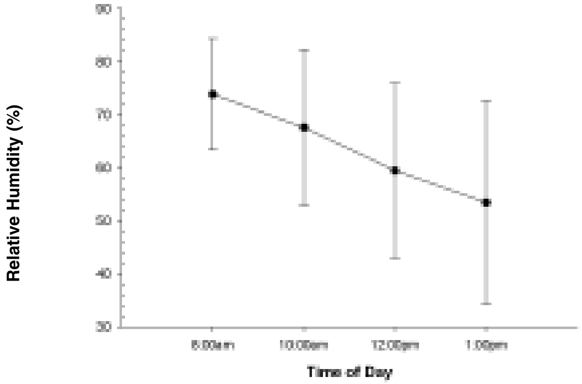


Figure 40: Heat Index

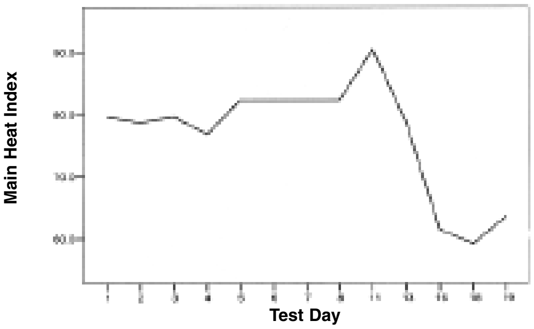
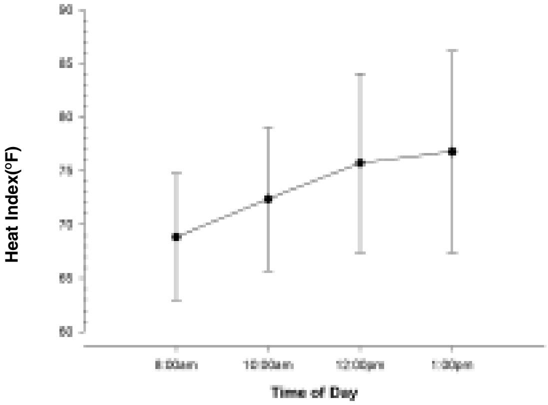


Figure 41: Heat Index Across Test Days

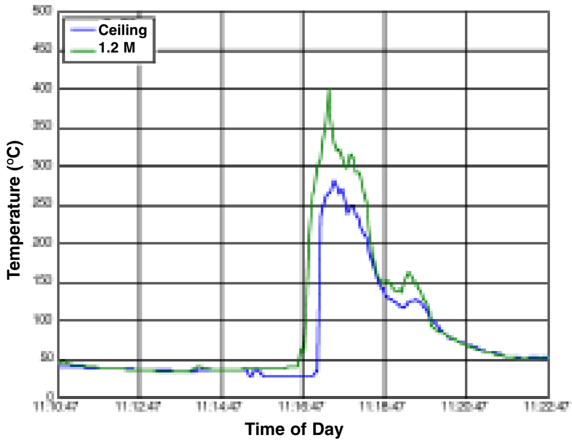


Temperature and Heat Flux Measurements

First Floor Evolution

The typical temperature trace for the first floor evolution is depicted in Figure 42. The fire, built with wooden pallets and excelsior wood fibers, exhibited rapid temperature excursions with little sustained heat release rates. The evolution is extremely rapid and there is minimal interest in characterizing the actual impact of the environmental thermal conditions on the firefighters since extinguishment occurs within one or two minutes from the access of the firefighters to the building.

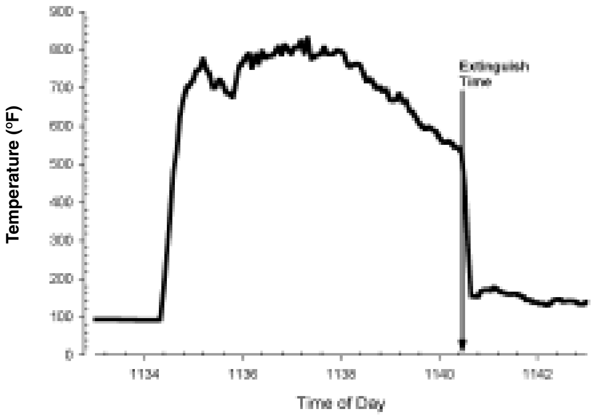
Figure 42: Typical Temperature Profile at the Ceiling (First Floor)



Third Floor Evolution

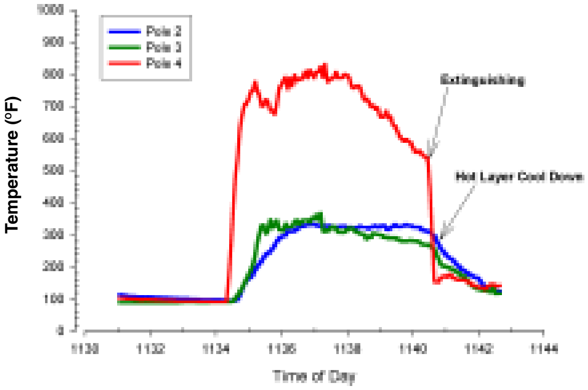
The evolution on the third floor provides an opportunity to quantify the physiological response of the firefighters to a sustained exposure to elevated temperatures. The fire in the third-floor burn room is built with wooden pallets and excelsior wood fibers. This combination provides the desired heat release rates for several minutes. Figure 43 depicts the temperature excursion in the fire room during the evolution. The temperatures shown are measured at the ceiling. The time of extinguishment is clearly identified by the sudden drop in temperatures at time 11:40 hours:minutes.

Figure 43: Typical Temperature Profile at the Ceiling (Third Floor)



The strong sustained fire develops a hot layer throughout the third floor as shown by measurements at the three poles in Figure 44. A uniform hot layer at about 160-220°C (320-430°F) is clearly present at the locations of poles two and three. In the fire room the fire plume is also evident with temperatures reaching up to 385°C (725°F) at the ceiling.

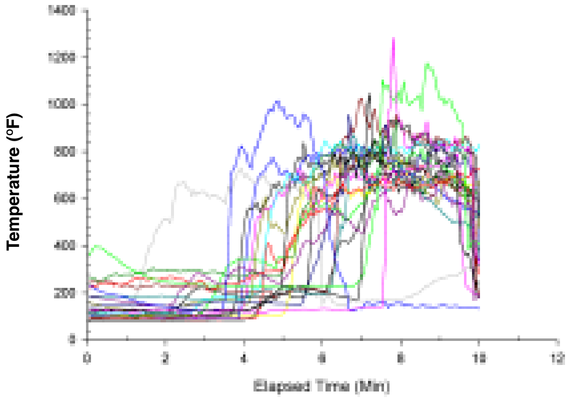
Figure 44: Third Floor Ceiling Temperatures



With this phenomenology we will now focus on the conditions in the fire room. Here the firefighters are asked to wait approximately four minutes before extinguishing the fire. During this time the average ceiling temperature measured over 17 fires is about 385°C (725 °F.) The ceiling temperature is reported in Figure 45 for all of the evolutions. The minimum values are at 378°C (714 °F) and the maximum values are at 696°C (1285°F.)

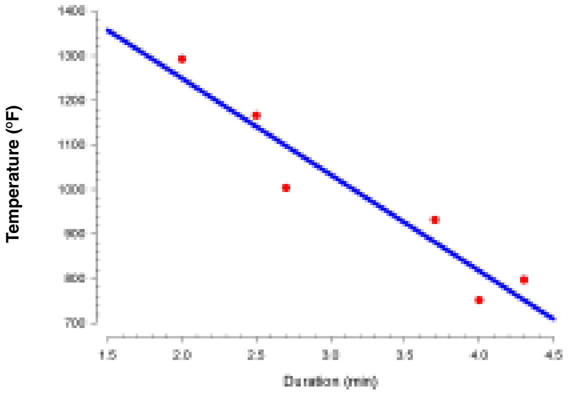
It is important to note that for the highest values of the range, we experienced some initial failures of the gear. Helmets delaminated and, on one occasion, a visor started to bubble. This is a very significant result suggesting that ceiling temperatures exceeding 500°C (930°F) can jeopardize the integrity of the gear and must be avoided in training evolutions.

Figure 45: Third Floor Ceiling Temperatures



Considering the times between entering the fire room and the fire extinguishment plotted against the time averaged ceiling temperatures, Figure 46 illustrates that the time that firefighters were able to withstand the burning room environment increases as the ceiling temperature decreases. The maximum time firefighters were required to remain in the burn room by the evolution protocol was four minutes. Therefore, for ceiling temperatures below 400°C (752°F), this waiting time is adequate. The few tests conducted at higher temperatures demonstrate that we were working close to the upper limit for both gear and personnel. In all cases it should be noted that the fire is started immediately before the firefighters enter the room.

Figure 46: Effect of Maximum Temperature on Duration in Burn Room

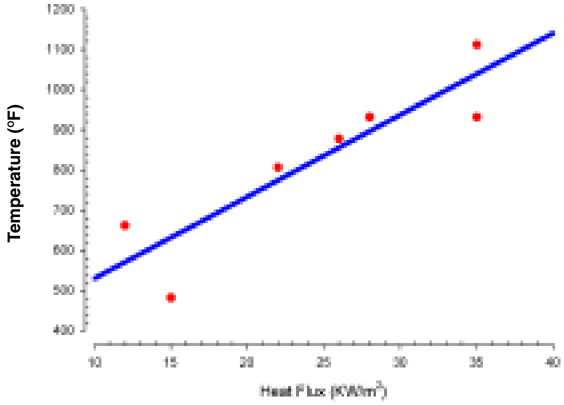


Heat Flux Measurements

The heat flux measurements indicate fluxes of 7 to 11 kW/m² at 1 m from the floor and 25 to 35 kW/m² at 1.5 m from the floor. These measurements clearly demonstrate the strong effects of thermal stratification in the fire room environment.

Figure 47 correlates the flux measurements at 1.5 m from the floor with the ceiling temperatures for seven evolutions. This shows that the flux is linearly related to the ceiling temperature.

Figure 47: Effect of Maximum Temperature on Heat Flux in Burn Room



Turnout Gear Performance

Making use of the skin temperature readings obtained using the LifeShirt System as measured by a thermistor attached on the subjects' torso inside the turnout gear, it is possible to deduce information on the gear performance during exposure to the severe fire conditions in the burn room. The typical temperatures measured in the room at the ceiling and at 1.2 meters from the floor are reported in Figures 48-50. These figures show temperatures between 150 - 300°C (300 - 575°F) with average temperatures of 200°C, 170°C and 330°C (390°F, 340°F and 625°F), respectively. The rapid drop in temperature coincides with the extinguishment of the fire.

FIGURE 48: Temperature in the Burn Room

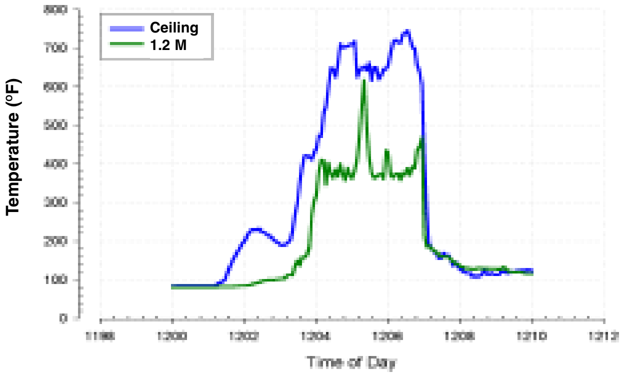


FIGURE 49: Temperature in the Burn Room

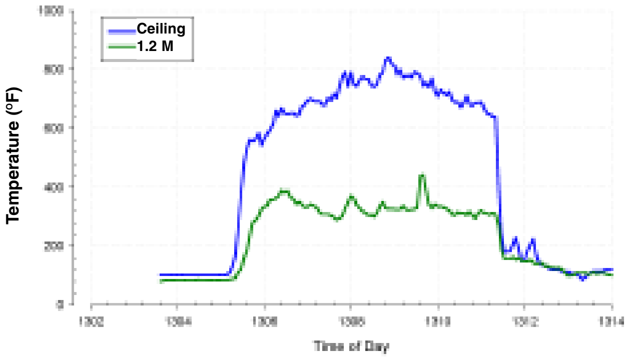
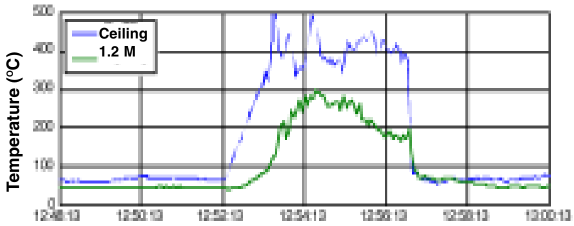


FIGURE 50: Temperature in the Burn Room



It is possible to correlate these temperatures with ones measured by the LifeShirt System. Since the firefighter is at rest, the temperature increase is not likely a function of significant internal heat generation. It is reasonable to assume that the temperature rise is a function of the convective and radiant heat input from the fire. The first element to consider is the time delay between the initial temperature rise and the time when the firefighter enters the burn room. Considering the gear as an insulating layer, it is appropriate to model it as a semi-infinite solid and to ask how long it will take for the heat wave to penetrate this layer.

From the analytical formulation of this problem, one can impose that a variation in temperature of 0.5 percent of the total range is felt when the following condition is reached:

$$x = 4\sqrt{\alpha t}$$

Where x is the gear thickness set at 10 mm
t is the time delay in seconds
α is the gear thermal diffusivity in m^2/s

With these values we obtain the following expression for the thermal diffusivity:

$$\alpha = \frac{7E-6}{t}$$

Note that the 0.5 percent temperature rise corresponds to a temperature increase of about 0.70 - 1.0°C given the temperature of 180-240°C (135 - 400°F) in the room and the initial temperature inside the gear of about 36°C (97°F). The values of the thermal diffusivity deduced from ten evolutions for the firefighter at the hose nozzle are reported in Table 14.

For the firefighters considered Figures 51 - 53 show the increase in temperature inside the gear. Note that the reference temperature is the initial temperature upon entering the room. The time delay and the slope of the temperature rise can be evaluated from this data.

Table 14 - Gear Behavior Estimates

Subject	Temperature *[°C]*	Time Delay *[s]*	Temperature *Rise [°C/s]*	Time to *40 °C [s]*	Total Time *Allowed [s]*
1	190	125	0.018	170	300
22	-	215	0.025	120	340
29	-	125	0.015	200	330
34	150	105	0.009	330	440
44	160	200	0.012	250	450
46	-	130	0.015	200	330
61	250	170	0.020	150	320
67	180	200	0.006	500	700
77	-	135	0.022	140	280
87	-	115	0.007	430	550

FIGURE 51: Temperature Rise - Subject 1

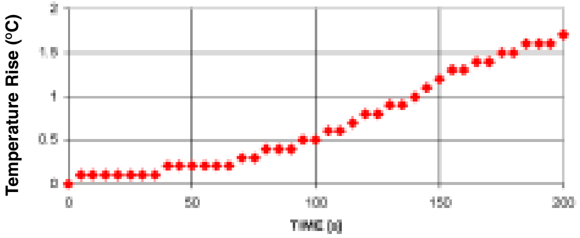


FIGURE 52: Temperature Rise - Subject 44

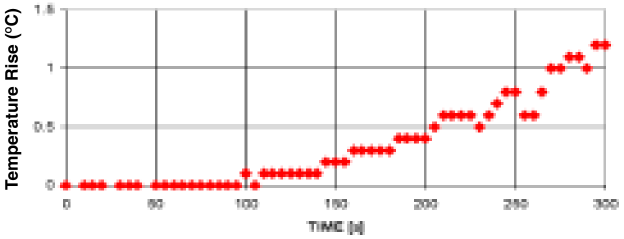
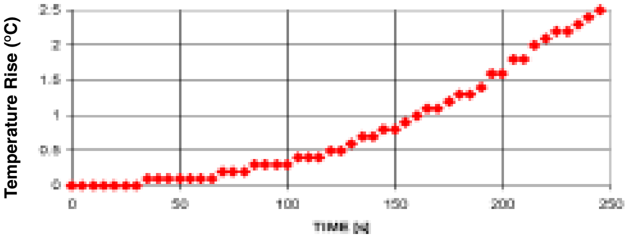


FIGURE 53: Temperature Rise - Subject 61



Note that for five cases, the maximum time allowed in the burn room is approximately five minutes. Two additional subjects show times of seven minutes and two times even longer. From this information we can estimate an average time delay of 150 seconds. This yields a thermal diffusivity of the gear of 4.9 ± 1.2 E - 8 m^2/s. The temperature rise is evaluated for those situations where the temperature in the burn room is high and it is conservatively set at 0.02 °C/s or 1.2 °C/min. The time to reach 104°F in the gear is therefore in the order of three minutes and 20 seconds. The total time allowed in the burn room would then be five to six minutes before the risk of heat illness or injuries would be increased.

Another important parameter can be deduced considering the temperature rise or the slope of the temperature trace S. From the analytical formulation of the thermal behavior for a layer of thickness L, one may assume that the internal conditions of the turnout gear are approximately adiabatic when compared to the convective and radiant heat transfer on the outside of the gear. The total incident heat flux outside the gear is about 9,000 W/m^2 while the flux inside the gear is of the order of 400 W/m^2. With this assumption, the ratio of the gear thermal conductivity, k, and the heat transfer coefficient, *h,* is given as:

$$\frac{k}{h} = (4E-3) + (3E-4)\frac{T_B - T_0}{S\ t}$$

Where T_B is the temperature in the burn room
T_0 is the initial temperature inside the gear
t is the time delay previously identified

With values of 150 seconds for the time delay and 0.02 for the temperature rise, one can estimate this ratio for a temperature difference of about 150 °C. This yields a value of k/h = 0.02. From the flux measurements of 7 - 11 kW/m^2, one can deduce that the heat transfer coefficient, h, should be of the order of 60 W/m^2 - K and the resulting gear thermal conductivity would be equal to about 1 W/m - K. This value seems high for insulating materials; however, in the gear there is a significant heat transfer due to vapor generation and condensation. This mechanism could significantly enhance a pure conductive heat transfer estimate.

For our testing scenario, one can evaluate the surface temperature of the gear based on the ratio k/h. This yields a typical gear surface temperature of 70 ± 10 °C. With an exposure of four minutes, a simple model is derived to predict the temperature rise inside the gear. Figure 54 shows a comparison of the inside temperature rise compared with actual data. The solid lines are the model predictions for the range of the parameter previously discussed. Figure 55 shows the predicted temperature evolution for the same exposure with the average value of the thermal diffusivity.

FIGURE 54: Comparison of Data and Calculations Based on a Simplified Gear Model

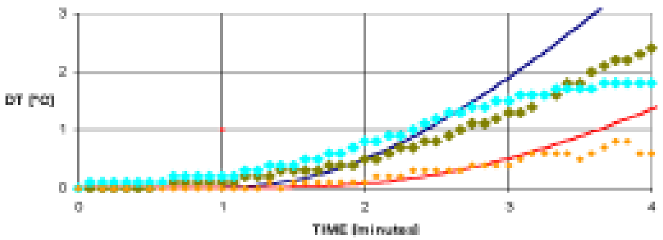
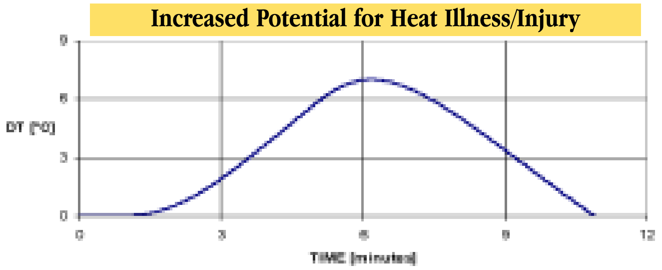


FIGURE 55: Temperature Evolution Inside the Gear



Several important considerations can be made from these results:

- *The firefighter has no feedback from the increased ambient temperature for about two minutes or 50% of the exposure time*

- *At the end of the exposure time, the temperature inside the gear has increased 4 °C. This increase is placing the firefighter at no risk of burn injuries. However, the temperature has reached only half of its excursion due to the insult. This means that in the following two minutes after the exposure the temperature will increase further before turning around.*

- *It is paramount to provide the firefighter with information about these processes. A real time predictor, based on measured gear surface temperature, could calculate immediately that residing in that environment for more than four minutes may cause excessive temperatures in the gear at a later time. Further, such a device could provide a calculated maximum allowable residence time based on the thermal history of the gear during the evolution. Hardware and software to generate this information are currently under development. This information would refer to the gear status in the same way that the air pressure refers to the time available with the breathing apparatus.*

Multiple Regression Analysis

Multiple regression analyses were performed to evaluate the relationships among the various demographic, environmental, and objective status measures to observed physiologic data during the evolutions. The Beta weights were evaluated to elucidate the structure among the relationships and provide guidance for developing a decision tree algorithm to guide evaluation of firefighter status on the fireground. For all physiologic measures age and fitness were heavily weighted in the prediction equation, frequently several times as influential as measures like heat index and BMI. Urine specific gravity as an indicator of hydration status was largely associated with mid - size beta weights, but this may have been skewed small because of the abnormal distribution of hydration status with substantial over - representation of dehydration in the population.

Prediction of Heart Rate during RIT Evolution

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.267**[a]	**.071**	**.042**	**15.079**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2763.759	5	552.752	2.431	.037[a]
	Residual	35925.281	158	277.375		
	Total	38689.039	163			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: HR

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	*Std. Error*	*Beta*		
1	(Constant)	43.382	165.759		.262	.794
	Age	-.405	.150	-.213	-2.703	.008
	BMI	-.083	.301	-.023	-.275	.784
	USG	128.910	163.897	.061	.787	.433
	Fitness Index	-.154	.082	-.149	-1.875	.063
	Heat Index	-.018	.145	-.010	-.122	.903

a. Dependent Variable: HR

RIT Heart Rate Prediction Equation

$$HR_{RIT} = 43.382 - (0.405*Age) - (0.083*BMI) + (128.910*USG) - (FI*0.154) - (HI*0.018)$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Heart Rate during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.228[a]**	**.052**	**.042**	**14.113**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5450.753	5	1090.151	5.473	.000[a]
	Residual	99590.827	500	199.182		
	Total	105041.6	505			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: HR

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	*Std. Error*	*Beta*		
1	(Constant)	19.260	89.318		.216	.829
	Age	-.224	.081	-.123	-2.760	.006
	BMI	-.047	.159	-.014	-.297	.767
	USG	149.823	88.299	.075	1.697	.090
	Fitness Indix	-.179	.044	-.185	-4.085	.000
	Heat Index	-.004	.077	-.002	-.056	.955

a. Dependent Variable: HR

RIT Heart Rate Prediction Equation

$$HR = 19.260 - (0.224*Age) - (0.047*BMI) + \quad + (149.823*USG) - (FI*0.179) - (HI*0.004)$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Relative Heart Rate (%HRMAX) during RIT Evolution

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.236**[a]	**.056**	**.026**	**8.093**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	611.917	5	122.383	1.869	.103[a]
	Residual	10348.579	158	65.497		
	Total	10960.495	163			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: %HRmax

Prediction Equation

The non - significant regression does not produce a viable prediction equation for the RIT evolution.

Prediction of Relative Heart Rate (%HRmax) during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.339**[a]	**.115**	**.106**	**7.559**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3697.609	5	739.522	12.942	.000[a]
	Residual	28571.479	500	57.143		
	Total	32269.088	505			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: %HRmax

Coefficients

Model		*B*	*Std. Error*	Standardized Coefficients *Beta*	t	Sig.
1	(Constant)	-6.694	47.841		-.140	.889
	Age	.291	.043	.289	6.696	.000
	BMI	-.018	.085	-.009	-.212	.832
	USG	83.072	47.294	.075	1.756	.080
	Fitness Indix	-.093	.023	-.173	-3.952	.000
	Heat Index	-.002	.041	-.002	-.052	.959

a. Dependent Variable: %HRmax

Working Evolution %HRmax Prediction Equation

$$\%HRMAX = (0.291*Age) - (0.018*BMI) + (83.072*USG) - (FI*0.093) - (HI*0.002) - 6.694$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Minute Ventilation (V_E) during RIT Evolution

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.232**[a]	**.054**	**.024**	**49.260**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	21761.344	5	4352.269	1.794	.117[a]
	Residual	383388.8	158	2426.512		
	Total	405150.2	163			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Ve

Prediction Equation

As a result of an insignificant regression, the generation of a viable prediction equation is not possible.

Prediction of Minute Ventilation (V_E) during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.298**[a]	**.089**	**.080**	**54.410**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	144004.7	5	28800.949	9.728	.000[a]
	Residual	1480247	500	2960.494		
	Total	1624252	505			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Ve

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	*Std. Error*	*Beta*		
1	(Constant)	-521.037	344.348		-1.513	.131
	Age	-.899	.313	-.126	-2.871	.004
	BMI	2.913	.613	.216	4.750	.000
	USG	602.564	340.417	.077	1.770	.077
	Fitness Indix	-.423	.169	-.111	-2.502	.013
	Heat Index	-.381	.295	-.056	-1.290	.198

a. Dependent Variable: Ve

Minute Ventilation Prediction Equation for Working Evolutions

$$VE = (2.9131 * BMI) - (0.889 * Age) + (602.564 * USG) - (FI * 0.423) - (HI * 0.381) - 521.384$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Tidal Volume (V_T) during RIT Evolution

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.222**[a]	**.049**	**.019**	**1377.150**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15509836	5	3101967.260	1.636	.154[a]
	Residual	3E+008	158	1896542.659		
	Total	3E+008	163			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable:Vt

Prediction Equation
As a result of an insignificant regression, the generation of a viable prediction equation is not possible.

Prediction of Tidal Volume (V_T) during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.256[a]**	**.066**	**.056**	**1480.326**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	77009964	5	15401992.85	7.028	.000[a]
	Residual	1E+009	500	2191366.511		
	Total	1E+009	505			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Vt

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	*Std. Error*	*Beta*		
1	(Constant)	-9067.80	9368.564		-.968	.334
	Age	-25.225	8.516	-.131	-2.962	.003
	BMI	61.472	16.684	.170	3.684	.000
	USG	12079.607	9261.607	.057	1.304	.193
	Fitness Indix	-8.677	4.601	-.085	-1.886	.060
	Heat Index	-14.744	8.035	-.081	-1.835	.067

a. Dependent Variable: Vt

Prediction Equation

$$VT = (61.472*BMI) - (25.225*Age) + (12079.607*USG) - (FI*8.667) - (HI*14.744) - 9067.08$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Breathing Frequency (B*f*) during RIT Evolution

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.229[a]**	**.052**	**.022**	**5.306**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	245.283	5	49.057	1.742	.128[a]
	Residual	4448.830	158	28.157		
	Total	4694.113	163			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Br/M

Prediction Equation
As a result of an insignificant regression, the generation of a viable prediction equation is not possible.

Prediction of Breathing Frequency (B*f*) during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.343**[a]	**.118**	**.109**	**5.121**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1747.984	5	349.597	13.330	.000[a]
	Residual	1312.673	500	26.225		
	Total	14860.657	505			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: BR/M

Coefficients

Model		*B*	*Std. Error*	Standardized Coefficients *Beta*	t	Sig.
1	(Constant)	-4.448	32.410		-.137	.891
	Age	-.020	.029	-.030	-.691	.490
	BMI	.387	.058	.300	6.705	.000
	USG	35.070	32.040	.047	1.095	.274
	Fitness Index	-.041	.016	-.112	-2.556	.011
	Heat Index	.005	.028	.007	.175	.861

a. Dependent Variable: Br/M

Prediction Equation

$$Bf = (0.387*BMI) - (0.020*Age) + (35.070*USG) - (FI*0.041) - (HI*0.005) - 4.448$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Prediction of Core Body Temperature during RIT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.250[a]**	**.062**	**.018**	**21.177**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3186.508	5	637.302	1.421	.223[a]
	Residual	47985.125	107	448.459		
	Total	51171.633	112			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Core Temperature

Equation

As a result of an insignificant regression, the generation of a viable prediction equation is not possible.

Prediction of Core Body Temperature during Working Evolutions

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**.223**[a]	**.050**	**.036**	**19.895**

a. Predictors: (Constant). Heat Index, Age, USG, Fitness Index, BMI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6845.626	5	1369.125	3.459	.005[a]
	Residual	130224.8	329	395.820		
	Total	137070.4	334			

a. Predictors: (constant), Heat Index, Age, USG, Fitness Index, BMI

b. Dependent Variable: Core Temperature

Coefficients

Model		Unstandardized Coefficients *B*	Unstandardized Coefficients *Std. Error*	Standardized Coefficients *Beta*	t	Sig.
1	(Constant)	170.750	156.454		1.091	.276
	Age	-.055	.142	-.021	-.388	.698
	BMI	.236	.288	.047	.820	.413
	USG	-61.467	154.955	-.022	-.397	.692
	Fitness Index	.187	.073	.142	2.567	.011
	Heat Index	-.445	.135	-.177	-3.298	.001

a. Dependent Variable: Core Temperature

Equation

$$T_{CORE} = 170.750 - (0.055 * Age) + (0.236 * BMI) - (61.467 * USG) + (FI * 0.187) - (HI * 0.445$$

Where: Age = Age in years
BMI = Body Mass Index
USG = Urine Specific Gravity
FI = Fitness Index as determined by the Harvard Step Test
HI = Heat Index

Beta Weight Analysis

Beta weights provide a mechanism of ranking variables with respect to their influence upon subject physiology. Table 15 ranks independent variables with respect to their influence on various physiological measures. When planning or executing training scenarios for firefighting, this ranking will provide the basis for a decision making process to help prevent adverse physiological events.

Table 15: Beta Weights

Variable	HR	$\%HR_{max}$	V_e	V_t	Bf	T_{core}	Mean
Fitness Index	0.185	0.173	0.111	0.085	0.112	0.142	**0.135**
BMI	0.014	0.009	0.216	0.170	0.300	0.047	**0.126**
Age	0.123	0.289	0.126	0.131	0.030	0.021	**0.120**
USG	0.075	0.075	0.077	0.057	0.047	0.022	**0.059**
Heat Index	0.002	0.002	0.056	0.081	0.007	0.177	**0.054**

Summary of Findings

The data collected in this study reveal that the standard working evolutions employed as part of the protocol result in similar physiologic stress, and in fact, the maze evolution may have been ultimately the most demanding test of the day. Participants in the study were largely dehydrated and the impact of hydration status was apparent in those evolutions associated with increased heat load. Fitness level as indexed via the Harvard Step Test was an important factor in predicting physiologic response to the various evolutions. One of the most important observations from this study is that factors that are under the control of each firefighter and fire department can have significant impact on the individual's physiologic capacity for the work of firefighting. Improving fitness level and following a disciplined hydration regime would improve capacity across the board. While this may appear obvious, the high percentage of subjects who were dehydrated during a day of training suggests that firefighters on the line are not hydrated any better.

Field/Training Management Decision Tree

A one page "decision tree" to provide guidance for evaluating physiologic stress in firefighters during training and on the fireground is presented in Figure 56. There are only two decision points required for field medical staff to determine levels at which a subject should be given additional attention. Age and fitness level according to the Harvard Step Test will provide information to classify a firefighter sufficiently to describe the normal range of physiologic responses observed during this study.

The objective of a set of guidelines is to provide warnings for when to intervene with a given individual. In order to develop this sort of guideline, a number of adverse events need to be observed. Thankfully, this experiment was not associated with any significant cardiovascular, respiratory, or other adverse health events. However, in the absence of this kind of data, "guideline" development needs to be rethought. The approach that was taken in this study was to describe the responses observed in the present population of firefighters based on the assumption that these participants are representative of the firefighter population in general. The data in the decision tree is summarized in Figure 57. Green numbers indicate one standard deviation above average and below as observed in the present study. Yellow numbers are from one to two standard deviations above the mean, and red are greater than two standard deviations above the mean observed in the present study. It should be noted that these values indicate the observed physiologic values by age and fitness level as assessed with the Harvard Step Test. These values can be used to evaluate firefighters and to determine their relative physiologic status , particularly as a means to identify changes in fitness.

In order to set thresholds to facilitate on-site monitoring of firefighters, green-yellow-red values should be determined from the high fitness group. Given the nature of physiologic response to stress, and the interaction of these responses and fitness, low-fitness individuals performed at higher heart rates, breathing frequencies, tidal volumes, and minute ventilations. It is not sensible to build guidelines based on allowing less fit individuals to operate at higher levels of physiologic stress, so threshold determination for observation should be based on the high-fitness group. Individual variation will have to be noted over time, and this will allow fire-team medical staff to ultimately develop individually customized data for each firefighter. It should also be noted that these data provide only a starting point and not a guarantee regarding the status of the firefighter. Specifically, it is possible, if not likely, that individuals having "red" values will be just fine, and an individual appearing all "green" may still have significant difficulties. This being said, the data collected in this study do provide an objective basis to start differentiating individuals and improve the ability of field medical staff to identify those firefighters who may require extra attention.

Figure 56: Age and Fitness Based Decision Tree

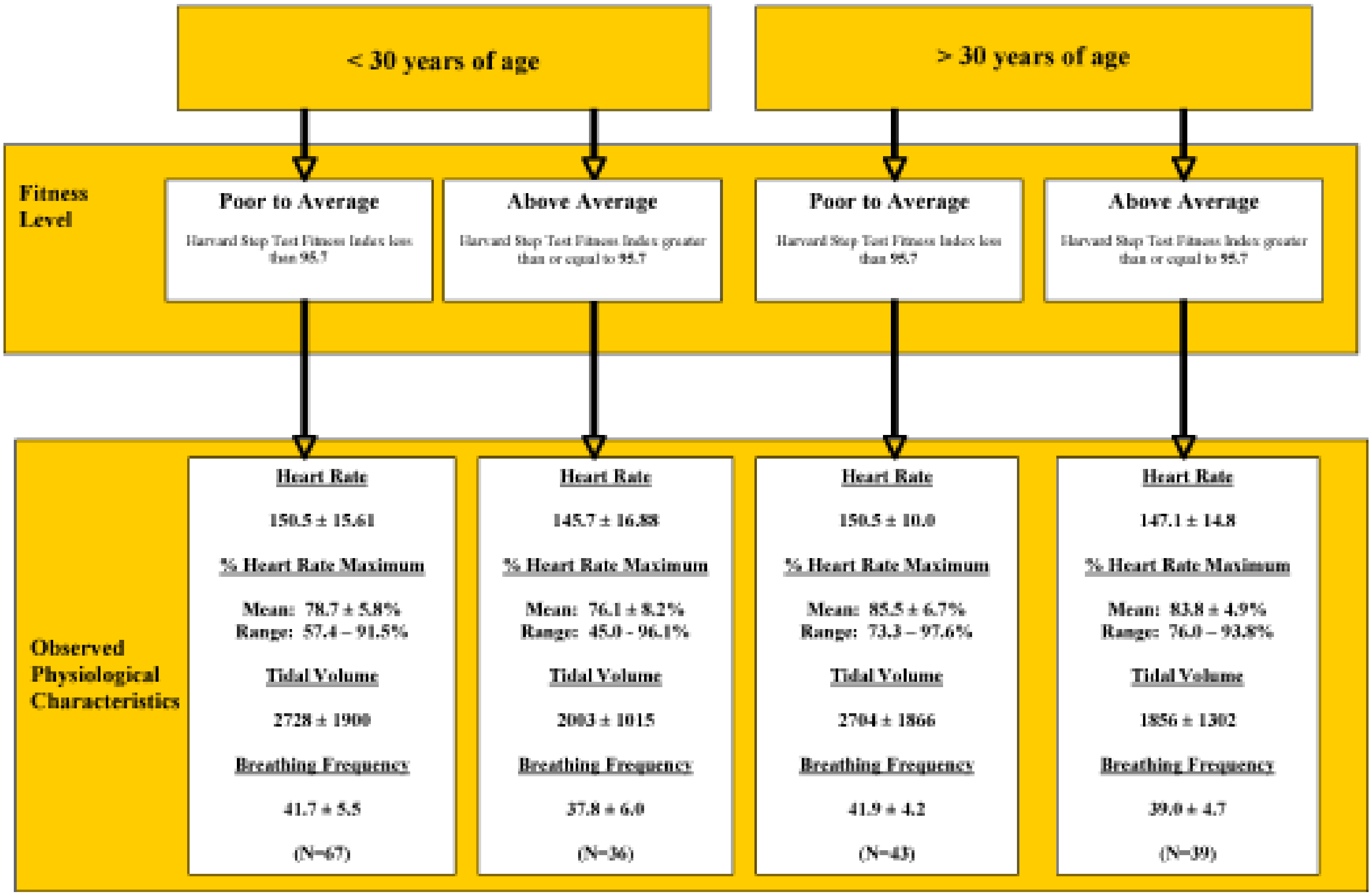


Table 57: Age and Fitness Based Data

Age (years)	Fitness	Heart Rate (BPM)	Percent of age predicted maximal heart rate	Breathing frequency (Br/M)	Tidal volume L/Breath	Minute ventilation L/Minute
<30	Avg – Low	166	85	47	2.93	138
	(HST <95.7)	167-182	86-90	48-54		138-158
		182+	90+	55+		158+
	High	163	84	45	2.00	88
		164-181	85-90	46-51		88-102
		182+	91+	52+		102+
>30	Avg – Low	161	91	45	1.87	84
	(HST < 95.7)	162-171	92-99	46-50		84-94
		172+	99+	51+		94+
	High	161	89	44	1.30	57
		162-166	90-95	45-50		57-65
		167+	96+	51+		65+

GUIDELINES

In order to implement the recommendations based on the research findings, certain minimum standards are expected to be in place. These standards are established, in many cases, through nationally recognized consensus standards and should be adopted and enforced by the authority having jurisdiction (AHJ). The National Fire Protection Association (NFPA) has developed several standards addressing safety and health in fire service training and emergency operations. Among these standards are NFPA 1041, *Fire Service Instructor Professional Qualifications*, NFPA 1403, *Standard on Live Fire Training Evolutions*, and NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*. These standards are "developed through a consensus standards development process approved by the American National Standards Institute. This process brings together individuals representing varied viewpoints and interests to achieve consensus on fire and other safety issues" (NFPA, 2002).

Instructors

Instructors are expected to comply with the standards in NFPA 1041, *Fire Service Instructor Professional Qualifications* (2002)

Instructors are expected to comply with the standards in NFPA 1041, *Fire Service Instructor Professional Qualifications* (2002). This standard outlines the Job Performance Requirements (JPRs) for the three levels of instructor certification. As a minimum requirement to lead a class individuals should possess the requisite knowledge and skills for certification at the Instructor II level.

The Minimum Standards Committee, a standing committee of the Maryland Fire Rescue Education and Training Commission (MFRETC), developed minimum uniform standards for the certification of emergency services instructors in the State of Maryland. These standards, based on the previously mentioned NFPA 1041 standards, provide more specific requirements for certification, evaluation and recertification of instructors. For instance, instructors are expected to have at least three years experience in the emergency services and to demonstrate their ability to perform the skills associated with the discipline in which they are instructing before they are recognized as an instructor. To ensure the requisite knowledge and skill required of an instructor they are to have been observed and evaluated by an evaluator approved by the AHJ prior to being certified as an instructor. In order to maintain currency in instructional methodologies, instructors are expected to comply with a regular, three-year recertification process. During the three-year certification, and in order to be recertified, instructors are expected to teach a minimum of 60 hours, receive a satisfactory teaching evaluation from an AHJ approved evaluator, and complete at least 12 hours of professional development in the areas of instructional methods, training applications, and/or safety. (COMAR Subtitle 03 Fire-Rescue Education and Training Commission, Section 13B.03.01 Certification Standards and Procedures for Emergency Services Instructors.)

Training Facilities

Facilities used for live fire training are expected to comply with NFPA 1403, *Standard on Live Fire Training Evolutions* (2002).

Total compliance with NFPA 1403, *Standard on Live Fire Training Evolution* (2002) is mandatory to ensure a safe training environment. Regardless of the type of structure used for live fire training it shall be carefully selected and prepared for live fire training evolutions. Training center burn buildings are to be visually inspected before any live fire training evolutions and any damage documented in accordance with the procedures established by the AHJ. In addition, the structural integrity of the building shall be evaluated annually by an engineer and the condition of the structure behind the thermal lining shall be evaluated once every five years. All equipment necessary for live fire training evolutions shall be operated before any evolution begins to ensure its proper operation. If any damage to the burn building sufficient to affect the safety of participants is found, training shall be suspended until appropriate repairs can be made.

Safety Plan

Before the beginning of any training evolution, and especially for live fire training evolutions, a safety plan must be developed.

During all training evolutions, safety of participants shall be a paramount consideration. Safe training evolutions require careful consideration and planning on the part of the lead instructor. First and foremost in this planning is ensuring a sufficient number of qualified instructors. In all practical evolutions, it is expected that there will be enough instructors meeting NFPA 1041, *Fire Service Instructor Professional Qualifications (2002) Instructor Requirements* to supervise all students in the class. During live fire training evolutions, NFPA 1403 *Standard on Live Fire Training Evolutions* (2002) requires a student-to-instructor ratio not greater than five to one. At a minimum, it is expected that there will be an instructor in charge, an instructor with the primary hose team, an instructor with the backup team, two interior instructors to ready the fires, and one safety officer. The complexity of the evolution will dictate whether more instructors are needed.

Before any live fire training begins, a training plan will be developed and all participants will be briefed on the plan, the evolutions to be conducted, and crew assignments shall be made. All participants shall be required to take part in a familiarization walkthrough of the facility prior to beginning any live fire training. During the walkthrough, the building's layout and evacuation provisions will be observed (NFPA, 2002b).


A MFRI instructor leads study participants on a walkthrough of the structural burn building

As part of the safety plan, a method of communications will be established to coordinate among the instructors and with the safety officer (NFPA, 2002b). As part of the communications considerations, an evacuation plan will be developed along with an evacuation signal that will be demonstrated for participants before the commencement of live fire training. In the event conditions require it, the instructor-in-charge or the designated safety officer shall direct the sounding of the evacuation signal and all participants shall immediately exit the structure.

It is expected that the instructor-in-charge will ensure an adequate water supply and that sufficiently staffed attack lines and backup lines are provided for the evolutions planned. The necessary attack and backup lines shall be staffed and ready before the beginning of the evolution including the standard fireground Rapid Intervention Team (RIT). In addition, there shall be a charged attack line in position when the fire is ignited (NFPA, 2002b).

The Incident Management System shall provide the organizational structure for all live fire training. The instructor-in-charge shall assign personnel and document those assignments using a command chart. The personnel assignments shall include Instructor-in-charge; safety officer(s); rapid intervention team (RIT); crew assignments with instructor; and reserve instructors, if available. The instructor-in-charge will be expected to maintain the command chart and amend it as necessary throughout the evolutions.

Finally, personnel accountability is a crucial element of the safety component of training evolutions. During all evolutions in which a participant could become disoriented, lost, or trapped an accountability system shall be established and strictly followed. The accountability system shall be a "point of entry" system, tracking all personnel in the hazard zone. When a participant enters the hazard zone, he shall be "logged in" using the recognized system and "logged out" upon his exit from the hazard zone. Close attention shall be paid to the time in the hazard zone and provisions made for rescue should a participant become unable to exit on his own.

It is expected that all instructors and students in training evolutions be held to a high standard of discipline. All participants—both students and instructors—are expected to follow the designated training plan and direction from the instructor-in-charge. In addition, all personnel are expected to adhere to their assigned duty without "freelancing" of any kind. It is expected that training instructors will closely supervise students as they go about their evolutions to ensure they complete the evolutions properly and safely. No deviation should be allowed from the standard of care designated by the AHJ. Strict disciplinary action should be taken against instructors who do not follow the adopted procedures.

Student accountability system

Personal Protective Equipment

Full personal protective equipment will be available and required for all students participating in practical training evolutions.

For live fire training evolutions, participants are expected to be equipped with and utilize protective coats, trousers, hoods, footwear, helmets, gloves, self-contained breathing apparatus (SCBA), and personal alarm devices meeting the appropriate NFPA standard (NFPA 1971, *Standard on Protective Ensemble for Structural Fire Fighting*, NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for the Fire Service*, and NFPA 1982, *Standard on Personal Alert Safety Systems* (PASS)). All participants involved in live structural fire training evolutions (students and instructors) are expected to be required to use all of the listed protective equipment as a condition of participating in the training evolution.

Safety Officer

During any live fire training evolution a qualified, experienced safety officer will be appointed and must remain through the duration of the evolutions.

During any live fire training evolution a qualified, experienced safety officer will be appointed and must remain through the duration of the evolutions. The instructor-in-charge or the safety officer may designate additional safety personnel to monitor conditions and participants within the structure. All safety personnel are expected to be trained and knowledgeable in safe firefighting operations and all features of the burn building being used. The responsibilities of the safety officer, and subordinate safety personnel, are to prevent unsafe acts and eliminate unsafe conditions. In all cases, the safety officer must have the authority to intervene and control any unsafe operations including suspending all operations until sufficient measures are taken to ensure the safety of participants (NFPA, 2002b).

Provisions are expected that allow students to stop training at any point without retribution. Students have varying levels of ability and skill. Allowing them to stop training gives them the ability to improve at their own pace, even if it is not the pace of the class. This is not to say that students will be allowed to deviate from the minimum standard. These students will still be required to meet the minimum established standard for successful completion of the class. It simply addresses different learning styles and speeds.

Environmental Conditions

Training facilities and instructors should monitor weather conditions and adjust or cancel related activities as conditions warrant.

Based on the results of this study and the related literature, environmental conditions have proven to have a significant impact on an individual's physiological response to physical activity.

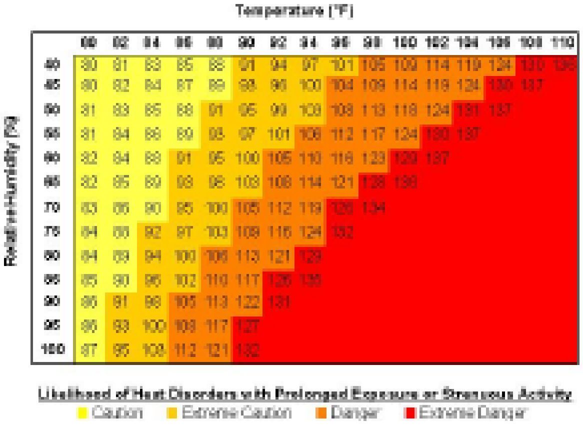
The heat and wind chill indexes as developed by the National Weather Service will be used as the guide for determining extreme heat and cold conditions (Figures 58-59). Weather information local to the class site should be used as even over a relatively small geographic area conditions can vary greatly.

Extreme Heat

Outside training activities requiring physical activity or full protective clothing shall not be conducted when the heat index reaches more than 110°F. Consideration should be given to the fact that full personal protective clothing may add 10° to the heat index value, and factors such as age and physical condition of individual students may affect susceptibility to heat disorders.

Where the heat index is between 100° and 110° F, conditions may be considered hazardous. The instructor shall use discretion with regard to outside activity cancellation and/or modification. Other factors such as the time of day and type of activity may influence the instructor's decision.

Figure 58: Heat Index Chart



	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Outside training activities requiring physical activity or full protective clothing may be conducted under the following conditions:

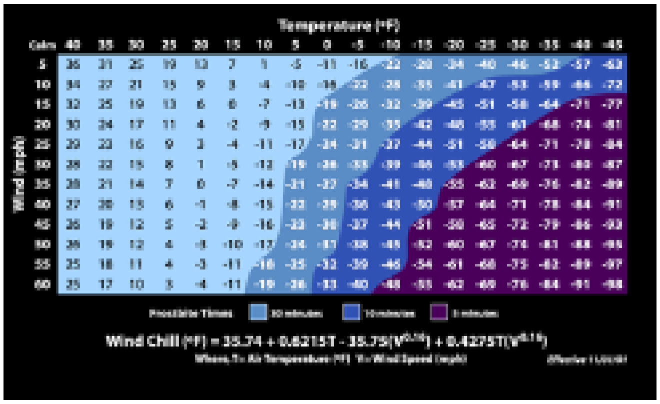
- *Live-fire and structural burns should be evaluated case by case.*
- *Activities other than live fire fighting can be safely conducted with reduced protective clothing (i.e., helmet, gloves, and boots or safety shoes).*
- *An adequate supply of cool drinking water is available at the training site.*
- *Strenuous physical activity is monitored and limited to 15 to 20 minutes.*
- *A rehabilitation area is established for rest and rehydration*

While other environmental conditions may not have a profound effect on physiological response, it is recommended that training facilities adopt additional guidelines with regard to environmental conditions for additional safety.

Extreme Cold

Wind chill factors may vary depending on the training location's proximity to wind barriers. Frostbite is possible at temperatures less than 0°F and temperatures are considered dangerous at 20°F. Outside training activities should not be conducted when the wind chill factor is less than 20°F, unless: students are properly dressed for an appropriate cold weather activity; the cold weather will not affect the safe and proper function of tools, equipment, and apparatus; an adequate supply of warm liquids and/or food is available at the training site; strenuous physical activity is monitored and limited to 15 to 20 minutes; and a heated indoor rehabilitation area is in close proximity to the training site. When conducting outside training activities in temperatures where climbing/ walking surfaces are subject to freezing and may create a slip hazard, instructors shall exercise due caution.

Figure 59: Wind Chill Chart



Temperature (°F)

Wind (mph)	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times 30 minutes 10 minutes 5 minutes

Wind Chill (°F) = $35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

Other Conditions

Instructors shall consider other extreme weather-related conditions and modify or cancel outside training activities accordingly. These conditions include high winds, snow or snow on the ground, ice, sleet, hail, rain, lightning, thunderstorm or tornado warnings.

Medical Evaluation

Medical evaluations in accordance with NFPA 1582, *Comprehensive Occupational Medical Program for Fire Departments* (NFPA, 2003) should be conducted as a baseline for surveillance and annually thereafter on all individuals engaged in firefighter emergency functions.

As outlined in the standard, each medical evaluation shall include a medical history (including exposure history), physical examination, blood test, urinalysis, vision test, audiograms, spirometry, chest X-ray (as indicated), electrocardiogram, cancer screening (as indicated) and immunization and infectious disease screening (as indicated).

Medical Screening

The seven-question PAR-Q should be used by fire training academies as a means to screen students prior to participation in firefighter emergency training evolutions.

In many cases the fire training academy is not the AHJ and therefore does not dictate compliance with NFPA 1582. These training academies often receive students from many jurisdictions, some of which do not comply with the standard. The most recent NFPA survey indicated that more than 80% of the nation's fire service does not have a requirement for medical evaluations or physical fitness.

The British Columbia Ministry of Health developed the Physical Activity Readiness Questionnaire (PAR-Q) in 1992 as a simple medical screening tool for use prior to an individual's participation in physical activity. This questionnaire has since been revised by the Canadian Society for Exercise Physiology and is now a universally accepted means of screening individuals between the ages of 15 and 69 prior to physical activity.

The seven-question PAR-Q should be used by fire training academies as a means to screen students prior to participation in firefighter emergency training evolutions. A positive answer to any of the seven questions on the PAR-Q would require an individual to consult with a doctor prior to engaging in any physical activity including a fitness assessment.

Individuals referred to a physician would need to provide documentation of a NFPA 1582 compliant medical examination or a completed Physical Activity Readiness Medical Examination (PARmed-X) prior to engaging in any firefighter emergency training.

Fitness Evaluation

Fitness evaluations in accordance with NFPA 1582, *Comprehensive Occupational Medical Program for Fire Departments* (NFPA, 2003) should be conducted as a baseline for surveillance and annually thereafter on all individuals engaged in firefighter emergency functions.

As part of the annual fitness evaluation, weight and body composition are measured and recorded. The fitness evaluation also includes an evaluation of aerobic capacity using either a stairmill or treadmill protocol, an evaluation of muscular strength including grip strength, leg and arm strength protocols, an evaluation of muscular endurance using a push-up and curl-up protocol and an evaluation of flexibility using a sit and reach protocol.

Fitness Screening

Fire training academies should conduct a two-fold fitness screening on all individuals prior to participation in firefighter emergency training.

Once again, a fire training academy cannot and should not assume that all students have received proper fitness evaluations. It is therefore recommended that fire training academies should conduct a two-fold fitness screening on all individuals prior to participation in firefighter emergency training.

Body Mass Index (BMI) is an index calculated from a person's weight and height. BMI does not measure body fat directly, but research has shown that BMI correlates to direct measures of body fat, such as underwater weighing and dual energy x-ray absorptiometry (DXA). BMI can therefore be considered an alternative for direct measures of body fat. Additionally, BMI is an inexpensive and easy-to-perform method of screening for weight categories that may lead to health problems. BMI is not a diagnostic tool. An individual may have a high BMI, but in order to determine if excess weight is a health risk, a healthcare provider would need to perform further assessments. These assessments might include skinfold thickness measurements, evaluations of diet, physical activity, family history, and other appropriate health screenings.

The results of the study indicate that BMI correlates with physiological response to training evolutions. As a result, the first step in the fitness screening should be the calculation of BMI for all participants. This can be done quite simply by measuring and recording height and weight. BMI can then be calculated using the following formula:

$$BMI = Weight\ (lb) / [height\ (in)]^2 \times 703$$

For adults 20 years old and older, BMI is interpreted using standard weight status categories that are the same for all ages and for both men and women. The standard weight status categories associated with BMI ranges for adults are shown in Table 16.

Table 16: BMI Classification

BMI	Weight Status
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

According to the BMI weight status categories, anyone with a BMI over 25 would be classified as overweight and anyone with a BMI over 30 would be classified as obese. It is important to remember, however, that BMI is not a direct measure of body fatness and that BMI is calculated from an individual's weight, which includes both muscle and fat. As a result, some individuals may have a high BMI but not have a high percentage of body fat. For example, highly trained athletes may have a high BMI because of increased muscularity rather than increased body fatness.

The correlation between the BMI and body fatness is fairly strong; however the correlation varies by sex, race, and age. These variations include the following examples:

- *At the same BMI, women tend to have more body fat than men do.*

- *At the same BMI, older people, on average, tend to have more body fat than younger adults do.*

- *Highly trained athletes may have a high BMI because of increased muscularity rather than increased body fatness.*

Although some people with a BMI in the overweight range (from 25.0 to 29.9) may not have excess body fat, most people with a BMI in the obese range (equal to or greater than 30) will have increased levels of body fat.

It is also important to remember that BMI is only one factor related to risk for disease. For assessing someone's likelihood of developing overweight- or obesity-related diseases, the National Heart, Lung, and Blood Institute guidelines recommend looking at two other predictors:

- *The individual's waist circumference (because abdominal fat is a predictor of risk for obesity-related diseases).*

- *Other risk factors the individual has for diseases and conditions associated with obesity (for example, high blood pressure or physical inactivity).*

The second element of the fitness screening is a sub-maximal estimation of aerobic fitness. In this study, the Harvard Step Test was chosen. This test is easy to conduct on large numbers of individuals simultaneously and requires minimal equipment.

In order to conduct the Harvard Step Test the fire training academy will need a step or platform 20 inches (50.8 cm) high, a stopwatch and a metronome or cadence tape. Students should take position in front of the steps in preparation for the start of the test. On verbal command, the students should begin stepping up and down on the platform at a rate of 30 steps per minute for five minutes or until exhaustion. Exhaustion is defined as when the student cannot maintain the stepping rate for 15 seconds. At the conclusion of the five minutes, the students should immediately sit down on the step or platform. The total number of heart beats are counted between 1 and 1.5 minutes after finishing, between 2 and 2.5 minutes and between 3 and 3.5 minutes.

The Fitness Index is determined by the following equation:

$$FI = \frac{(100 \times \text{test duration in seconds})}{(2 \times \text{Total Heart Beats in the Recovery Period})}$$

The Fitness Index can then be classified as shown in Table 17.

Table 17: Fitness Index Classification

Fitness Level	Fitness Index
Excellent	>90
Good	80-89
High Average	65-79
Low Average	55-64
Poor	< 55

It should be noted that there are other sub-maximal fitness assessments that can be substituted for the Harvard Step Test depending on the resources available at a particular fire training academy.

Hydration

The training academy should provide instructions to participants prior to and during firefighter emergency training to encourage proper hydration.

The results of the study indicate that dehydration has a significant impact on the physiological response to the stresses of firefighting. The training academy should provide instructions to participants prior to and during firefighter emergency training to encourage proper hydration.

The following recommendations should be followed:

- *Drink at least eight 8-ounce servings of water each day in addition to what is consumed in fruit juice and/or sports drinks. More active individuals will require more water to replenish lost fluids.*
- *Do not wait until you are thirsty to drink water. By the time you feel thirsty, you have probably already lost two or more cups of your total body water and your performance will suffer.*
- *Do not substitute beverages with alcohol or caffeine for water. Caffeine and alcohol act as diuretic beverages and can cause water loss through increased urination.*
- *On training days, drink three glasses of water two hours before exercising, and another two glasses 10-15 minutes before exercising.*
- *Once training begins, drink up to 1 liter of water per hour, either as pure water or an isotonic carbohydrate drink, throughout the training session.*
- *Do not underestimate the amount of fluids lost from perspiration. Following exertion, drink two cups of water for each pound lost.*

Training academies may consider using the urine specific gravity measures used in this study as a means to identify dehydrated individuals upon arrival for training. In the absence of this test, the training academy must assume that participants arrive dehydrated and actively take measures to avoid severe dehydration once training begins. Based on the research, we can estimate that firefighters regularly lose two or more liters of sweat during strenuous firefighting activities. When considering the amount of sweat lost during these activities, it is important to note that under most circumstances firefighters will begin sweating as soon as they don personal protective gear and will continue to sweat even after the training evolution is completed. Adequate water should be available on site and students should begin hydrating upon arrival and throughout the training day.

Fluid replacement is the single most important component of an effective rehabilitation program. Water is vital to every body system and comprises 60 percent of our total body mass. Water is the fluid of choice and it is recommended that participants drink two to four ounces every twenty minutes during training.

Medical Monitoring/Rehabilitation

Training academies should adhere to NFPA 1584, *Recommended Practice on the Rehabilitation of Members Operating at Incident Scene Operations and Training Exercises*.

The goal of the NFPA 1584 is to ensure that the physical and mental condition of firefighters operating at the scene of an emergency or training exercise does not deteriorate to a point that affects firefighter safety.

A key component of an effective rehabilitation system is medical monitoring. Medical monitoring involves the evaluation of rating of perceived exertion (RPE), heart rate, blood pressure and temperature. In the future, real-time, detailed physiologic monitoring such as was done during this study may be more readily available to the fire service as technology advances and cost is reduced.

In the absence of continuous real-time monitoring, periodic medical monitoring should be conducted by personnel trained to evaluate vital signs and must provide assessments of the firefighters' level of distress from hyper or hypothermia and cardiorespiratory compromise.

Body temperature is a very difficult variable to accurately measure on the training ground. Oral temperatures will be artificially low following heavy breathing, use of SCBA and fluid ingestion. Tympanic thermometers are very convenient, but measurements are affected by tester differences, physical activity, and environmental conditions. Under resting conditions, tympanic thermometers tend to underestimate core body temperature. Following exercise or in a cool environment the underestimation is even greater. Thus, if tympanic temperature is measured, rehabilitation personnel must consider it just one piece of the information in an overall clinical picture. A firefighter with an elevated heart rate or blood pressure, profuse sweating, nausea, headache and a tympanic temperature of 98.8°F could indeed be suffering from heat stress. (Dickinson, et al., 2003)

Along with the urgent need to rehydrate personnel, it is also necessary to rapidly cool core body temperature. Students should be provided a shaded area far enough away from the burn structures to rest. It is essential that firefighters remove their protective equipment in warm weather. The use of wet towels around the head and neck, fans and water misting fans are all helpful in the cooling process if an air conditioned space is not readily available.

Cold emergencies provide a special challenge as well. Firefighters need to stay warm and dry to the extent possible. Students should be instructed to bring dry socks, gloves and sweatshirts to minimize the risks of hypothermia following the hyperthermic experience of the fire training evolution. It is important to remember that even in cold temperatures firefighters will lose water during evolutions and need to be rehydrated following the recommendations above.

During periods of rest and recovery students need to be encouraged to sit down and allow their bodies to recover. A work/rest ratio of 10 minutes of self-rehabilitation break after 30 minutes of SCBA use or 20 - minutes of intense work is recommended. A 20 - minute rehabilitation period is recommended after two 30-minute SCBA bottles, one 45 - 60 minute SCBA bottle, 40 minutes of intense work, or operation within encapsulating chemical protective clothing.

Fuel Load and Exposure

In all cases, only fuels with known burning characteristics that are controllable are to be used and only in quantities needed to create the desired fire size.

Only fuels appropriate to the design of the burn building shall be used during live fire training evolutions. Flammable and combustible liquids are not to be used for live fire training evolutions in structures. In the structural burn evolutions the combination of wooden pallets and excelsior wood fibers creates an environment that adequately simulates actual firefighting conditions without placing students and instructors at unnecessary risk for injury.

The results of this study indicate that the fuel loads used were safe, but at the upper limits of what would be considered appropriate for the length of exposure required to complete the standard fire training evolutions.

Ceiling temperatures in the burn room should not exceed 400°C. At temperatures greater than 400°C helmet delamination was witnessed and the integrity of the protective eye shield was compromised. It is further recommended that the time of exposure in the burn room prior to extinguishment of the fire be limited to no more than 4 minutes. Longer exposure times could increase the risk of thermal illness or injury to the firefighter.

REFERENCES

Albert, B. (2006). Interviews with Emergency Room Physicians, Personal Communications.

American College of Sports Medicine. (1987). Position Stand on the Prevention of Thermal Injuries During Distance Running. *Medicine & Science in Sports and Exercise* , 19, 529-533.

Anonymous (1994). Firefighter Fatalities Remained Low in 1993. *NFPA Journal*, July/August 1994.

Armstrong, L.D., Maresh, S.M., & Castellani, J.W. (1994). Urinary Indices of Hydration Status. *International Journal of Sports Nutrition*, 4, 265-279.

Babcock, C.J., & Kirby, T.E. (2004). Entry Level Firefighter Cadets: Aerobic Fitness Levels and the Effects of a Training Program. *Medicine & Science in Sports and Exercise,* 36 (5), S219.

Baker, S.J., Grice, J., et al. (2000). Cardiorespiratory and Thermoregulatory Response of Working in Firefighter Protective Clothing in a Temperate Environment. *Ergonomics*, 43 (9), 1350-1358.

Barrow, M.W., & Clark, K.A. (1998). Heat Related Illnesses. *American Family Physician*, Retrieved December 3, 2003 from www.gafp.org/afp/980901ap/barrow.html.

Becker, L.R., Zaloshjna, E., et al. (2003). Relative Risk of Injury and Death in Ambulances and Other Emergency Vehicles. *Accident Analysis and Prevention,* 35, 241-248.

Berrios-Torres, S.I., Green, J.A., et al. (2003). World Trade Center Rescue Worker Injury and Illness Surveillance, New York, 2001. *American Journal of Preventive Medicine*, 25 (2), 79-87.

Blevins, J.S., Bounds, R.G., et al. (2005). Minor Changes in Lifestyle Programming Significantly Improve Health and Fitness in Firefighters. *Medicine & Science in Sport and Exercise*, 37 (5), S405.

Blevins, J.S., Coast, J.R., et al. (2004). Do Volunteer and Staff Firefighters Meet Minimum Rates of Physical Activity Despite Demands of the Job? *Medicine & Science in Sport and Exercise,* 36 (5), S246.

Boal, W. L., Hales, T., et al. (2005). Bloodborne Pathogens Among Firefighters and Emergency Medical Technicians. *Prehospital Emergency Care*, 9, 236-247.

Bolstad-Johnson, D. M., Burgess, J.L., et al. (2000). Characterization of Firefighter Exposures During Fire Overhaul. *American Industrial Hygiene Association Journal*, 61, 636-641.

Bonen, A. (1975). An Evaluation of Three Fitness Tests. *Canadian Journal of Public Health*, 66 (4), 288-290.

Borg, G.A.V. (1974). *Psychological Aspects of Physical Activities. Fitness, Health and Work Capacity*. L.A. Larson. New York: Macmillan.

Brouha, L. (1942). The Step Test: A Simple Method of Measuring Physical Fitness for Muscular Work in Young Men. *Research Quarterly*, 1942.

Budd, G.M. (2001) How do Wildland Firefighters Cope? Physiological and Behavioral Temperature Regulation in Men Supressing Australian Summer Brush Fires with Hand Tools. *Journal of Thermal Biology*, 26, 381-386.

Burgess, J.L., Pappas, G.P., et al. (1999). Longitudinal Decline in Measured Firefighter Single Breath Diffusing Capacity of Carbon Monoxide Values: A Respiratory Surveillance Dilemma. *American Journal of Respiratory and Critical Care Medicine*, 159 (1), 119-124.

Burks, C.A., Sharkey, B.J., et al. (1998). Estimating Energy Expenditure in Wildland Firefighters Using Heart Rate Monitoring and Physical Activity Records. *Medicine & Science in Sports and Exercise*, 30 (5), 56.

Byczek, L., Samo, D.G., et al. (2004). Cardiovascular Risks in Firefighters: Implications for Occupational Health Nurse Practice. *American Association of Occupational Health Nurses Journal,* 52 (2), 66-76.

Campbell, D.L., Noonan, G.P., et al. (1994). Estimated Workplace Protection Factors for Positive Pressure Self-Contained Breathing Apparatus. *American International Health Alliance Journal*, 55 (4), 322-329.

Campbell, M.H., Pefia, O., et al. (1999). Firefighters Heart Rate Response to a Live Burn. *Medicine & Science in Sports and Exercise*, 31 (5), S376.

Campbell, M. H., Ritter, G. N., et al. (1998). Comprehensive Fitness Assessment in Firefighters. *Medicine & Science in Sports and Exercise*, 30 (5), S316.

Canadian Society for Exercise Physiology. (2002). *Physical Activity Readiness Questionare (PAR-Q)*. Retrieved April 2006 from htttp://www.csep.ca/forms/asp.

Carter, J.B., Bannister, E.W., et al. (1999). Effectiveness of Rest Pauses and Cooling in Alleviation of Heat Stress During Simulated Firefighting Activity. *Ergonomics*, 42 (2), 299-313.

Casa, D.J., Armstrong, L.E., et al. National Athletic Trainers Association Position Statement: Fluid Replacement in Athletes. *Journal of Athletic Training*, 35 (7), 212-224.

Caux, C., O'Brian, C.O., et al. (2002). Determination of Firefighter Exposure to Polycyclic Aromatic Hydrocarbons and Benzene During Firefighting Using Measurement of Biological Indicators. *Applied Occupational and Environmental Hygiene,* 17 (5), 379-386.

Clark, S., Rene, A., et al. (2002). Association of Body Mass Index and Health Status in Firefighters. *Journal of Occupational and Environmental Medicine*, 44, 940-946.

COMAR Subtitle 03 Fire-Rescue Education and Training Commission, Section 13B.03.01 Certification Standards and Procedures for Emergency Services Instructors.

Cone, D.C., MacMillian, D.S, et al. (2005). Noninvasive Fireground Assessment of Carboxyhemoglobin Levels in Firefighters. *Prehospital Emergency Care*, 9, 8-13.

Costrini, A.M., Pott, H.A., et al. (1979). Cardiovascular and Metabolic Manifestations of Heat Stroke and Severe Heat Exhaustion. *American Journal of Medicine*, 66, 296-302.

Dancesafe (2005). *Watch Out for Heat Stroke*. Retrieved May 2005 fromhttp://www.dancesafe.org/documents/druginfo/heatstroke.php

Davies, C.T.M. (1968). Limitations to the Prediction of Maximal Oxygen Intake from Cardiac Frequency Measurements. *Journal of Applied Physiology*, 24 (5), 700-706.

Deblina-Data, S., Armstrong, G. L., et al. (2003). Blood Exposures and Hepatitis C Virus Infections Among Emergency Responders. *Archives of Internal Medicine*, 163, 2605-2610.

Dempsey, W. L., Stevens, S.R., et al. (2002) Changes in Physical Performance and Medical Measures Following a Mandatory Firefighter Wellness Program. *Medicine & Science in Sports and Exercise*, 34 (5), S258.

Dickinson, E.T., Bevilacqua, J.J., et al. (2003). The Utility of Tympanic versus Oral Measurements of Firefighters in Emergency Incident Rehabilitation Operations. *Prehospital Emergency Care,* 7, 363-367.

Donovan, K.J. & McConnell, A.K. (1999). Do Firefighters Develop Specific Ventilatory Responses in Order to Cope with Exercise While Wearing Self-Contained Breathing Apparatus? *European Journal of Applied Physiology*, 80, 107-112.

Eglin, C.M., Coles, S., et al. (2004) Physiological Responses of Firefighter Instructors During Training Exercises. *Ergonomics*, 47 (5), 483-494.

Eves, N.D., Petersen, S.R., et al. (2002). Hyperoxia Improves Maximal Exercise with Self-Contained Breathing Apparatus. *Ergonomics*, 45 (12), 829-839.

Expert Panel on Detection and Treatment of High Blood Cholesterol in Adults. (2001). Executive Summary of the Third Report of the National Cholesterol Expert Panel (NCEP) on Detection, Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). *Journal of the American Medical Association*, 285 (19), 2486-2497.

Fabio, A., Ta, M., et al. (2002). Incident-Level Risk Factors for Firefighter Injuries at Structural Fires. *Journal of Occupational and Environmental Medicine,* 44 (11), 1059-1063.

Fahy, R.F. (2005). *U.S. Firefighter Fatalities Due to Sudden Cardiac Death,* 1995-2004. Quincy, MA: National Fire Protection Association.

Fangchao-Ma, L., Fleming, E., et al. (2005). Mortality in Florida Professional Firefighters, 1972-1999). *American Journal of Industrial Medicine*, 47, 509-517.

Feldman, D.M., Baron, S.L., et al. (2004). Symptoms, Respirator Use, and Pulmonary Function Changes Among New York City Firefighters Responding to the World Trade Center Disaster. *Chest*, 125, 1256-1264.

Ferris, J., Schnieders, M., et al. (2003). Blood Pressure Responses During the USFS Wildland Firefighter Pack Test. *Medicine & Science in Sports and Exercise*, 35 (5), S132.

Feunckes, F.D., Jongeneelen, F.J., et al. (1997). Uptake of Polycyclic Aromatic Hydrocarbons Among Trainers in a Firefighting Training Facility. *American Industrial Hygiene Association Journal*, 58, 23-28.

Firefighter Fatalities in the United States in 2004. (2005), Emmitsburg, MD: United States Fire Administration.

Firefighter Fatality Retrospective Study. (2002). Emmitsburg, MD: United States Fire Administration.

Fogarty, A.L., Armstrong, K.A., et al. (2004). Cardiovascular and Thermal Consequences of Protective Clothing: A Comparison of Clothed and Unclothed States. *Ergonomics*, 47 (10), 1073-1086.

Francis, K. & Brasher, J. (1992). A Height-Adjusted Step Test for Predicting Maximal Oxygen Consumption in Males. *Journal of Sports Medicine and Physical Fitness*, 32, 282-287.

Frim, J. & Romet, T.T. (1988). *Role of Moisture/Vapor Barrier in the Retention of Heat During Firefighting*. Ontario: Defense and Civil Institute of Environmental Medicine.

Ftaiti, F., Duflot, J.C., et al. (2001) Tympanic Temperature and Heart Rate Changes in Firefighters During Treadmill Runs Performed with Different Fireproof Jackets. *Ergonomics*, 44 (5), 502-512.

Gallanter, T. & Bozeman, W.P. (2002). Firefighter Illnesses and Injuries at a Major Fire Disaster. *Prehospital Emergency Care*, 6, 22-26.

Garfi, J., Marcotte, J., et al. (1996). The Effects of 16 Weeks of Cross Training on Resting Blood Pressure in Firefighter Recruits. *Medicine & Science in Sports and Exercise*, 28 (5), 14.

Gaskill, S.E., Ruby, B.C., et al. (2003). Seasonal Changes in Wildland Firefighter Aerobic Fitness. *Medicine & Science in Sports and Exercise*, 35 (5), S131.

Gathiram, P., Gaffin, J.G., et al. (1987). Time Course of Endotoxemia and Cardiovascular Changes in Heat-Stressed Primate. *Aviation Space Environmental Medicine.* 58, 1070-1074.

Gavin, T.P., Babington, J.P., et al. (2001). Clothing Fabric Does Not Affect Thermoregulation During Exercise in Moderate Heat. *Medicine & Science in Sports and Exercise*, 33 (12), 212-217.

Goodson, A. Gaskill, S. et al. (2005). Effects of Supplemental Feeding on Cognitive Function in Wildland Firefighters During Arduous Fire Suppression. *Medicine & Science in Sports and Exercise,* 37 (5), S307.

Green, R.C. (19998). A Monetary Incentive Program for Encouraging Improved Fitness for Professional Firefighters. *Medicine & Science in Sports and Exercise*, 30 (5), 98.

Haas, N.S., Wartenberg, D., et al. (2003). Latent Heath Effects in Firefighters. *International Journal of Occupational and Environmental Health*, 9 (2), 95-103.

Hagan, R.D., Feith, S.J., et al. (1996). Aggressive Water Fog Attack Reduces Heat Strain During Shipboard Firefighting. *Medicine & Science in Sports and Exercise*, 28 (5), 197-198.

Harger, B., Matthews, M.D., et al. (1999). Moderate Aerobic Work and Regular Resistive Exercises Improve Selected Fitness Components in Professional Firefighters. *Medicine & Science in Sports and Exercise*, 31 (5), S376.

Heil, D.P. (2001). Estimating Energy Expenditure in Montana's Wildland Firefighters Using the CSA Accelerometer. *Medicine & Science in Sports and Exercise*, 33 (5), S168.

Heil, D.P., Ruby, B.C., et al. (2004). Prediction of Energy Expenditure During Simulated Wildland Suppression Tasks. *Medicine & Science in Sports and Exercise*, 36 (5), S219.

Hodous, T.K., Pizatella, R., et al. (2004). Firefighter Fatalities 1998-2001: Overview with an Emphasis on Structure Related Traumatic Fatalities. *Injury Prevention*, 10, 222-226.

Houser, A.N., Jackson, B.A, et al. (2004). *Emergency Responder Injuries and Fatalities: An Analysis of Surveillance Data*. Santa Monica, CA: Rand Corporation.

Hubbard, R.W., Criss, R.E.I., et al. (1979), Diagnostic Significance of Serum Enzymes in a Rat Heat Stoke Model. *Journal of Applied Physiology*, 46, 334-339.

Johnson, A.T., Scott, W.H., et al. (1999). Effect of Respirator Inspiratory Resistance Level on Constant Load Treadmill Work Performance. *American Industrial Hygiene Association Journal*, 60 (4), 474-479.

Johnson, A.T. (1991). *Biomechanics and Exercise Physiology*. New York: John Wiley and Sons, Inc.

Johnson, A.T., Groove, C.M., & Weiss, R.A. (1992). Respirator Performance Rating Tables for Non-Temperate Environments. *American Industrial Hygiene Association Journal*, 53, 548-555.

Johnson, A.T., Dooly, C.R., et al. (1995). Influence of Anxiety Level on Work Performance with and without a Respirator Mask. *American Industrial Hygiene Association Journa*l, 56, 858-865.

Johnson, B.M., Somarriba, G.A., et al. (2005). Ineffectiveness of Torso Colling Vests in Reducing Uncompensable Heat Stress. *Medicine & Science in Sports and Exercise*, 37 (5), S404.

Jurca, R.M., Lamonte, M.J., et al. (2004). Association of Muscle Strength and Aerobic Fitness with Metabolic Syndrome in Men. *Medicine & Science in Sports and Exercise*, 36 (8), 1301-1307.

Kales, S.N., Soteriades, E.S., et al. (2003). *Firefighters and On-Duty Deaths from Coronary Heart Disease: A Case Control Study.* Environmental Health: A Global Access Science Source, 2, 14.

Karter, J. (2005). *United States Fire Department Profile Through 2003*. Quincy, MA: National Fire Protection Association.

Karter, Jr., M.J., & Molis, J.L. (2004). *United States Firefighter Injuries – 2003*. Quincy, MA: National Fire Protection Association.

Knockel, J.P., Beisel, W.R., et al. (1961). The Renal, Cardiovascular, Hematologic, and Serum Electrolyte Abnormalities of Heat Stroke. *American Journal of Medicine*, 30, 299-309.

Kreider, R.B., Burke, E.R., et al. (2003). The Neurosurgeon in Sport: Awareness of the Risks of Heat Stroke and Dietary Supplements. *Neurosurgery*, 52, 252-255.

Kunihiro, A. & Foster, J. (1998). *Heat Exhaustion and Heat Stroke*. Retrieved May 2005 from http://www.emedicine.com/emerg/topic236.htm.

Lakka, T.A., Laaksonen, D.E., et al. (2003). Sedentary Lifestyle, Poor Cardiorespiratory Fitness and the Metabolic Syndrome. *Medicine & Science in Sports and Exercise*, 35 (8), 1279-1286.

Lankford, D.E., Heil, D.P., et al. (2002). A Revised Algorithm for Estimating Energy Expenditure in Wildland Firefighters with the CSA Activity Monitor. *Medicine & Science in Sports and Exercise*, 34 (5), S195.

Leadbetter, G.W.I., Ruby, B.C., et al. (2001). Wildland Firefighter Load Carriage: Effects on Transit Time and Physiological Responses During Simulated Escape to Safety Zone. *Medicine & Science in Sports and Exercise*, 33 (5), S99.

LeBlanc, P.R., & Fahy, R.F. (2005). *Firefighter Fatalities in the United States – 2004*. Quincy, MA: National Fire Protection Association.

Lee, D.J., Fleming, L.E., et al. (2004). Risk of Hospitalization Among Firefighters: The National Health Interview Survey, 1986-1994. *American Journal of Public Health*, 94 (11), 1938-1939.

Legg, S. & Cruz, C.O. (2004). Effect of Single and Double Strap Backpacks on Lung Function. *Ergonomics*, 47 (3), 318-323.

Lim, S. & Yee, B. (2002). *Coach's Companion – Health Monitoring System*. Retrieved February 23, 2004 from http://limlloyed.com/coach/coach-below.html.

Lugo-Amador, N.M., Rothenhaus, T., & Moyer, D. (2004). *Heat Related Illness.* Emergency Medicine Clinics of North America, 22, 315-327.

Magnetti, S.M., Wyant, W.D., et al. (1999). Injuries to Volunteer Firefighters in West Virginia. *Journal of Occupational and Environmental Medicine*, 41 (2), 104-110.

McDowell, M.A., Fryar, C.D., et al. (2005). *Anthropometric Reference Data: Children and Adults, 1999-2002*. CDC: Advanced Data from Vital Statistics and Health, 361.

McLellan, T.M. & Selkirk, G.A. (2003). Effects of Replacing Pants with Shorts on the Heat Stress of Wearing Firefighting Protective Clothing. *Medicine & Science in Sports and Exercise*, 35 (5), S210.

Mechem, C.C., Dickenson, E.T., et al. (2002). Injuries from Assaults on Paramedics and Firefighters in an Urban Emergency Medical Services System. *Prehospital Emergency Care,* 6, 396-401.

Metcalf, B.S., Curnow, J.S.H., et al. (2002). Technical Reliability of the CSA Activity Monitor: The Early Bird Study. *Medicine & Science in Sports and Exercise*, 34 (9), 1533-1537.

Mol, E., Bos, J., et al. (2003). Differences in Physical Demands Between Actual Firefighting and Simulated Firefighting. *Medicine & Science in Sports and Exercise*, 35 (5), S210.

Moran, D.S., Montain, S.J., et al. (19998). Evaluation of Different Levels of Hydration Using a New Physiological Strain Index. *American Journal of Physiology*, 44, R854-R860.

Morren, M. Yzermans, C.J., et al. (2005). The Health of Volunteer Firefighters Three Years After a Technological Disaster. *Journal of Occupational Health,* 47, 523-532.

Myrthe, L.G., Grimm, W.H., et al. (1997). *Relationship Between Selected Measures of Physical Fitness and Performance of a Simulated Firefighting Emergency Task*. Brooks AFB, TX: Armstrong Laboratory, Crew Systems Directorate, Crew Technology Division 26.

National Institute for Occupational Safety and Health. (2002). Firefighter Death from Tanker Truck Rollovers. *Applied Occupational and Environmental Hygiene*, 17 (6), 398-399.

National Institute for Occupational Safety and Health. (2002). Traffic Hazards to Firefighters While Working Along Roadways. *Applied Occupational and Environmental Hygiene*, 17 (6), 398-399.

National Institute for Occupational Safety and Health. (2004). *Preventing Deaths and Injuries to Firefighteres During Live-Fire Training in Acquired Structures. Workplace Solutions* DHHS (NIOSH), 12.

National Fire Prevention Association. (1987). *NFPA 1403. Standard on Live Fire Training Evolutions in Structures.* Quincy, MA: National Fire Protections Association.

National Fire Protection Association. (1987). *NFPA 1500: Standard on Fire Department Occupational Safety and Health Program.* Quincy, MA: National Fire Protection Association.

Norberg, M. (2005). Heart Healthy Firefighter Program. *Emergency Medical Services*, 34 (2), 91.

Oh, R.C., & Hennings, J.S. (2003). Exertional Heat Stroke in an Infantry Soldier Taking Ephedra-Containing Dietary Supplements. *Military Medicine*, 168, 429-430.

Parker, A.G., Womack, J.G., et al. (2005). Association of Aerobic Fitness and Metabolic Syndrome in Male Firefighters. *Medicine & Science in Sports and Exercise*, 37 (5), S383.

Perzant, D.J., Dhala, A., et al. (1999). The Incidence, Prevalence and Severity of Sarcoidosis in New York City Firefighters. *Chest*, 116 (5), 1183-1193.

Perzant, D.J., Weiden, M., et al. (2002). Cough and Bronchial Responsiveness in Firefighters at the World Trade Center Site. *New England Journal of Medicine*, 347 (11), 806-815.

Rabbits, A., Alden, N.E., et al. (2005). Outpatient Firefighter Burn Injuries: A 10-Year Longitudinal Study. *Journal of Burn Care Rehabilitation*, 25 (5), 430-434.

Rayson, M.P., Wilkinson, D., et al. (2004). Physiological Assessment of Firefighters During a High Rise Scenario. *Medicine & Science in Sports and Exercise*, 36 (5), S245-S246.

Reinhart, T.E., & Ottmar, R.D. (2004). Baseline Measurement of Smoke Exposure Among Wildland Firefighters. *Journal of Occupational and Environmental Hygiene*, 1, 593-606.

Rhea, M.R., Alvar, B.A., et al. (2004). Physical Fitness and Job Performance of Firefighters. *Journal of Strength and Conditioning Research*, 18 (2), 348-352.

Roberts, M.A., O'Dea, J., et al. (2002). Fitness Levels of Firefighter Recruits Before and After a Supervised Exercise Training Program. *Medicine & Science in Sports and Exercise*, 16 (2), 271-277.

Roberts, O. (2004). Death in the Heat: Can Football heat Stroke be Prevented? *Current Sports Medicine Reports*, 3, 1-3.

Rodriguez, J.L. & Eldridge, J.A. (2003). The Function of Aerobic capacity and Strength in Predicting the Probability of Injury in Firefighters. *Medicine & Science in Sports and Exercise*, 35 (5), S209.

Rossi, R. (2003). Firefighting and its Influence on the Body. *Ergonomics*, 46 (10), 1017-1033.

Ruby, B.C., Schoeller, D.A., et al. (2005). Water Turnover and Changes in Body Composition During Arduous Wildfire Suppression. *Medicine & Science in Sports and Exercise*, 35 (10), 1760-1765.

Ruby, B.C., Schriver, T.C., et al. (2002). Total Energy Expenditure During Arduous Wildfire Suppression. *Medicine & Science in Sports and Exercise*, 34 (6), 1048-1054.

Selkirk, G.A. & McLellan, T.M. (2004). Physical Work Limits for Toronto Firefighteres in Warm Environments. *Journal of Occupational and Environmental Hygiene*, 1, 199-212.

Selkirk, G.A., McLellan, T.M., et al. (2004). Active versus Passive Cooling During Work in Warm Environments While Wearing Firefighting Protective Clothing. *Journal of Occupational and Environmental Hygiene*, 1, 521-531.

Slaughter, J., Koenig, J., et al. (2004). Association Between Lung Function and Exposure to Smoke Among Firefighters at Prescribed Burns. *Journal of Occupational and Environmental Hygiene*, 1 (1), 45-49.

Smith, D.L. (2002). Acute Effects of Firefighting Activity on Coagulation. *Medicine & Science in Sports and Exercise,* 34 (5), S194.

Smith, D.L., Manning, T.S., et al. (2001). Effects of Strenuous Live-Fire Drills on Cardiovascular and Psychological Responses of Recruit Firefighting. *Ergonomics*, 44 (3), 244-254.

Smith, D.L., & Petruzzello, S. J. (1998). Selected Physiological and Psychological Responses to Live-Fire Drills in Different Configurations of Firefighting Gear. *Ergonomics*, 41 (8), 1141-1154.

Smith, D.L., Petruzzello, S. J., et al. (2005). Selected Hormonal and Immunological Responses to Strenuous Live-Fire Firefighting Drills. *Ergonomics*, 48 (1), 55-65.

Smith, D.L., Petruzzello, S.J., et al. (1997). The Effect of Different Thermal Environments on the Physiological and Psychological responses of Firefighters to a Training Drill. *Ergonomics*, 40 (4), 500-510.

Smolander, J., Kuklane, K., et al. (2004). Effectiveness of Light-Weight Ice-Vest for Body Cooling While Wearing Firefighter Protective Clothing in the Heat. *International Journal of Occupational Safety and Ergonomics*, 10 (2), 111-117.

Snook, E.S., Petruzzello, S.J., et al. (2004). Perceptual and Physiological Heat Strain: Examination in Firefighters Performing Simulated Firefighting Activities in the Heat. *Medicine & Science in Sports and Exercise*, 36 (5), S219-S220.

Sothmann, M.S., Landy, F., et al, (1992). Age as a Bona Fide Occupational Qualification for Firefighting: A Review on the Importance of Measuring Aerobic Power. *Journal of Occupational Medicine*, 34 (1), 26-33.

Soukup, J.T., Maynard, T.S., et al. (2005). Maximal Oxygen Consumption in Professional Firefighters Across Position and Gender. *Medicine & Science in Sports and Exercise*, 37 (5), S87.

Speilberger, C.D. (1983). *Manual for the State-Trait Anxiety Inventory (STAI)*. Palo Alto, CA: Consulting Psychologists Press.

Stevens, S.R., Dempsey, W.L., et al. (2002). The Reduction of Occupational Absenteeism Following Two Years of Firefighter Wellness Program. *Medicine & Science in Sports and Exercise*, 34 (5), S194.

Thiel, A., Stern, J., et al. (2003). *Trends and Hazards in Firefighting Training - Special Report*. Emmitsburg, MD: United States Fire Administration.

Tikuisis, P., McLellan, T.M., et al. (2002). Perceptual versus Physiological Heat Strain During Exercise Heat Stress. *Medicine & Science in Sports and Exercise,* 34 (9), 1454-1461.

Tonya, L., Rozenek, R., et al. (2004). Prevalence and Trends in Coronary Artery Disease Risk Factors in Southern California Firefighters. *Medicine & Science in Sports and Exercise,* 36 (5), S307.

Treitman, R.D., Burgess, W.A., et al. (1980). Air Contaminants Encountered by Firefighters. *American Industrial Hygiene Association Journal,* 14 (11), 796-802.

Tysk, S., & Ruby, B.C. (1999). Estimating Energy Expenditure with Minute-by-Minute Heart Rate Monitoring in Tasks Associated with Wildland Firefighting. *Medicine & Science in Sports and Exercise*, 31 (5), S285.

United States Department of Health and Human Services (DHHS). (2000). *Healthy People 2010, Second Edition*. Washington D.C.: United States Government Printing Office.

United States Fire Administration. (2002). *Firefighter Fatality Retrospective Study*. Emmitsburg, MD: Federal Emergency Management Agency.

Van Winjngaarden, E. & Stewart, P.A. (2003). Critical Literature Review of Determinants and Levels of Occupational Benzene Exposure for United States Community Based Case-Control Studies. *Applied Occupational and Environmental Hygiene*, 18, 678-693.

Warfolk, B. (2000). Heat Waves: Their Impact on the Health of Elders. *Geriatric Nursing,* 21 (2), 70-77.

Webster, M.J., Maynard, T.S., et al. (2005). A Preliminary Report on Risk Stratification, Ischemic ECG Change Prevalence and Functional Capacity in Professional Firefighters. *Medicine & Science in Sports and Exercise*, 37 (5), S231.

Williford, H.N., Duey, B., et al. (19998). Physiological Changes as a Result of 18 Weeks of Firefighter Recruit Training. *Medicine & Science in Sports and Exercise*, 30 (5), 317.

Williford, H.N., Duey, W.J., et al. (1999). Relationship Between Firefighting Suppression Tasks and Physical Fitness. *Ergonomics*, 42 (9), 1179-1186.

Wilson, J.R., Raven, P.B., et al. (1999). Prediction of Respiratory Distress During Maximal Physical Exercise: The Role of Trait Anxiety. *American Industrial Hygiene Association Journal*, 60, 512-517.

Womack, J.W., Green, J.S., et al. (2004). Prevalence of Metabolic Syndrome in Male Firefighters Compared to Prevalence of the United States Male Population at Large as Estimated by the National Education Program. *Medicine & Science in Sports and Exercise*, 36 (5), S161.

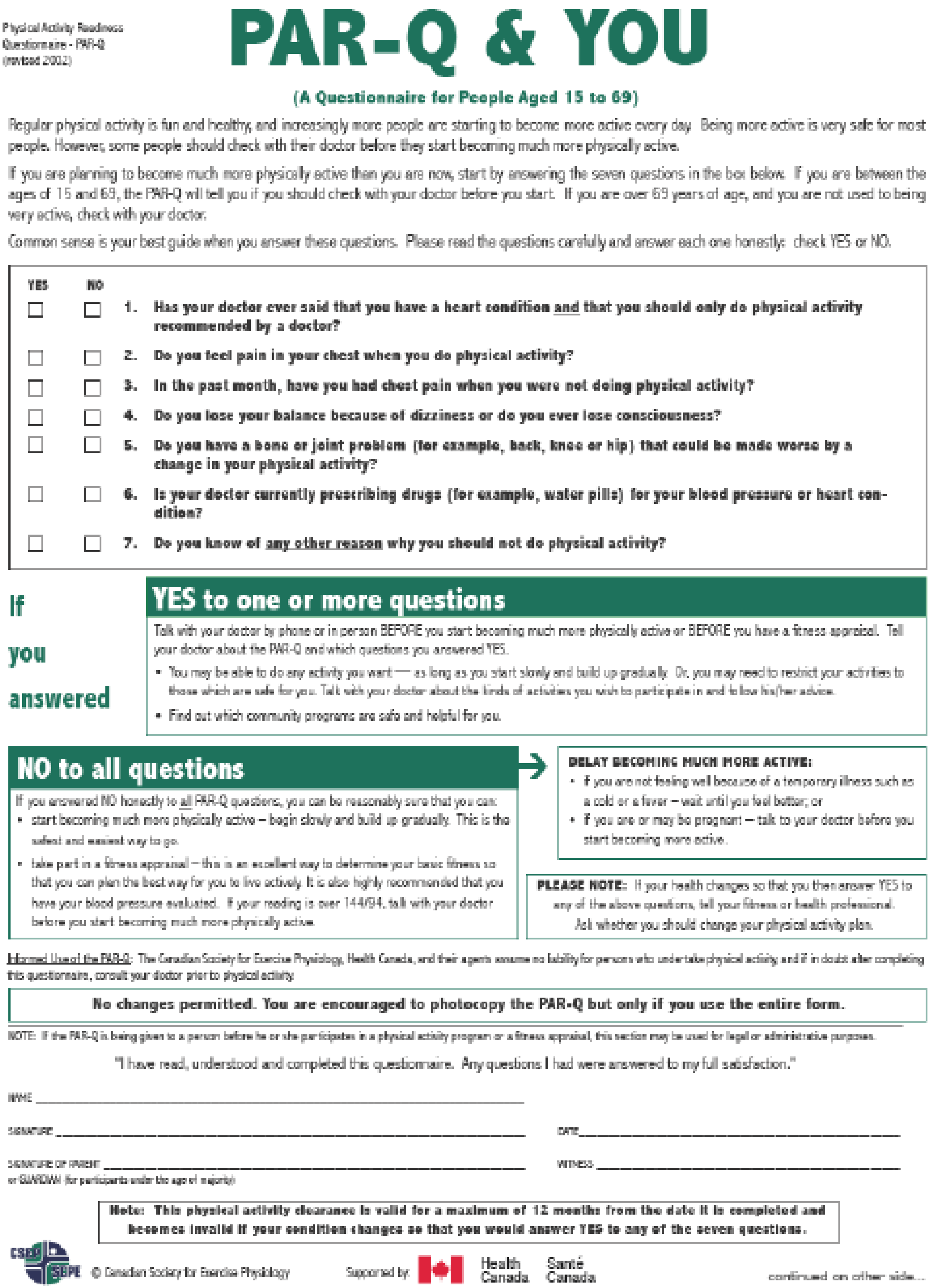
Womack, J.W., Green, J.S., et al. (1999). Long-Term Changes in Cardiovascular Risk Markers for Firefighters: A Six Year Longitudinal Study. *Medicine & Science in Sports and Exercise*, 31 (5), S57.

Womack, J.W., Humbarger, C.D., et al. (2005). Coronary Artery Disease Risk Factors in Firefighters: Effectiveness of a One-Year Voluntary Health and Wellenss Program. *Medicine & Science in Sports and Exercise*, 37 (5), S385.

Yaqub, B. & Deeb, S.A. (1998). Heat Strokes: Aetiopathogenesis. Neurological Characteristics, Treatment and Outcome. *Journal of Neurological Science,* 56, 144-151.

Yeo, T.D. (2004). Heat Stroke: A Comprehensive Review. *AACN Clinical Issues*, 15 (2), 280-293.

APPENDIX A - MEDICAL SCREENING FORMS



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

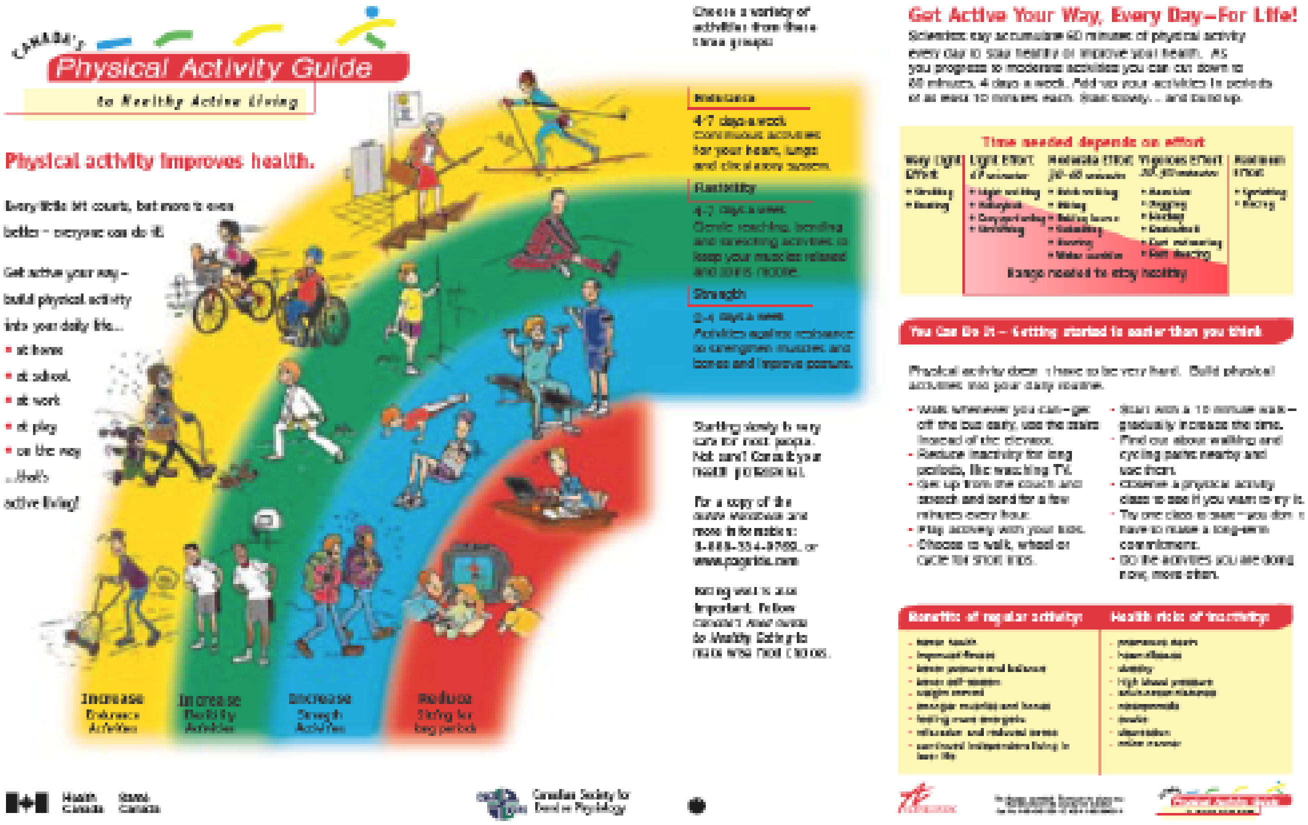
Supported by: Health Canada Santé Canada

continued on other side...

...continued from other side

PAR-Q & YOU

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)



Physical activity improves health.

Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life...

- at home
- at school
- at work
- at play
- on the way

...that's active living!

Choose a variety of activities from these three groups:

Endurance
4-7 days a week
Continuous activities for your heart, lungs and circulatory system.

Flexibility
4-7 days a week
Gentle reaching, bending and stretching activities to keep your muscles relaxed and joints mobile.

Strength
2-4 days a week
Activities against resistance to strengthen muscles and bones and improve posture.

Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the Guide Handbook and more information: 1-888-334-9769, or www.paguide.com

Eating well is also important. Follow Canada's Food Guide to Healthy Eating to make wise food choices.

Get Active Your Way, Every Day–For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly... and build up.

Time needed depends on effort

Very Light Effort	Light Effort 60 minutes	Moderate Effort 30-60 minutes	Vigorous Effort 20-30 minutes	Maximum Effort
• Strolling • Dusting	• Light walking • Volleyball • Easy gardening • Stretching	• Brisk walking • Biking • Raking leaves • Swimming • Dancing • Water aerobics	• Aerobics • Jogging • Hockey • Basketball • Fast swimming • Fast dancing	• Sprinting • Racing
	Range needed to stay healthy			

You Can Do It – Getting started is easier than you think

Physical activity doesn't have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don't have to make a long-term commitment.
- Do the activities you are doing now, more often.

Benefits of regular activity:	Health risks of inactivity:
- better health - improved fitness - better posture and balance - better self-esteem - weight control - stronger muscles and bones - feeling more energetic - relaxation and reduced stress - continued independent living in later life	- premature death - heart disease - obesity - high blood pressure - adult-onset diabetes - osteoporosis - stroke - depression - colon cancer

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health.** Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

Supported by: Health Canada Santé Canada

Physical Activity Readiness
Medical Examination
(revised 2002)

PARmed-X PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION

The PARmed-X is a physical activity-specific checklist to be used by a physician with patients who have had positive responses to the Physical Activity Readiness Questionnaire (PAR-Q). In addition, the Conveyance/Referral Form in the PARmed-X can be used to convey clearance for physical activity participation, or to make a referral to a medically-supervised exercise program.

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. The PAR-Q by itself provides adequate screening for the majority of people. However, some individuals may require a medical evaluation and specific advice (exercise prescription) due to one or more positive responses to the PAR-Q.

Following the participant's evaluation by a physician, a physical activity plan should be devised in consultation with a physical activity professional (CSEP-Professional Fitness & Lifestyle Consultant or CSEP-Exercise Therapist™). To assist in this, the following instructions are provided:

PAGE 1: • Sections A, B, C, and D should be completed by the participant BEFORE the examination by the physician. The bottom section is to be completed by the examining physician.

PAGES 2 & 3: • A checklist of medical conditions requiring special consideration and management.

PAGE 4: • Physical Activity & Lifestyle Advice for people who do not require specific instructions or prescribed exercise.

• Physical Activity Readiness Conveyance/Referral Form - an optional tear-off tab for the physician to convey clearance for physical activity participation, or to make a referral to a medically-supervised exercise program.

This section to be completed by the participant

A PERSONAL INFORMATION:

NAME ____

ADDRESS ____

____

TELEPHONE ____

BIRTHDATE ________________________ GENDER ________

MEDICAL No. _______________________________________

B PAR-Q: Please indicate the PAR-Q questions to which you answered YES

- ☐ Q 1 Heart condition
- ☐ Q 2 Chest pain during activity
- ☐ Q 3 Chest pain at rest
- ☐ Q 4 Loss of balance, dizziness
- ☐ Q 5 Bone or joint problem
- ☐ Q 6 Blood pressure or heart drugs
- ☐ Q 7 Other reason:

____

C RISK FACTORS FOR CARDIOVASCULAR DISEASE:

Check all that apply

- ☐ Less than 30 minutes of moderate physical activity most days of the week.
- ☐ Currently smoker (tobacco smoking 1 or more times per week).
- ☐ High blood pressure reported by physician after repeated measurements.
- ☐ High cholesterol level reported by physician.
- ☐ Excessive accumulation of fat around waist.
- ☐ Family history of heart disease.

***Please note:** Many of these risk factors are modifiable. Please refer to page 4 and discuss with your physician.*

D PHYSICAL ACTIVITY INTENTIONS:

What physical activity do you intend to do?

____

____

____

This section to be completed by the examining physician

Physical Exam:

Ht	Wt	BP i) /
		BP ii) /

Conditions limiting physical activity:

- ☐ Cardiovascular
- ☐ Musculoskeletal
- ☐ Respiratory
- ☐ Abdominal
- ☐ Other

Tests required:

- ☐ ECG
- ☐ Blood
- ☐ Exercise Test
- ☐ Urinalysis
- ☐ X-Ray
- ☐ Other

Physical Activity Readiness Conveyance/Referral:

Based upon a current review of health status, I recommend:

Further information:
- ☐ Attached
- ☐ To be forwarded
- ☐ Available on request

- ☐ No physical activity
- ☐ Only a medically-supervised exercise program until further medical clearance
- ☐ Progressive physical activity:
  - ☐ with avoidance of: ______________________________
  - ☐ with inclusion of: ______________________________
  - ☐ under the supervision of a CSEP-Professional Fitness & Lifestyle Consultant or CSEP-Exercise Therapist™
- ☐ Unrestricted physical activity–start slowly and build up gradually

Supported by: Health Canada Santé Canada

Physical Activity Readiness
Medical Examination
(revised 2002)

PARmed-X PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION

Following is a checklist of medical conditions for which a degree of precaution and/or special advice should be considered for those who answered "YES" to one or more questions on the PAR-Q, and people over the age of 69. Conditions are grouped by system. Three categories of precautions are provided. Comments under Advice are general, since details and alternatives require clinical judgement in each individual instance.

	Absolute Contraindications	**Relative Contraindications**	**Special Prescriptive Conditions**	**ADVICE**
	Permanent restriction or temporary restriction until condition is treated, stable, and/or past acute phase.	Highly variable. Value of exercise testing and/or program may exceed risk. Activity may be restricted. Desirable to maximize control of condition. Direct or indirect medical supervision of exercise program may be desirable.	Individualized prescriptive advice generally appropriate: • limitations imposed; and/or • special exercises prescribed. May require medical monitoring and/or initial supervision in exercise program.	
Cardiovascular	☐ aortic aneurysm (dissecting) ☐ aortic stenosis (severe) ☐ congestive heart failure ☐ crescendo angina ☐ myocardial infarction (acute) ☐ myocarditis (active or recent) ☐ pulmonary or systemic embolism—acute ☐ thrombophlebitis ☐ ventricular tachycardia and other dangerous dysrhythmias (e.g., multi-focal ventricular activity)	☐ aortic stenosis (moderate) ☐ subaortic stenosis (severe) ☐ marked cardiac enlargement ☐ supraventricular dysrhythmias (uncontrolled or high rate) ☐ ventricular ectopic activity (repetitive or frequent) ☐ ventricular aneurysm ☐ hypertension—untreated or uncontrolled severe (systemic or pulmonary) ☐ hypertrophic cardiomyopathy ☐ compensated congestive heart failure	☐ aortic (or pulmonary) stenosis—mild angina pectoris and other manifestations of coronary insufficiency (e.g., post-acute infarct) ☐ cyanotic heart disease ☐ shunts (intermittent or fixed) ☐ conduction disturbances • complete AV block • left BBB • Wolff-Parkinson-White syndrome ☐ dysrhythmias—controlled ☐ fixed rate pacemakers	• clinical exercise test may be warranted in selected cases, for specific determination of functional capacity and limitations and precautions (if any). • slow progression of exercise to levels based on test performance and individual tolerance. • consider individual need for initial conditioning program under medical supervision (indirect or direct).
			☐ intermittent claudication	progressive exercise to tolerance
			☐ hypertension: systolic 160-180; diastolic 105+	progressive exercise; care with medications (serum electrolytes; post-exercise syncope; etc.)
Infections	☐ acute infectious disease (regardless of etiology)	☐ subacute/chronic/recurrent infectious diseases (e.g., malaria, others)	☐ chronic infections ☐ HIV	variable as to condition
Metabolic		☐ uncontrolled metabolic disorders (diabetes mellitus, thyrotoxicosis, myxedema)	☐ renal, hepatic & other metabolic insufficiency	variable as to status
			☐ obesity ☐ single kidney	dietary moderation, and initial light exercises with slow progression (walking, swimming, cycling)
Pregnancy		☐ complicated pregnancy (e.g., toxemia, hemorrhage, incompetent cervix, etc.)	☐ advanced pregnancy (late 3rd trimester)	refer to the "PARmed-X for PREGNANCY"

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health.** Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17: 4 338-345.

The PAR-Q and PARmed-X were developed by the British Columbia Ministry of Health. They have been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

No changes permitted. You are encouraged to photocopy the PARmed-X, but only if you use the entire form.

Disponible en français sous le titre
«Évaluation médicale de l'aptitude à l'activité physique (X-AAP)»

Continued on page 3...

Physical Activity Readiness
Medical Examination
(revised 2002)

	Special Prescriptive Conditions	ADVICE
Lung	☐ chronic pulmonary disorders	special relaxation and breathing exercises
	☐ obstructive lung disease ☐ asthma	breath control during endurance exercises to tolerance; avoid polluted air
	☐ exercise-induced bronchospasm	avoid hyperventilation during exercise; avoid extremely cold conditions; warm up adequately; utilize appropriate medication.
Musculoskeletal	☐ low back conditions (pathological, functional)	avoid or minimize exercise that precipitates or exasperates e.g., forced extreme flexion, extension, and violent twisting; correct posture, proper back exercises
	☐ arthritis—acute (infective, rheumatoid; gout)	treatment, plus judicious blend of rest, splinting and gentle movement
	☐ arthritis—subacute	progressive increase of active exercise therapy
	☐ arthritis—chronic (osteoarthritis and above conditions)	maintenance of mobility and strength; non-weightbearing exercises to minimize joint trauma (e.g., cycling, aquatic activity, etc.)
	☐ orthopaedic	highly variable and individualized
	☐ hernia	minimize straining and isometrics; stregthen abdominal muscles
	☐ osteoporosis or low bone density	avoid exercise with high risk for fracture such as push-ups, curl-ups, vertical jump and trunk forward flexion; engage in low-impact weight-bearing activities and resistance training
CNS	☐ convulsive disorder not completely controlled by medication	minimize or avoid exercise in hazardous environments and/or exercising alone (e.g., swimming, mountainclimbing, etc.)
	☐ recent concussion	thorough examination if history of two concussions; review for discontinuation of contact sport if three concussions, depending on duration of unconsciousness, retrograde amnesia, persistent headaches, and other objective evidence of cerebral damage
Blood	☐ anemia—severe (< 10 Gm/dl) ☐ electrolyte disturbances	control preferred; exercise as tolerated
Medications	☐ antianginal ☐ antihypertensive ☐ beta-blockers ☐ diuretics ☐ others ☐ antiarrhythmic ☐ anticonvulsant ☐ digitalis preparations ☐ ganglionic blockers	NOTE: consider underlying condition. Potential for: exertional syncope, electrolyte imbalance, bradycardia, dysrhythmias, impaired coordination and reaction time, heat intolerance. May alter resting and exercise ECG's and exercise test performance.
Other	☐ post-exercise syncope	moderate program
	☐ heat intolerance	prolong cool-down with light activities; avoid exercise in extreme heat
	☐ temporary minor illness	postpone until recovered
	☐ cancer	if potential metastases, test by cycle ergometry, consider non-weight bearing exercises; exercise at lower end of prescriptive range (40-65% of heart rate reserve), depending on condition and recent treatment (radiation, chemotherapy); monitor hemoglobin and lymphocyte counts; add dynamic lifting exercise to strengthen muscles, using machines rather than weights.

*Refer to special publications for elaboration as required

The following companion forms are available online: http://www.csep.ca/forms.asp

The **Physical Activity Readiness Questionnaire (PAR-Q)** - a questionnaire for people aged 15-69 to complete before becoming much more physically active.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for PREGNANCY)** - to be used by physicians with pregnant patients who wish to become more physically active.

For more information, please contact the:

Canadian Society for Exercise Physiology
202 - 185 Somerset St. West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565 • Online: www.csep.ca

Note to physical activity professionals...

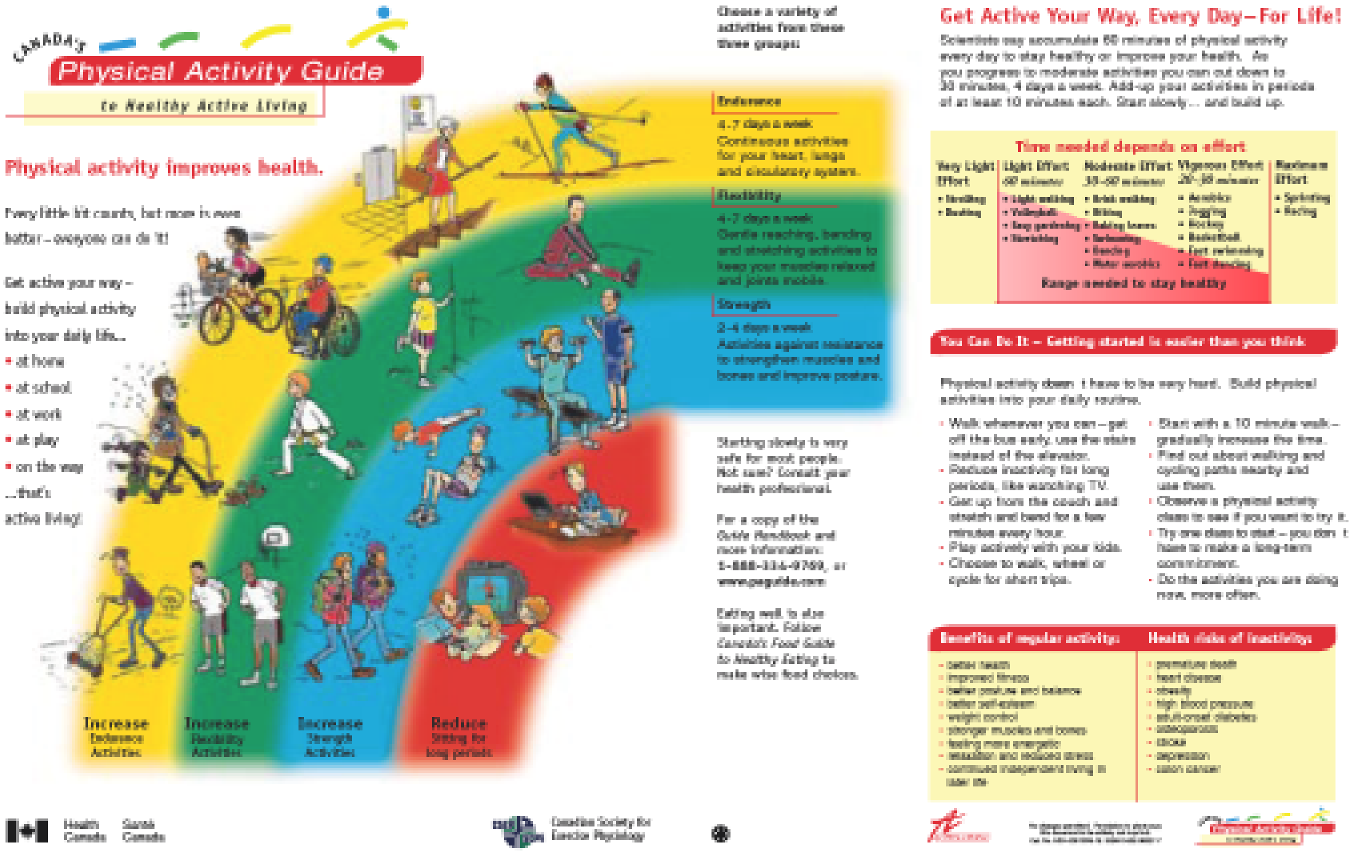
It is a prudent practice to retain the completed Physical Activity Readiness Conveyance/Referral Form in the participant's file.

Supported by: Health Canada Santé Canada

Continued on page 4...

Physical Activity Readiness
Medical Examination
(revised 2002)

PARmed-X PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION



Physical activity improves health.

Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life...

- at home
- at school
- at work
- at play
- on the way

...that's active living!

Choose a variety of activities from these three groups:

Endurance
4-7 days a week
Continuous activities for your heart, lungs and circulatory system.

Flexibility
4-7 days a week
Gentle reaching, bending and stretching activities to keep your muscles relaxed and joints mobile.

Strength
2-4 days a week
Activities against resistance to strengthen muscles and bones and improve posture.

Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the *Guide Handbook* and more information: 1-888-334-9769, or www.paguide.com

Eating well is also important. Follow *Canada's Food Guide to Healthy Eating* to make wise food choices.

Get Active Your Way, Every Day – For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly... and build up.

Time needed depends on effort

Very Light Effort	Light Effort 60 minutes	Moderate Effort 30-60 minutes	Vigorous Effort 20-30 minutes	Maximum Effort
• Strolling • Dusting	• Light walking • Volleyball • Easy gardening • Stretching	• Brisk walking • Biking • Raking leaves • Swimming • Dancing • Water aerobics	• Aerobics • Jogging • Hockey • Basketball • Fast swimming • Fast dancing	• Sprinting • Racing

Range needed to stay healthy

You Can Do It – Getting started is easier than you think

Physical activity doesn't have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don't have to make a long-term commitment.
- Do the activities you are doing now, more often.

Benefits of regular activity:	Health risks of inactivity:
- better health - improved fitness - better posture and balance - better self-esteem - weight control - stronger muscles and bones - feeling more energetic - relaxation and reduced stress - continued independent living in later life	- premature death - heart disease - obesity - high blood pressure - adult-onset diabetes - osteoporosis - stroke - depression - colon cancer

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

PARmed-X Physical Activity Readiness Conveyance/Referral Form

Based upon a current review of the health status of ______________________________, I recommend:

☐ No physical activity

☐ Only a medically-supervised exercise program until further medical clearance

☐ Progressive physical activity

☐ with avoidance of: ______________________________

☐ with inclusion of: ______________________________

☐ under the supervision of a CSEP-Professional Fitness & Lifestyle Consultant or CSEP-Exercise Therapist™

☐ Unrestricted physical activity — start slowly and build up gradually

Further Information:
☐ Attached
☐ To be forwarded
☐ Available on request

Physician/clinic stamp:

NOTE: This physical activity clearance is valid for a maximum of six months from the date it is completed and becomes invalid if your medical condition becomes worse.

______________________________ M.D.

______________________________ 20______
(date)

APPENDIX B - SUPPORTING DATA

		N	Mean	Std. Error	Min	Max
AccM	1st Floor	176	3.52	0.07	0.73	5.97
	MAZE	186	4.41	0.06	0.76	5.84
	3rd Floor	177	3.50	0.05	0.46	5.17
	RIT	173	0.60	0.03	0.13	2.38
VT	1st Floor	176	2,184	111	490	10,329
	MAZE	186	2,395	122	261	12,933
	3rd Floor	177	2,431	122	511	12,129
	RIT	173	756	36	183	4,220
VE	1st Floor	176	75.67	4.05	12.00	378.91
	MAZE	186	87.86	4.81	5.98	505.37
	3rd Floor	177	85.06	4.43	10.24	425.38
	RIT	173	18.18	0.89	4.18	72.36
Br/M	1st Floor	176	37.4	0.4	22.5	52.4
	MAZE	186	40.4	0.4	21.5	55.5
	3rd Floor	177	37.4	0.4	19.7	51.9
	RIT	173	25.5	0.4	12.6	39.7
PifVt	1st Floor	176	4,396	228	864	21,560
	MAZE	186	4,952	262	453	27,258
	3rd Floor	177	4,898	249	827	23,562
	RIT	173	1,338	64	329	6,256
PefVt	1st Floor	176	4,039	217	688	20,042
	MAZE	186	4,689	255	330	27,345
	3rd Floor	177	4,506	236	626	22,998
	RIT	173	1,102	54	324	4,989
HR	1st Floor	176	144.7	1.1	85.4	170.1
	MAZE	186	148.8	1.1	59.5	175.1
	3rd Floor	177	149.0	1.0	85.4	174.4
	RIT	173	98.9	1.4	0.0	141.3
%HRmax	1st Floor	176	76.3	0.6	44.0	99.1
	MAZE	185	78.5	0.6	30.2	99.8
	3rd Floor	177	78.5	0.5	44.9	97.6
	RIT	173	70.9	1.1	0.0	112.5
Core Temp	1st Floor	122	94.5	1.9	18.6	242.1
	MAZE	117	95.5	1.3	25.0	129.3
	3rd Floor	119	96.5	2.1	3.6	253.7
	RIT	121	94.6	1.8	23.2	241.9

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	1459.588	3	486.519	396.380	<0.001
	Within Groups	367.859	708	.520		
	Total	1827.417	711			
Vt	Between Groups	3E+008	3	111342362.3	56.5169	<0.001
Within Groups	!E+008	708	1966648.806			
	Total	4E+008	711			
Ve	Between Groups	564103.8	3	188.034.601	68.816	<0.001
	Within Groups	1934549	708	2732.414		
	Total	2498653	711			
Br/M	Between Groups	23086.357	3	7695.452	288.618	<0.001
	Within Groups	18877.488	708	26.663		
	Total	41963.845	711			
PifVt	Between Groups	2E+009	3	520219391.5	61.299	<0.001
	Within Groups	6E+009	708	8486588.007		
	Total	8E+009	711			
PefVt	Between Groups	1E+009	3	493008916.3	63.422	<0.001
Within Groups	6E+009	708	7773453.687			
	Total	7E+009	711			
HR	Between Groups	311704.7	3	103901.564	451.359	<0.001
Withing Groups	162979.4	708	230.197			
Total	474684.0	711				
%HRmax	Between Groups	6865.803	3	2288.601	24.243	<0.001
	Within Groups	66741.372	707	94.401		
	Total	73607.174	710			
Core	Between Groups	317.979	3	105.993	.269	.848
Temp	Withing Groups	187451.4	475	394.635		
	Total	187769.4	478			

Working Evolution Physical Stress as a Function of RIT Stress Level

This table contains the observed physiologic data from the working evolutions in units of the RIT evolution (e.g. RIT heart rate = 50, 1st floor heart rate = 150 3 RIT units). This analysis provides context for evaluating the relative physiologic stress across evolutions.

		N	Mean	Std. Error	Min	Max
AccM / RIT Factor	1st Floor	167	8.25	0.38	1.00	28.00
	Maze	172	10.13	0.43	1.10	32.90
	3rd Floor	165	8.00	0.35	1.20	24.30
VT / RIT Factor	1st Floor	167	3.10	0.08	1.40	7.30
	Maze	172	3.39	0.12	0.60	10.90
	3rd Floor	165	3.36	0.09	1.20	8.80
Ve / RIT Factor	1st Floor	167	4.56	0.13	1.50	13.30
	Maze	172	5.21	0.21	0.50	24.80
	3rd Floor	165	4.98	0.16	0.90	18.60
Br/M / RIT Factor	1st Floor	167	1.51	0.02	0.80	2.70
	Maze	172	1.62	0.02	0.90	2.90
	3rd Floor	165	1.51	0.02	0.80	2.80
PifVT / RIT Factor	1st Floor	167	3.55	0.10	1.30	8.70
	Maze	172	3.96	0.15	0.50	16.80
	3rd Floor	165	3.85	0.11	1.10	9.70
PefVT / RIT Factor	1st Floor	167	3.98	0.11	1.50	11.10
	Maze	172	4.56	0.18	0.50	20.70
	3rd Floor	165	4.30	0.13	0.90	11.80
HR / RIT Factor	1st Floor	166	1.49	0.02	0.70	2.50
	Maze	171	1.57	0.04	0.60	7.90
	3rd Floor	164	1.56	0.04	0.90	7.50
%HRmax / RIT Factor	1st Floor	166	1.10	0.02	0.50	2.20
	Maze	170	1.16	0.03	0.40	5.80
	3rd Floor	164	1.15	0.03	0.70	5.60

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM Rit Factor	Between Groups	463.664	2	231.892	3.089	<0.001
	Within Groups	12778.253	201	25.505		
	Total	13241.917	503			
VtRIT	Between Groups	8.832	2	4.416	2.789	.062
	Within Groups	790.609	501	1.578		
	Total	799.441	503			
VeRIT	Between Groups	37.225	2	18.612	3.766	.024
	Within Groups	2475.987	501	4.942		
	Total	2513.211	503			
BrFRIT	Between Groups	1.422	2	.711	8.624	<0.001
	Within Groups	41.297	501	.082		
	Total	2513.211	503			
PiFRIT	Between Groups	15.044	2	7.522	2.966	.052
	Within Groups	1270.542	501	2.536		
	Total	1285.586	503			
PeFRIT	Between Groups	28.324	2	14.162	4.227	0.15
	Within Groups	1678.729	501	3.351		
	Total	1707.053	503			
HRRIT	Between Groups	.621	2	.311	1.399	.2048
	Withing Groups	110.544	498	.222		
	Total	111.166	500			
RelHRRIT	Between Groups	.323	2	.161	1.225	.295
	Within Groups	65.445	497	.132		
	Total	65.768	499			

Working Evolution Analysis (RIT Removed)

Removing the RIT values from the statistical analysis allows the comparison of the working evolutions without the variance associated with including a categorically different evolution in the analysis.

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	99.695	2	49.847	78.413	<0.001
	Within Groups	340.737	536	.636		
	Total	440.432	538			
Vt	Between Groups	6272159	2	3136079.503	1.242	.290
Within Groups	1E+009	536	2524083.243			
	Total	1E+009	538			
Ve	Between Groups	14604.464	2	77302.232	2.048	.130
Within Groups	1910731	536	3564.797			
	Total	1925336	538			
Br/M	Between Groups	1058.317	2	529.158	18.922	<0.001
Within Groups	14989.606	536	27.966			
	Total	16047.922	538			
PifVt	Between Groups	33468087	2	16734043.62	1.524	.219
Within Groups	6E+009	536	10982979.83			
	Total	6E+009	538			
PefVt	Between Groups	40235441	2	20117720.66	1.991	.138
Within Groups	5E+009	536	10103321.17			
	Total	5E+009	538			
HR	Between Groups	2049.303	2	20117720.66	1.991	.138
Withing Groups	107940.5	536	201.381			
	Total	109989.8	538			
%HRmax	Between Groups	567.425	2	283.713.	4.568	.011
Within Groups	33226.508	535	62.106			
	Total	33793.934	537			
Core	Between Groups	242.424	2	121.212	.312	.732
Temp	Withing Groups	138084.3	355	388.970		
	Total	138326.7	357			

Effects of Age on Physical Performance Characteristics

Evolutions Within 20-29 year old Age Group

		N	Mean	Std. Error	Minimum	Maximum
AccM	1st Floor	96	3.6	0.1	0.9	5.2
	Maze	103	4.4	0.1	0.8	5.8
	3rd Floor	98	3.4	0.1	1.7	5.1
	RIT	94	0.6	0.0	0.1	2.4
Vt	1st Floor	96	2,286	144	490	9,793
	Maze	103	2,475	165	359	12,933
	3rd Floor	98	2,499	167	820	12,129
	RIT	94	818	55	183	4,220
Ve	1st Floor	96	78.70	5.34	12.00	378.91
	Maze	103	91.36	6.73	7.70	505.37
	3rd Floor	98	87.51	6.13	15.02	425.38
	RIT	94	18.98	1.21	4.18	72.36
Br/M	1st Floor	96	37.6	0.5	23.4	50.1
	Maze	103	40.3	0.6	21.5	55.5
	3rd Floor	98	37.6	0.5	19.7	50.7
	RIT	94	24.9	0.5	17.0	39.7
PifVt	1st Floor	96	4,594	301	864	21,560
	Maze	103	5,151	363	580	27,258
	3rd Floor	98	5,032	339	1,215	23,562
	RIT	94	1,412	90	329	6,256
PefVt	1st Floor	96	4,202	289	688	20,042
	Maze	103	4,877	357	459	27,345
	3rd Floor	98	4,633	328	1,127	22,998
	RIT	94	1,162	77	328	4,989
HR	1st Floor	96	147.06	1.41	85.36	170.09
	Maze	103	148.78	1.59	59.50	174.85
	3rd Floor	98	150.30	1.20	97.33	174.36
	RIT	94	97.43	1.94	0.00	122.77
%HRmax	1st Floor	96	75.36	0.72	44.00	86.47
	Maze	103	76.69	0.86	30.20	99.78
	3rd Floor	98	77.05	0.60	49.16	88.51
	RIT	94	70.09	1.48	0.00	105.17
Core Temp	1st Floor	62	97.2	3.1	18.6	242.1
	Maze	59	96.3	1.8	35.3	126.8
	3rd Floor	65	94.8	2.0	36.6	123.0
	RIT	62	96.4	3.0	33.5	241.9

Evolution Differences Within 20-29 yr olds

ANOVA

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	798.140	3	266.047	509.676	<0.001
	Within Groups	202.011	387	.522		
	Total	1000.151	390			
Vt	Between Groups	2E+008	3	62088736.65	31.305	<0.001
Within Groups	8E+008	387	1383376.939			
	Total	1E+009	390			
Ve	Between Groups	328995.3	3	109655.099	38.366	<0.001
Within Groups	1106207	387	2858.415			
	Total	1435202	390			
Br/M	Between Groups	13773.365	3	4591.1022	171.033	<0.001
Within Groups	10388.442	387	26.844			
	Total	24161.807	390			
PifVt	Between Groups	9E+009	3	300502226.0	34.460	<0.001
Within Groups	3E+009	387	8720358.296			
	Total	4E+009	390			
PefVt	Between Groups	9E+009	3	285413472.5	34.789	<0.001
Within Groups	3E+009	387	8204072.335			
	Total	4E+009	390			
HR	Between Groups	188350.3	3	68783.423	266.723	<0.001
	Withing Groups	91095.050	387	235.388		
	Total	279445.3	390			
%HRmax	Between Groups	2982.988	3	994.329	10.992	<0.001
Within Groups	35007.366	387	90.458			
	Total	37990.354	390			
Core	Between Groups	192.949	3	64.316	.163	.921
Temp	Withing Groups	96422.088	244	395.172		
	Total	96615.037	247			

Evolutions Within 30-39 year old Age Group

		N	Mean	Std. Error	Minimum	Maximum
AccM	1st Floor	53	3.6	0.1	1.5	6.0
	Maze	55	4.5	0.1	3.1	5.8
	3rd Floor	55	3.6	0.1	0.5	5.2
	RIT	53	0.6	0.1	0.2	2.3
Vt	1st Floor	53	2,318	249	587	10,329
	Maze	55	2,544	260	808	9,163
	3rd Floor	55	2,605	242	511	9,559
	RIT	53	756	61	232	2,302
Ve	1st Floor	53	80.75	8.92	13.17	319.99
	Maze	55	91.93	9.70	33.38	326.02
	3rd Floor	55	90.21	8.69	10.24	307.65
	RIT	53	19.05	1.82	6.72	60.43
Br/M	1st Floor	53	37.2	0.7	22.5	50.6
	Maze	55	40.4	0.6	30.9	50.3
	3rd Floor	55	37.0	0.7	22.2	51.7
	RIT	53	25.9	0.6	18.6	36.2
PifVt	1st Floor	53	4,662	500	961	18,395
	Maze	55	5,198	538	1,889	18,108
	3rd Floor	55	5,230	498	827	17,650
	RIT	53	1,388	122	464	4,132
PefVt	1st Floor	53	4,321	476	938	17,252
	Maze	55	4,901	512	1,806	17,385
	3rd Floor	55	4,800	459	626	16,622
	RIT	53	1,141	103	405	3,483
HR	1st Floor	53	143.7	2.1	88.3	161.1
	Maze	55	150.3	1.5	120.1	171.5
	3rd Floor	55	147.5	2.0	85.4	168.3
	RIT	53	100.4	1.9	71.3	135.1
%HRmax	1st Floor	53	76.8	1.2	47.4	86.6
	Maze	55	80.1	0.8	63.2	90.8
	3rd Floor	55	78.9	1.1	44.9	91.5
	RIT	53	70.9	1.5	49.0	101.3
Core Temperture	1st Floor	41	92.6	2.6	19.1	101.6
	Maze	39	94.4	2.8	25.0	129.3
	3rd Floor	39	95.8	3.8	3.6	177.7
	RIT	39	92.4	2.9	23.2	109.8

F-table Evolution Differences Within 30-39 yr olds

ANOVA

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	453.119	3	151.040	328.704	<0.001
	Within Groups	97.414	212	.460		
	Total	550.533	215			
Vt	Between Groups	1E+008	3	40961519.22	15.617	<0.001
Within Groups	6E+008	212	2622958.457			
	Total	7E+009	215			
Ve	Between Groups	192422.8	3	64147.615	18.575	<0.001
Within Groups	732111.3	212	3453.355			
	Total	924554.1	215			
Br/M	Between Groups	6426.880	3	2143.293	93.410	<0.001
Within Groups	4862.047	212	22.934			
	Total	11288.9207	215			
PifVt	Between Groups	5E+008	3	180883569.8	16.482	<0.001
Within Groups	2E+009	212	10974543.63			
	Total	3E+009	215			
PefVt	Between Groups	5E+008	3	170222897.5	17.542	<0.001
Within Groups	2E+009	212	9703833.943			
	Total	3E+009	215			
HR	Between Groups	89022.473	3	29674.158	153.749	<0.001
	Withing Groups	40916.874	212	193.004		
	Total	129939.3	215			
%HRmax	Between Groups	2671.920	3	890.640	12.100	<0.001
Within Groups	15605.239	212	73.610			
	Total	18277.159	215			
Core	Between Groups	309.988	3	103.329	.283	.837
Temp	Withing Groups	56148.346	154	364.600		
	Total	56458.334	157			

Evolutions Within 40+ year old Age Group

		N	**Mean**	**Std. Error**	**Minimum**	**Maximum**
AccM	1st Floor	26	3.4	0.2	0.7	5.8
	Maze	27	4.2	0.2	0.8	5.6
	3rd Floor	23	3.5	0.1	2.3	4.8
	RIT	26	0.5	0.1	0.2	1.4
Vt	1st Floor	26	1,554	86	583	2,727
	Maze	27	1,807	144	261	4,137
	3rd Floor	23	1,745	134	613	3,834
	RIT	26	531	46	228	1,231
Ve	1st Floor	26	54.57	4.10	23.12	105.32
	Maze	27	67.37	6.04	5.98	167.41
	3rd Floor	23	62.67	5.57	21.96	140.43
	RIT	26	13.54	1.39	5.17	29.12
Br/M	1st Floor	26	37.3	1.2	24.4	52.4
	Maze	27	40.7	1.1	23.9	50.8
	3rd Floor	23	37.4	1.2	30.6	51.9
	RIT	26	26.6	1.2	12.6	39.2
PifVt	1st Floor	26	3,141	222	1,394	6,158
	Maze	27	3,748	323	453	9,123
	3rd Floor	23	3,549	299	1,364	7,837
	RIT	26	969	88	403	2,156
PefVt	1st Floor	26	2,902	203	1,199	5,076
	Maze	27	3,603	318	330	8,891
	3rd Floor	23	3,291	294	1,116	7,710
	RIT	26	805	80	324	1,806
HR	1st Floor	26	138.0	3.6	98.6	167.5
	Maze	27	145.8	2.9	84.2	175.1
	3rd Floor	23	146.9	2.0	131.3	165.0
	RIT	26	101.3	4.2	62.4	141.3
%HRmax	1st Floor	26	79.3	2.0	57.3	99.1
	Maze	26	82.8	1.8	48.4	92.7
	3rd Floor	23	84.7	1.2	73.3	97.6
	RIT	26	73.7	3.4	42.3	112.5
Core Temp	1st Floor	19	90.0	3.1	57.0	102.9
	Maze	19	95.4	1.8	71.0	105.2
	3rd Floor	15	105.9	10.8	78.5	253.7
	RIT	20	93.3	2.9	44.9	102.5

F-Table Evolutions Within 40+ yr olds

ANOVA

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	207.794	3	69.265	105.548	<0.001
	Within Groups	64.311	98	.656		
	Total	272.105	101			
Vt	Between Groups	27470057	3	9156685.825	30.065	<0.001
Within Groups	29847465	98	304565.973			
	Total	57317523	101			
Ve	Between Groups	46891.511	3	15630.504	28.651	<0.001
Within Groups	53463.795	98	545.549			
	Total	100355.3	101			
Br/M	Between Groups	2951.892	3	983.964	27.741	<0.001
Within Groups	3476.033	98	35.470			
	Total	6427.925	101			
PifVt	Between Groups	1E+008	3	42407034.65	26.691	<0.001
Within Groups	2E+008	98	15888102.097			
	Total	3E+008	101			
PefVt	Between Groups	1E+008	3	41378168.55	27.839	<0.001
Within Groups	1E+008	98	1486313.737			
	Total	3E+008	101			
HR	Between Groups	35654.849	3	11884.950	41.709	<0.001
	Withing Groups	27925.066	98	2084.950		
	Total	63579.915	101			
%HRmax	Between Groups	1751.410	3	583.803	4.299	.007
Within Groups	13173.883	97	135.813			
	Total	14925.293	100			
Core	Between Groups	2289.538	3	763.179	1.653	.185
Temp	Withing Groups	31856.012	69	461.681		
	Total	34145.549	72			

Age Groups Within 1st Floor Burn Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	20-29 years	96	3.56	0.09	0.86	5.22
	30-39 years	53	3.56	0.12	1.46	5.97
	40+ years	26	3.37	0.21	0.73	5.83
Skin Temp	20-29 years	37	33.5	0.9	6.7	37.0
	30-39 years	18	35.0	0.6	27.7	37.0
	40+ years	13	31.4	2.7	0.0	37.0
Vt	20-29 years	96	2,286	144	490	9,793
	30-39 years	53	2,318	249	587	10,329
	40+ years	26	1,554	86	583	2,727
Ve	20-29 years	96	78.70	5.34	12.00	378.91
	30-39 years	53	80.75	8.92	13.17	319.99
	40+ years	26	54.57	4.10	23.12	105.32
Br/M	20-29 years	96	37.6	0.5	23.4	50.1
	30-39 years	53	37.2	0.7	22.5	50.6
	40+ years	26	37.3	1.2	24.4	52.4
PifVt	20-29 years	96	4,594	301	864	21,560
	30-39 years	53	4,662	500	961	18,395
	40+ years	26	3,141	222	1,394	6,158
PefVt	20-29 years	96	4,202	289	688	20,042
	30-39 years	53	4,321	476	938	17,252
	40+ years	26	2,902	203	1,199	5,076
HR	20-29 years	96	147.1	1.4	85.4	170.1
	30-39 years	53	143.7	2.1	88.3	161.1
	40+ years	26	138.0	3.6	98.6	167.5
%HRmax	20-29 years	96	75.4	0.7	44.0	86.5
	30-39 years	53	76.8	1.2	47.4	86.6
	40+ years	26	79.3	2.0	57.3	99.1
Core Temp	20-29 years	62	97.2	3.1	18.6	242.1
	30-39 years	41	92.6	2.6	19.1	101.6
	40+ years	19	90.0	3.1	57.0	102.9

Age Group W 1st Floor

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	.795	2	.398	.477	.621
Within Groups	143.300	172	.833			
	Total	144.096	174			
Skin Temp	Between Groups	94.706	2	47.353	1.282	.284
Within Groups	2401.247	65	36.942			
	Total	2495.953	67			
Vt	Between Groups	12273818	2	6136908.953	2.887	.058
Within Groups	4E+008	172	2125538.218			
	Total	4E+008	174			
Ve	Between Groups	13826.218	2	6913.109	2.426	.091
Within Groups	490125.0	172	2849.564			
	Total	503951.2	174			
Br/M	Between Groups	4.956	2	2.479	.086	.918
Within Groups	4950.695	172	28.783			
	Total	4955.650	174			
PifVt	Between Groups	48439218	2	24219609.86	2.690	.071
Within Groups	2E+009	172	9001998.391			
	Total	2E+009	174			
PefVt	Between Groups	40346704	2	20173352.05	2.459	.088
Withing Groups	1E+009	172	8202255.180			
	Total	1E+009	174			
HR	Between Groups	1751.306	2	875.653	3.899	.022
Within Groups	38824.943	172	224.561			
	Total	40376.249	174			
%HRmax	Between Groups	339.314	2	169.657	2.629	.075
Within Groups	11099.786	172	64.534			
	Total	11439.100	174			
Core	Between Groups	1010.651	2	505.325	1.186	.309
Temp	Within Groups	50698.447	119	426.037		
	Total	51709.098	121			

Age Groups Within Maze Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	20-29 Years103	4.4	0.1	0.8	5.8	
	30-39 Years55	4.5	0.1	3.1	5.8	
	40 + Years27	4.2	0.2	0.8	5.6	
Skin Temp	20-29 Years41	32.9	1.4	0.0	37.3	
	30-39 Years21	33.2	2.1	0.0	37.1	
	40 + Years13	32.2	2.6	5.6	37.0	
Vt	20-29 Years103	2,475	165	359	12,933	
	30-39 Years55	2,544	260	808	9,163	
	40 + Years27	1,807	144	261	4,137	
Ve	20-29 Years103	91.36	6.73	7.70	505.37	
	30-39 Years55	91.93	9.70	33.38	326.02	
	40 + Years27	67.37	6.04	5.98	167.41	
Br/M	20-29 Years103	40.3	0.6	21.5	55.5	
	30-39 Years55	40.4	0.6	30.9	50.3	
	40 + Years27	40.7	1.1	23.9	50.8	
PifVt	20-29 Years103	5,151.3	362.9	580.3	27,258.3	
	30-39 Years55	5,197.5	537.9	1,888.7	18,108.0	
	40 + Years27	3,748.0	323.1	453.3	9,123.1	
PefVt	20-29 Years103	4,877.5	356.9	458.6	27,344.8	
	30-39 Years55	4,901.2	512.3	1,806.1	17,385.3	
	40 + Years27	3,602.6	318.3	330.1	8,891.0	
HR	20-29 Years103	148.8	1.6	59.5	174.9	
	30-39 Years55	150.3	1.5	120.1	171.5	
	40 + Years27	145.8	2.9	84.2	175.1	
%HRmax	20-29 Years103	76.7	0.9	30.2	99.8	
	30-39 Years55	80.1	0.8	63.2	90.8	
	40 + Years26	82.8	1.8	48.4	92.7	
Core Temp	20-29 Years59	96.3	1.8	35.3	126.8	
	30-39 Years39	94.4	2.8	25.0	129.3	
	40 + Years19	95.4	1.8	71.0	105.2	

Age Groups Within Maze

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	1.142	2	.571	.967	.382
Within Groups	107.463	182	.590			
	Total	108.604	184			
Skin Temp	Between Groups	8.086	2	4.043	.046	.955
	Within Groups	6297.209	72	87.461		
	Total	6305.295	74			
Vt	Between Groups	11197661	2	5598830.741	2.028	.135
Within Groups	781433.5	182	4893.591			
	Total	794940.6	184			
Br/M	Between Groups	2.979	2	1.489	.050	.951
	Within Groups	5370.841	182	29.510		
	Total	5373.820	184			
PifVt	Between Groups	46538063	2	23269031.33	1.828	.164
Within Groups	2E+009	182	12727002.92			
	Total	2E+009	184			
PefVt	Between Groups	37986069	2	18993034.47	1.579	.209
Withing Groups	2E+009	182	12026312.63			
	Total	2E+009	184			
HR	Between Groups	377.171	2	188.585	.882	.416
Within Groups	38920.536	182	213.849			
	Total	39297.707	184			
%HRmax	Between Groups	966.138	2	483.069	7.526	.001
Within Groups	11617.618	181	64.186			
	Total	12583.755	183			
Core	Between Groups	80.432	2	40.216	.176	.822
Temp	Within Groups	23356.965	114	204.886		
	Total	23437.396	116			

Age Groups Within 3rd Floor Burn Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	20-29 years	98	3.4	0.1	1.7	5.1
	30-39 years	55	3.6	0.1	0.5	5.2
	40+ years	23	3.5	0.1	2.3	4.8
Skin Temp	20-29 years	39	33.0	1.3	0.0	38.4
	30-39 years	20	30.7	2.5	0.0	37.1
	40+ years	10	34.4	0.8	28.2	36.8
Vt	20-29 years	98	2,499	167	820	12,129
	30-39 years	55	2,605	242	511	9,559
	40+ years	23	1,745	134	613	3,834
Ve	20-29 years	98	87.51	6.13	15.02	425.38
	30-39 years	55	90.21	8.69	10.24	307.65
	40+ years	23	62.67	5.57	21.96	140.43
Br/M	20-29 years	98	37.60	0.51	19.66	50.74
	30-39 years	55	37.01	0.69	22.24	51.73
	40+ years	23	37.43	1.18	30.55	51.94
PifVt	20-29 years	98	5,032	339	1,215	23,562
	30-39 years	55	5,230	498	827	17,650
	40+ years	23	3,549	299	1,364	7,837
PefVt	20-29 years	98	4,633	328	1,127	22,998
	30-39 years	55	4,800	459	626	16,622
	40+ years	23	3,291	294	1,116	7,710
HR	20-29 years	98	150.3	1.2	97.3	174.4
	30-39 years	55	147.5	2.0	85.4	168.3
	40+ years	23	146.9	2.0	131.3	165.0
%HRmax	20-29 years	98	77.1	0.6	49.2	88.5
	30-39 years	55	78.9	1.1	44.9	91.5
	40+ years	23	84.7	1.2	73.3	97.6
Core Temp	20-29 years	65	94.8	2.0	36.6	123.0
	30-39 years	39	95.8	3.8	3.6	177.7
	40+ years	15	105.9	10.8	78.5	253.7

Age Groups Within 3rd Floor Evolution

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	.675	2	.338	.679	.508
Within Groups	85.992	173	.497			
	Total	86.667	175			
Skin Temp	Between Groups	111.274	2	55.637	.759	.472
	Within Groups	4835.231	66	73.261		
	Total	4946.505	68			
Vt	Between Groups	12929908	2	6464953.806	2.498	.085
	Within Groups	4E+008	173	2587667.124		
	Total	5E+008	175			
Ve	Between Groups	13572.925	2	6786.463	1.966	.143
	Within Groups	597064.6	173	3451.240		
	Total	610637.5	175			
Br/M	Between Groups	12.404	2	6.202	.234	.792
	Within Groups	4591.548	173	26.541		
	Total	4603.952				
PifVt	Between Groups	49663087	2	24831543.48	2.291	.104
Withing Groups	2E+009	173	10838101.61			
	Total	2E+009	175			
PefVt	Between Groups	40296161	2	20148080.70	2.059	.131
Within Groups	2E+009	173	9784800.695			
	Total	2E+009	175			
HR	Between Groups	388.114	2	194.057	1.207	.302
	Within Groups	27816.256	173	160.788		
	Total	28204.369	175			
%HRmax	Between Groups	1085.659	2	542.830	12.099	<0.001
	Within Groups	7819.682	173	45.200		
	Total	8905.341	175			
Core	Between Groups	1513.348	2	756.674	1.429	.244
Temp	Within Groups	61424.450	116	529.521		
	Total	62937.799	118			

Age Group Differences Within RIT Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	20-29 years	94	0.60	0.04	0.13	2.38
	30-39 years	53	0.63	0.05	0.18	2.26
	40+ years	26	0.55	0.06	0.21	1.41
Skin Temp	20-29 years	37	32.93	1.29	0.00	36.89
	30-39 years	18	33.12	1.97	0.00	37.00
	40+ years	12	34.35	0.45	30.97	36.68
Vt	20-29 years	94	818.27	54.61	182.57	4,219.98
	30-39 years	53	755.72	61.25	231.78	2,301.85
	40+ years	26	531.04	46.17	228.30	1,230.85
Ve	20-29 years	94	18.98	1.21	4.18	72.36
	30-39 years	53	19.05	1.82	6.72	60.43
	40+ years	26	13.54	1.39	5.17	29.12
Br/M	20-29 years	94	24.91	0.46	17.03	39.68
	30-39 years	53	25.91	0.60	18.55	36.16
	40+ years	26	26.62	1.24	12.56	39.19
PifVt	20-29 years	94	1,411.91	90.24	328.82	6,256.02
	30-39 years	53	1,387.93	122.35	464.20	4,132.12
	40+ years	26	968.71	87.70	403.47	2,155.92
PefVt	20-29 years	94	1,162.37	77.23	328.08	4,988.71
	30-39 years	53	1,141.41	102.95	405.42	3,483.46
	40+ years	26	804.54	79.82	324.21	1,806.05
HR	20-29 years	94	97.43	1.94	0.00	122.77
	30-39 years	53	100.37	1.91	71.31	135.07
	40+ years	26	101.27	4.24	62.44	141.29
%HRmax	20-29 years	94	70.09	1.48	0.00	105.17
	30-39 years	53	70.93	1.54	49.01	101.27
	40+ years	26	73.69	3.43	42.31	112.49
Core Temp	20-29 years	62	96.41	2.95	33.48	241.92
	30-39 years	39	92.45	2.93	23.19	109.84
	40+ years	20	93.26	2.93	44.93	102.46

Age Group Within RIT Evolution

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	.140	2	.070	.442	.643
	Within Groups	26.982	170	.159		
	Total	27.122	172			
Skin Temp	Between Groups	18.592	2	9.296	.173	.841
	Within Groups	3435.445	64	53.679		
	Total	3454.037	66			
Vt	Between Groups	1680275	2	840137.403	3.779	.025
Within Groups	37798462	170	222343.893			
	Total	39478737	172			
Ve	Between Groups	659.571	2	329.786	2.241	.092
	Within Groups	23158.563	170	136.227		
	Total	23818.135	172			
Br/M	Between Groups	74.443	2	373222	1.659	.193
	Within Groups	3813.439	170	22.432		
	Total	3881.882	172			
PifVt	Between Groups	4191362	2	2095680.938	3.034	.051
Withing Groups	1E+008	170	690798.582			
	Total	1E+008	172			
PefVt	Between Groups	2725375	2	1362687.501	2.709	.069
	Within Groups	85500226	170	502942.505		
	Total	88225601	172			
HR	Between Groups	463.712	2	231.856	.722	.487
	Within Groups	54575.255	170	321.031		
	Total	55038.967	172			
%HRmax	Between Groups	265.460	2	132.730	.679	.509
	Within Groups	33249.403	170	195.585		
	Total	33514.863	172			
Core Temp	Between Groups	420.524	2	210.262	.507	.604
	Within Groups	48946.584	118	414.802		
	Total	49367.108	120			

Effects of Hydration Groups Within 1st Floor Burn Evolution

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
AccM	1	6	3.8	0.8	0.3	2.6	4.5
	2	13	3.7	0.8	0.2	2.6	6.0
	3	28	3.7	1.0	0.2	2.0	5.2
	4	32	3.4	0.7	0.1	2.1	4.6
	5	47	3.3	1.0	0.1	0.7	5.0
	6	43	3.7	0.9	0.1	1.8	5.8
Vt	1	6	2,182	1,049	428	1,184	4,098
	2	13	2,265	1,326	368	1,227	6,226
	3	28	2,103	1,507	285	587	8,725
	4	32	2,355	1,626	287	583	10,329
	5	47	1,906	1,063	155	490	7,284
	6	43	2,289	1,469	224	561	9,135
Ve	1	6	78.14	43.57	17.79	37.01	154.08
	2	13	79.25	40.02	11.10	36.81	166.68
	3	28	72.98	56.49	10.68	13.17	319.99
	4	32	77.70	51.27	9.06	23.12	318.21
	5	47	63.96	39.75	5.80	12.00	280.43
	6	43	82.69	55.90	8.53	21.38	331.36
Br/M	1	6	38	4	2	33	43
	2	13	39	6	2	31	47
	3	28	37	6	1	24	51
	4	32	36	4	1	23	44
	5	47	37	6	1	22	50
	6	43	39	5	1	25	52
PifVt	1	6	4,534	2,406	982	2,172	8,765
	2	13	4,588	2,400	666	2,242	10,669
	3	28	4,236	3,228	610	961	18,395
	4	32	4,515	2,793	494	1,394	17,543
	5	47	3,760	2,296	335	864	16,187
	6	43	4,752	3,108	474	1,145	18,330
PefVt	1	6	4,143	2,301	939	2,142	8,114
	2	13	4,147	2,052	569	1,811	8,443
	3	28	3,925	3,000	567	938	17,010
	4	32	4,176	2,789	493	1,199	17,252
	5	47	3,412	2,099	306	688	15,018
	6	43	4,429	3,073	469	1,107	18,742
HR	1	6	131.6	13.1	5.4	108.2	147.0
	2	13	146.8	11.1	3.1	127.1	164.6
	3	28	149.1	11.8	2.2	121.3	165.3
	4	32	146.4	13.4	2.4	97.2	169.4
	5	47	140.8	19.5	2.8	85.4	170.1
	6	43	146.2	13.7	2.1	98.6	168.6
%HRmax	1	6	67.4	5.8	2.4	57.3	73.8
	2	13	78.3	5.6	1.5	67.3	85.3
	3	28	78.7	6.1	1.2	63.9	89.9
	4	32	76.9	7.3	1.3	50.9	86.6
	5	47	75.2	10.1	1.5	44.0	99.1
	6	43	76.8	7.9	1.2	57.3	92.3
Core Temp	1	5	70.8	32.9	14.7	25.6	98.1
	2	9	99.5	2.4	0.8	94.0	102.9
	3	17	97.1	6.8	1.7	81.2	114.3
	4	27	94.1	14.6	2.8	36.6	114.3
	5	30	93.2	16.1	2.9	18.6	107.4
	6	29	96.8	32.8	6.1	19.1	242.1

Hydration Groups Within 1st Floor Burn

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	5.376	5	1.075	.307	.263
Within Groups	134.070	163	.823			
	Total	139.447	168			
Vt	Between Groups	5198217	5	1039643.398	.542	.744
Within Groups	3E+008	163	1917650.822			
	Total	3E+008	168			
Ve	Between Groups	8875.435	5	1775.87	.723	.607
Within Groups	400295.5	163	2455.800			
	Total	409170.9	168			
Br/M	Between Groups	169.263	5	33.853	1.172	.325
Within Groups	4708.923	1263	28.889			
	Total	4878.186	168			
PifVt	Between Groups	25376422	5	5075284.307	.652	.661
Within Groups	1E+009	163	7787253.379			
	Total	1E+009	168			
PefVt	Between Groups	25645549	5	5129109.810	.721	.609
Within Groups	1E+009	163	7118472.089			
	Total	1E+009	168			
HR	Between Groups	2509.918	5	501.984	2.205	.056
Withing Groups	37101.379	163	227.616			
Total	39611.2097	168				
%HRmax	Between Groups	762.737	5	152.547	2.371	.042
	Within Groups	10488.927	163	64.349		
	Total	11251.6+63	168			
Core	Between Groups	3345.320	5	669.064	1.539	.183
Temp	Withing Groups	48253.2037	111	43.4.714		
	Total	51598.557	116			

Hydration Groups Within Maze Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	1	6	4.3	0.6	1.7	5.2
	2	13	4.4	0.1	3.7	5.1
	3	31	4.4	0.1	2.6	5.8
	4	33	4.3	0.2	0.8	5.2
	5	50	4.3	0.1	0.9	5.6
	6	46	4.5	0.1	1.8	5.6
Vt	1	6	1,866	589	619	4,707
	2	13	2,393	326	1,308	5,367
	3	31	2,149	263	940	8,648
	4	33	2,511	291	261	9,163
	5	50	2,125	165	359	7,589
	6	46	2,747	322	637	12,933
Ve	1	6	65.23	21.00	19.00	166.58
	2	13	86.41	11.00	36.60	173.26
	3	31	78.02	10.17	33.38	326.02
	4	33	89.48	10.01	5.98	282.54
	5	50	75.50	6.01	7.70	257.14
	6	46	105.72	13.66	24.51	505.37
Br/M	1	6	39.9	1.3	34.3	42.9
	2	13	40.8	1.5	32.4	50.8
	3	31	40.3	0.7	34.3	47.4
	4	33	39.3	1.0	22.0	45.9
	5	50	39.5	0.8	21.5	52.1
	6	46	41.8	0.8	30.5	52.4
PifVt	1	6	3,704	1,156	1,195	9,277
	2	13	4,843	608	2,227	9,266
	3	31	4,396	558	1,889	18,108
	4	33	5,096	557	453	16,222
	5	50	4,312	344	623	15,265
	6	46	5,858	725	1,341	27,258
PefVt	1	6	3,529	1,150	1,075	9,101
	2	13	4,594	578	2,010	9,015
	3	31	4,197	543	1,806	17,385
	4	33	4,766	530	330	15,537
	5	50	4,053	323	468	14,019
	6	46	5,614	720	1,313	27,345
HR	1	6	150.2	5.2	137.2	171.5
	2	13	153.0	2.6	139.2	170.8
	3	31	150.5	2.5	114.6	175.1
	4	33	145.2	2.8	84.2	160.8
	5	50	146.5	2.6	59.5	174.9
	6	46	151.3	1.6	112.1	172.7
%HRmax	1	6	76.6	2.9	69.6	88.0
	2	13	81.5	1.1	76.5	88.6
	3	30	78.8	1.2	59.4	87.7
	4	33	76.3	1.5	48.4	89.1
	5	50	78.4	1.5	30.2	99.8
	6	46	79.6	1.0	57.2	92.3
Core Temp	1	4	77.8	14.6	35.3	97.1
	2	9	96.1	2.3	82.4	103.7
	3	15	99.8	2.6	86.4	129.3
	4	25	96.4	3.4	25.0	125.0
	5	30	94.1	2.4	37.7	105.2
	6	30	95.9	2.6	36.0	126.8

Hydration Groups Within Maze

		Sum of Squares	df	Mean Square	F	Sig.	
AccM	Between Groups	.912	5	.182	.304	.910	
Within Groups	103.764	173	.600				
	Total	104.676	178				
Vt	Between Groups	13235714	5	3647142.778	.990	.426	
	Within Groups	5E+008	173	2674377.216			
	Total	5E+008	178				
Ve	Between Groups	28259.947	5	5651.989	1.379	.234	
Within Groups	708892.5	173	4097.644				
	Total	737152.4	178				
Br/M	Between Groups	171.930	5	34.386	1.241	.292	
	Within Groups	4794.717	173	27.715			
	Total	4966.648	178				
PifVt	Between Groups	77199960	5	15439991.90	1.275	.277	
Within Groups	2E+009	173	12112063.81				
	Total	2E+009	178				
PefVt	Between Groups	74918215	5	14983643.05	1.302	.265	
Within Groups	2E+009	173	11506379.11				
	Total	2E+009	178				
HR	Between Groups	1307.169	5	261.434	1.208	.307	
Withing Groups	37426.155	173	216.336				
Total	38733.323	178					
%HRmax	Between Groups	354.644	5	70.929	1.008	.414	
	Within Groups	12100.752	172	70.353			
	Total	12455.396	177				
Core	Between Groups	1617.805	5	323.561	1.591	.169	Temp
Withing Groups	21766.625	107	203.426				
	Total	23384.430	112				

Hydration Groups Within 3rd Floor Burn Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	1	6	3.3	0.3	1.7	4.0
	2	13	3.5	0.2	2.6	5.2
	3	31	3.4	0.1	2.1	5.2
	4	32	3.5	0.1	2.3	5.1
	5	49	3.5	0.1	0.5	5.1
	6	40	3.5	0.1	2.5	4.9
Vt	1	6	2,154	399	1,024	3,566
	2	13	2,446	393	1,245	6,700
	3	31	2,239	251	882	8,635
	4	32	2,588	293	613	9,559
	5	49	2,197	160	511	8,018
	6	40	2,637	308	820	12,129
Ve	1	6	77.40	22.51	15.02	151.88
	2	13	82.92	9.89	35.54	174.02
	3	31	76.12	8.30	25.32	277.09
	4	32	88.31	10.13	21.96	307.65
	5	49	76.22	6.07	10.24	307.55
	6	40	94.74	11.27	29.60	410.51
Br/M	1	6	35.4	4.3	19.7	51.7
	2	13	37.5	1.5	29.5	51.9
	3	31	37.3	0.8	29.7	45.3
	4	32	36.4	0.6	28.0	42.8
	5	49	37.2	0.8	22.2	50.7
	6	40	38.2	0.8	29.6	47.6
PifVt	1	6	4,415	1,129	1,215	7,855
	2	13	4,832	655	2,258	11,607
	3	31	4,417	494	1,514	16,912
	4	32	5,115	575	1,364	17,650
	5	49	4,410	343	827	17,639
	6	40	5,401	620	1,633	22,393
PefVt	1	6	4,125	1,184	1,127	8,011
	2	13	4,367	529	1,967	9,012
	3	31	4,077	444	1,459	14,752
	4	32	4,681	539	1,116	16,622
	5	49	4,031	322	626	16,331
	6	40	5,015	610	1,548	22,998
HR	1	6	135.35	9.30	97.33	159.02
	2	13	151.08	3.37	131.29	174.36
	3	31	149.03	1.92	123.43	168.29
	4	32	148.10	2.13	111.31	169.21
	5	49	147.55	2.16	85.36	171.96
	6	40	152.13	1.14	137.54	169.74
%HRmax	1	6	69.38	4.78	49.16	79.91
	2	13	80.48	1.43	71.93	88.51
	3	31	78.50	1.06	64.91	91.46
	4	32	77.88	1.26	57.38	93.75
	5	49	78.72	1.24	44.93	97.63
	6	40	79.71	0.71	70.85	93.27
Core Temp	1	5	84.94	12.01	37.16	99.47
	2	9	98.93	1.19	93.58	103.71
	3	16	104.98	4.86	95.61	177.68
	4	27	96.42	3.12	23.03	123.03
	5	30	98.93	6.06	36.60	253.70
	6	28	90.47	4.04	3.61	102.33

Hydration Groups Within 3rd Floor

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	.373	5	.075	.148	.980
Within Groups	83.025	165	.503			
Total	83.398	170				
Vt	Between Groups	6605091	5	1321018.131	.573	.721
Within Groups	4E+008	165	2305438.414			
	Total	4E+008	170			
Ve	Between Groups	10307.633	5	2061.527	.707	.619
Within Groups	480945.7	165	2914.823			
	Total	491253.4	170			
Br/M	Between Groups	78.257	5	15.651	.593	.705
	Within Groups	4352.717	165	26.380		
	Total	4430.974	170			
PifVt	Between Groups	30539415	5	6107882.957	.656	.657
Within Groups	2E+009	165	9313244.213			
	Total	2E+009	170			
PefVt	Between Groups	27971371	5	5594274.143	.668	.648
Within Groups	1E+009	165	8375957.830			
	Total	1E+009	170			
HR	Between Groups	1691.366	5	388.273	2.205	.056
Withing Groups	25310.674	165	153.398			
Total	27002.039	170				
%HRmax	Between Groups	662.661	5	124.532	2.558	.029
	Within Groups	8033.884	165	48.690		
	Total	8656.545	170			
Core	Between Groups	3067.3.61	5	613.472	10.119	.355
Temp	Withing Groups	59760.522	109	548.262		
Total	62827.883	114				

Hydration Groups Within RIT Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	1	6	0.5	0.2	0.1	1.3
	2	13	0.7	0.2	0.2	2.2
	3	29	0.5	0.0	0.2	1.2
	4	32	0.6	0.1	0.2	2.1
	5	48	0.6	0.1	0.1	1.5
	6	40	0.6	0.1	0.2	2.4
Vt	1	6	703	168	317	1,382
	2	13	726	124	291	1,626
	3	29	647	64	228	2,056
	4	32	787	69	261	2,302
	5	48	683	43	183	1,346
	6	40	879	114	197	4,220
Ve	1	6	19.84	6.15	8.78	45.51
	2	13	19.38	3.82	7.32	52.96
	3	29	15.45	1.88	5.17	60.43
	4	32	18.47	1.91	5.69	59.39
	5	48	16.02	1.01	6.38	39.02
	6	40	21.12	2.44	4.18	72.36
Br/M	1	6	27.2	1.9	21.9	34.0
	2	13	27.7	1.5	21.0	39.7
	3	29	24.8	0.8	18.6	34.2
	4	32	24.3	0.8	12.6	33.0
	5	48	25.6	0.7	17.4	39.2
	6	40	25.7	0.8	17.6	38.0
PifVt	1	6	1,304	354	563	2,757
	2	13	1,305	228	520	3,187
	3	29	1,150	126	403	4,011
	4	32	1,363	130	329	4,132
	5	48	1,198	74	414	2,801
	6	40	1,580	189	443	6,256
PefVt	1	6	1,131	326	534	2,482
	2	13	1,136	221	420	2,989
	3	29	927	109	324	3,483
	4	32	1,105	107	328	3,390
	5	48	985	62	371	2,508
	6	40	1,296	155	348	4,989
HR	1	6	99.03	4.83	86.21	115.85
	2	13	98.96	4.24	75.61	132.43
	3	29	98.46	3.53	20.62	123.52
	4	32	96.01	4.23	0.00	135.07
	5	48	100.53	2.16	72.02	134.09
	6	40	99.08	2.68	62.44	141.29
%HRmax	1	6	69.63	3.49	60.82	84.91
	2	13	72.79	3.09	57.06	95.95
	3	29	68.95	2.68	14.52	90.40
	4	32	68.61	3.06	0.00	101.27
	5	48	72.83	1.92	43.92	105.17
	6	40	71.49	2.16	42.31	112.49
Core Temp	1	5	82.74	12.38	33.48	98.33
	2	10	96.43	1.93	82.79	101.55
	3	17	97.15	1.38	80.97	101.45
	4	27	92.45	3.28	33.81	107.39
	5	31	93.40	2.94	37.87	105.20
	6	27	97.65	6.37	23.19	241.92

Hydration Groups Within RIT

ANOVA

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
AccM	Between Groups	.402	5	.080	.548	.740
	Within Groups	23.799	162	.147		
Total	24.202	167				
Vt	Between Groups	1251842	5	250368.335	1.143	.340
Within Groups	35476788	162	218992.516			
	Total	36728629	167			
Ve	Between Groups	818.676	5	163.735	1.234	.295
Within Groups	21489.457	162	132.651			
	Total	22308.133	167			
Br/M	Between Groups	145.8587	5	29.177	1.330	.254
	Within Groups	3553.964	162	21.938		
	Total	3699.851	167			
PifVt	Between Groups	4322111	5	864422.135	1.279	.276
	Within Groups	1E+008	162	676099.844		
	Total	1E+008	167			
PefVt	Between Groups	3042290	5	608457.906	1.264	.282
Within Groups	77995328	162	481452.639			
	Total	81037617	167			
HR	Between Groups	400.607	5	80.121	.244	.942
	Within Groups	53097.337	162	327.761		
Total	53497.944	167				
%HRmax	Between Groups	527.440	5	105.488	.524	.758
	Within Groups	32640.051	162	201.482		
	Total	33167.492	167			
Core	Between Groups	126.924	5	253.385	.586	.711
Temp	Withing Groups	47997.346	111	432.409		
	Total	49264.269	116			

Hose line position differences within Evolutions

Hose line position Within 1st Floor Burn Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	1	52	3.0	0.1	0.9	4.7
	2	49	3.6	0.1	1.9	5.2
	3	45	3.7	0.1	0.7	6.0
	4	30	4.0	0.1	2.1	5.8
Skin Temp	1	19	33.4	1.6	6.7	36.9
	2	17	33.3	2.1	0.0	36.7
	3	18	33.2	1.0	23.9	37.0
	4	14	34.1	0.7	27.3	37.0
PifVt	1	52	4,327	443	864	18,395
	2	49	4,318	356	961	16,187
	3	45	4,159	377	1,856	18,330
	4	30	5,002	746	1,618	21,560
PefVt	1	52	3,962	428	688	17,252
	2	49	3,955	332	938	15,018
	3	45	3,859	386	1,648	18,742
	4	30	4,582	679	1,530	20,042
Core Temp	1	38.0	96.0	1.5	63.9	114.3
	2	34.0	97.2	5.1	36.6	242.1
	3	27.0	96.0	1.8	57.0	101.1
	4	23.0	86.4	5.6	18.6	100.5
Vt	1	52	2,223	234	490	10,329
	2	49	2,141	160	587	7,284
	3	45	2,047	185	1,061	9,135
	4	30	2,396	345	793	9,793
Ve	1	52	74.09	7.90	12.00	319.99
	2	49	74.00	6.26	13.17	280.43
	3	45	71.90	6.88	27.12	331.36
	4	30	86.76	13.04	29.34	378.91
Br/M	1	52	36.10	0.70	22.48	50.61
	2	49	37.17	0.71	23.60	50.11
	3	45	38.03	0.71	27.29	49.41
	4	30	39.23	1.22	23.36	52.41
%HRmax	1	52	75.78	1.24	44.00	90.32
	2	49	76.46	1.11	53.92	99.09
	3	45	75.98	1.25	50.91	92.29
	4	30	77.72	1.24	57.32	86.14

Hose line Within 1st Floor Evolution

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	20.956	3	6.985	9.681	<0.001
	Within Groups	124.108	172	.722		
Total	145.064	175				
Skin	Between Groups	7.992	3	2.664	.069	.976
Temp	Within Groups	2487.961	64	38.874		
	Total	2495.953	67			
PifVt	Between Groups	14096663	3	4698887.699	.511	.675
Within Groups	2E+009	172	9202603.585			
	Total	2E+009	175			
PefVt	Between Groups	10942261	3	3647420.382	.435	.728
	Within Groups	1E+009	172	8377964.339		
	Total	1E+009	175			
Core	Between Groups	1909.355	3	636.452	1.508	.216
Temp	Within Groups	49799.743	118	422.032		
Total	51709.098	121				
Vt	Between Groups	2370433	3	790144.276	.362	.781
	Within Groups	4E+008	172	2184177.850		
	Total	4E+008	175			
Ve	Between Groups	4596.419	3	1532.140	.528	.664
	Withing Groups	499503.4	172			
Total	50499.8	175				
Br/M	Between Groups	208.617	3	69.539	2.518	.060
Withing Groups	4750.555	172	27.620			
Total	4959.172	175				
%HRmax	Between Groups	80.161	3	26.720	.402	.751
Withing Groups	11420.194	172	66.396			
Total	11500.355	175				

Hose line position Within 3rd Floor Burn Evolution

		N	Mean	Std. Error	Minimum	Maximum
AccM	1	52	3.2	0.1	0.5	4.8
	2	52	3.6	0.1	1.7	5.1
	3	47	3.7	0.1	2.1	5.2
	4	26	3.6	0.1	2.6	5.2
Vt	1	52	2,359	250	511	12,129
	2	52	2,716	272	859	10,871
	3	47	2,374	123	1,142	4,730
	4	26	2,106	300	613	8,018
Ve	1	52	78.62	8.34	10.24	410.51
	2	52	95.92	9.89	15.02	425.38
	3	47	84.19	5.58	33.74	218.80
	4	26	77.83	11.77	21.96	307.55
Br/M	1	52	36.2	0.7	22.2	50.7
	2	52	38.0	0.7	19.7	49.6
	3	47	37.5	0.8	28.3	51.7
	4	26	38.6	1.0	31.4	51.9
PifVt	1	52	4,566	469	827	22,393
	2	52	5,522	562	1,215	23,562
	3	47	4,828	297	1,957	12,144
	4	26	4,441	659	1,364	17,639
PefVt	1	52	4,202	461	626	22,998
	2	52	5,051	517	1,127	22,192
	3	47	4,465	280	1,709	10,688
	4	26	4,096	642	1,116	16,331
HR	1	52	147.5	1.8	85.4	164.9
	2	52	149.1	1.8	97.3	174.4
	3	47	149.5	1.5	123.4	168.3
	4	26	150.7	2.9	90.2	172.0
%HRmax	1	52	76.9	1.0	44.9	84.5
	2	52	78.7	1.1	49.2	97.6
	3	47	79.4	0.9	66.2	93.7
	4	26	80.0	1.6	47.5	93.3
Core Temp	1	31	100.1	2.8	74.7	177.7
	2	38	94.0	3.6	3.6	123.0
	3	31	97.6	5.9	36.6	253.7
	4	19	94.1	3.4	37.2	101.8

F-Table: Hose line Within 3rd Floor Evolution

		Sum of Squares	df	Mean Square	F	Sig.
AccM	Between Groups	9.033	3	3.011	6.679	.<0.001
	Within Groups	77.984	173	.451		
Total	87.016	176				
Vt	Between Groups	7978190	3	2459396.567	.938	.423
	Within Groups	5E+008	173	262433.614		
	Total	5E+008	176			
Ve	Between Groups	9687.251	3	32287.084	.929.	428
	Within Groups	601017.1	173			
	Total	610698.4	176			
Br/M	Between Groups	131.157	3	43.719	1.679	.173
	Within Groups	4505.222	173	26.042		
	Total	4636.380	176			
PifVt	Between Groups	31645860	3	10548619.85	.964	.411
	Within Groups	2E+009	173	10943019.23		
Total	2E+009	176				
PefVt	Between Groups	24689112	3	2889704.015	.833	.477
	Within Groups	2E+009	173	8977734.137		
	Total	2E+009	176			
HR	Between Groups	208.755	3	69.585	.430	.732
	Withing Groups	28006.379	173			
Total	28215.134	176				
%HRmax	Between Groups	229.431	3	76.477	1.499	.217
Withing Groups	8828.437	173	51.031			
Total	9057.868	176				
Core	Between Groups	780.310	3	260.103	.481	.696
Temp	Withing Groups	62157.488	115	540.500		
Total	62937.799	118				

UNIVERSITY OF
MARYLAND

CENTER FOR FIREFIGHTER SAFETY
RESEARCH AND DEVELOPMENT

MARYLAND FIRE AND RESCUE INSTITUTE
COLLEGE PARK, MARYLAND
20742