

Running head: Firefighter rehabilitation in Orange County Fire

Firefighter Rehabilitation in the Orange County

Fire Authority:

Are We Meeting the Need?

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Orange County (CA) Fire Authority

## CERTIFICATION STATEMENT

I hereby certify that this paper constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

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## Abstract

The problem was that the Orange County Fire Authority has not addressed the rehabilitation needs following the intrinsic physical demands and stress from firefighting operations. The purpose of this research was to evaluate the effects of hydration status, exertion level, core body temperature and post-incident cooling techniques on firefighter performance and rehabilitation.

Descriptive research was used to study the present situation and formulate a foundation for a course of action. Through descriptive research, questions were asked on the effects of physical exertion, hydration levels, and core body temperature on firefighters' performance. The research also evaluated methods of rehabilitating firefighters during firefighting operations. The research was carried out through literature review, and applied methodologies.

The results and recommendations identified a need to develop a rehabilitation policy. Further recommendations were made to require mandatory participation in the Orange County Fire Authority's physical fitness program, provide training to department commanders on the importance of rehabilitation, and provide training to all department members on proper rehydration.

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## Table of Contents

	Page
Abstract.....	3
Introduction.....	7
Literature Review.....	14
Procedures.....	44
Results.....	51
Discussion.....	69
Recommendations.....	80
References.....	83

## Appendixes

Appendix A (Research participant questionnaire).....	91
Appendix B (Research participant questionnaire).....	93

## List of Tables

	Page
Table 1: Final number of research participants.....	54
Table 2: Final research participant data.....	55
Table 3: Average heart rates observed during research.....	56
Table 4: Hydration status prior to research.....	58
Table 5: Total fluid loss of participants during research.....	59
Table 6: Peak body core temperatures during research.....	62
Table 7: Cooling station assignments in research.....	66
Table 8: Average core temperature.....	66
Table 9: Core body and tympanic temperature comparison.....	67

## INTRODUCTION

Fire fighting is an inherently dangerous occupation that involves a high frequency of both injuries and death. Firefighters are faced daily with an endless variety of dangers - including entering burning and collapsing buildings, traffic hazards, exposure to smoke and other products of combustion, environmental conditions, physical hazards from trips and falls, and performing most physically demanding tasks while wearing bulky protective clothing. For most of its history the fire service has treated these job-related dangers as a badge of courage; something to be worn with pride. Firefighters often bragged of these dangers when sharing the merits of various operations in which they had participated.

While firefighters must continue to respond to emergency incidents that require extreme physical output and often result in physiological and psychological outcomes, the attitude of the fire service toward these risks and challenges has changed dramatically. In an effort to build a stronger fire service, fire departments have focused on strengthening their very foundation – the firefighter. The Orange County Fire Authority (OCFA) has recognized the benefits of protecting this foundation. In order to maintain fit, healthy, and capable firefighters throughout their 25-30 plus year career, in January 2004, the Orange County Fire Authority began its wellness and fitness program. The program uses a holistic wellness approach that includes medical evaluation, fitness development, injury prevention, medical rehabilitation, and behavioral health.

The mission of the Orange County Fire Authority Wellness and Fitness Program (WEFIT) is to provide OCFA firefighters and professionals with knowledge, support and opportunities to improve their physical health, wellness and fitness in order to enhance job performance and an overall healthy personal life style (Firefighter Wellness & Fitness Magazine, 2007). One of the unique aspects of the OCFA program in creating a comprehensive, safe and

effective program is its emphasis on the collection and scientific analysis of firefighter-specific data. This is accomplished by conducting practical, research-based examinations on the specific needs of firefighter job performance. The problem is that the Orange County Fire Authority has not addressed the rehabilitation needs following the intrinsic physical demands and stress from firefighting operations. The purpose of this research is to evaluate the effects of hydration status, exertion level, core body temperature and post-incident cooling techniques on firefighter performance and rehabilitation.

Descriptive research was used to study the present situation and formulate a foundation for a course of action. Descriptive research focuses on examining and reporting the status of a subject at the present time. (National Fire Academy [NFA], 2008, p.II-16). This research will address the following questions:

1. What are the effects of physical exertion on firefighters' performance?
2. What are the impacts of hydration levels on firefighters' performance?
3. What effects do changes in core body temperature have on firefighters' performance?
4. What are the most effective methods of rehabilitating firefighters during firefighting operations?

## **BACKGROUND AND SIGNIFICANCE**

Orange County is located in the heart of the Southern California coastline between Los Angeles County to the north, and San Diego County to the south. The County covers 798 square miles with a population of over 2.9 million people. The profile of Orange County includes both high-density urban as well as rural areas situated in remote canyons. The geographical make-up

of the County ranges from a remote undeveloped mountainous region on the east, to forty-two miles of scenic coastline on the west.

The Orange County Fire Authority provides fire protection to the unincorporated areas of Orange County and twenty-two incorporated cities. With 61 fire stations it is the fourth largest fire department in California. The OCFA is a combination career and reserve fire department and provides a wide range of emergency response services, fire prevention efforts, and community education to its customers. In addition to traditional response to fires, the OCFA also provides advanced and basic life support response, hazardous materials response, urban search and rescue, aerial firefighting and rescue, wildland fire response, and others. The OCFA provides these services to a community of 1.3 million residents in a 551 square mile area. On December 31, 2007, the OCFA's authorized staffing level was 1,127 full-time positions. The OCFA responded to 85,682 calls for service during 2007 (David Paschke, personal communication, January 16, 2008). A total of 849 positions provide front-line services including emergency response. The remaining 278 positions provide dispatch, fire prevention, technical, and administrative support. The OCFA also has 390 authorized reserve firefighter positions (OCFA 2007-2009 Adopted Budget, June 2007).

Firefighting is a stressful activity that requires firefighters to work at near-maximal heart rates for extended periods of time. According to McEvoy (2008), firefighting has the greatest short-surge physiological demands of any profession. Its abrupt requirements are the equivalent to marathon running, often after waking from a sound sleep with little or no ability to physically warm up (McEvoy). These physical and mental demands of firefighting associated with the environmental dangers of extreme heat and humidity or extreme cold can create conditions that can have an adverse impact upon the safety and health of fire department personnel.

Most firefighters learn early in their careers to take care of yourself first, your partner next, and then the victims of your incident. Firefighters cannot help victims if they become victims themselves. In spite of being taught this priority proverb, the number of firefighter injuries has increased. According to the National Fire Protection Association's report, U.S. Firefighter Injuries - 2006 (Karter & Molis, 2007), there were approximately 83,400 firefighter injuries in 2006. This is an increase of 4.1 percent and the highest increase since 2000 (Karter et al, 2007). Karter et al. (2007) asserts that the largest share of injuries occur during fire ground operations. In 2006, 44,210 or 53.0 percent of all firefighter injuries occurred on the fire ground (Karter et al, 2007). This is the largest percentage since 1999. According to Karter et al (2007), the leading cause of these injuries was overexertion including heat related illnesses resulting in 25.5 percent of the reported injuries.

The Orange County Fire Authority has also experienced injuries related to overexertion. According to Fausto Reyes, Risk Manager for the OCFA (personal communication, April 10, 2008), in 2007 the OCFA had 14 injuries reported that were experienced during high levels of exertion. This included 11 cases diagnosed as cardiac related, two attributed to heat stress, and one diagnosed as dehydration.

In addition to an increase in injuries, firefighter deaths also slightly increased in 2006 to 89 on-duty fatalities (Fahy, LeBlanc & Molis, 2007). Of these 89 deaths, fire ground operations accounted for 38 fatalities (Fahy et al.) During the ten-year period from 1995 through 2004 there were 1,006 on-duty firefighter fatalities (Fahy, 2005). What is significant about these fatalities is that during this ten-year period, 440, or 43.7 percent fell into the category of sudden cardiac death. The largest portion, 155 deaths, occurred during fire ground operations. This pattern has continued. According to Fahy et al (2007), of the 89 deaths in 2006, 38 of these fatalities resulted

from exertion and stress; this exertion and stress was caused by firefighting operations. Thirty-four of these were fatalities were classified as sudden cardiac deaths (Fahy et al.).

While training is a vital part of any fire department's operations, it also often results in deaths and injuries (Fahy, 2006). According to the NFPA (2006), 100 firefighters died while engaged in training-related activities between 1996 and 2005. Again, the most common cause of these fatalities was cardiac death, it being responsible for 53 of the 100 deaths (NFPA).

Some of these training deaths were attributed to the fatigue brought on by heat related stress. On May 19, 2005, a 22-year-old male firefighter in Florida collapsed while completing a class run during recruit academy training. When the ambulance arrived at the emergency department his rectal temperature was found to be 108.6 degrees Fahrenheit (Jackson, 2006). Just 12 days later on May 31, a 58-year-old New Jersey firefighter also collapsed during physical fitness training (Baldwin, 2006). On July 2, 2002 a 23-year-old firefighter from Gettysburg, Pennsylvania died from heat stroke after participating in a run. Upon arrival at the hospital his rectal temperature was 107.4 degrees Fahrenheit (The Evening Sun, 2007). In all of these cases, the investigation concluded that the physical stress of the training combined with the heat and humidity attributed to the deaths (Jackson).

While the number of on-duty cardiac deaths in 2006 was at its lowest level in 30 years, these deaths are most often the result of heart attack (Fahy et al. 2007). The three likely culprits behind these deaths are medical condition, fitness and rehabilitation (McEvoy, 2007). No matter how conditioned firefighters are, each one has a point after which fatigue and exhaustion reduces the ability to perform, and increases the likelihood of a stress-induced or fatigue related injury. While many incidents are resolved long before fatigue becomes a significant problem, there are some incidents that extend well beyond the safe operating period for firefighters.

Firefighter deaths and injuries have a dramatic impact on firefighters, their families and their departments. Beyond the immediate impact the loss of a firefighter to death or career ending injury causes, there are long-term effects on the department. These include both loss of morale and financial impacts. The OCFA has experienced these losses first hand, losing one percent of its firefighters to potentially preventable deaths between 1998 and 2004 (Fausto Reyes, personal communication, April 10, 2008).

The tragic losses noted above inspired the OCFA to create a program its WEFIT Program aimed at reducing firefighter injury and illness and improving firefighter health and safety. In addition to creating an exercise, fitness and wellness program, one unique goal of the WEFIT Program is to analyze the job demands of our firefighters and implement specialized programs specifically tailored to reduce injuries to our firefighters. It is critical to protect our firefighters from preventable injuries or death. It is critical to examine the relationship between cardiovascular strain and heat stress and to examine certain factors such as hydration, core body temperature and cooling techniques that may contribute to these stress related injuries.

This applied research project is relevant to the course work included in the curriculum of the National Fire Academy's Executive Fire Officer Program (EFOP), *Executive Leadership* (EL), R125 course (National Fire Academy [NFA], 2005). Although this course was designed specifically to provide a framework of executive-level competencies by focusing primarily on issues and areas of personal effectiveness, it also includes units associated with this project. The researcher noted the following distinct associations:

First, *Unit 3: Developing Self as a Leader* summarized that the successful executive leader must have a vision and a purpose. This leader must have the ability to create and

articulate a vision that empowers others to transform this vision, or in this case, findings from research into action.

Second, *Unit 7: Succession/Replacement Planning*- which is building an organizational capability through improved competencies. The vary nature of this research properly applied will enhance the understanding of the effects firefighting activities can have on a firefighter.

Third, *Unit 8: Introduction to Influencing* in which this research is the basis for developing a strategy for influencing change, implementing those changes, then evaluating their effectiveness.

Fourth, *Unit 9: Power*, or more specifically, personal power where people concede based on a perception of expertise or special information. The action of conducting research and developing a certain level of knowledge can result in others granting the researcher personal power.

Finally, *Unit 12: Influencing Styles* in which the researcher is able to change the beliefs of others by creating a common vision through factual and logical arguments. These discussions must appeal to the values and emotions of the other person.

The evaluation of the effects of hydration status, exertion level, core body temperature and post-incident rehabilitation techniques during fire fighting operations, will provide a better understanding of potential health dangers and potentially improve firefighter safety. This effort relates to and supports both the two of the United States Fire Administration's (USFA) operational objective. These are the first operational objective, to reduce the loss of firefighter's lives, and the third operational objective, to appropriately respond in a timely manner to emergent issues (USFA, 2003).

## LITERATURE REVIEW

The purpose of this literature review is to summarize the findings of other research on exertional related illnesses, associated conditions, and rehabilitation of these illnesses and conditions. The literature review for this applied research project focuses on the effects of physical exertion on the ability of an individual to sustain prolonged physical performance, the impacts of hydration levels on physical performance, and the effects changes in body core temperature can have on a firefighter. The literature review also examines rehabilitation options and techniques for sustaining elevated levels of physical activity. The literature review examined these impacts on both firefighters and athletes. According to Dickinson and Wieder (2004), firefighting is not that unlike organized team sports. Over the years many fire instructors have made comparisons between firefighting and football. Both activities involve groups of properly conditioned and players (Dickinson and Wieder).

Firefighting is a high-hazard job, and the work is at times extremely physically demanding. It involves heavy lifting and maneuvering in sometimes awkward and unstable positions while wearing heavy clothing and protective gear in a hot environment (Rosenstock and Olsen, 2007). The USFA (1992) states the workloads that firefighters are likely to endure for what may be considered routine incidents can exceed their physical capabilities. Pye (2006) asserts that operations involving high temperatures, high humidity, close proximity or direct physical contact with hot objects, or strenuous physical activities have a high potential for causing heat injuries also known as heat stress. Hostler and Suyama (2007) agree stating that a firefighter is exposed to a combination of heat from the fire and environment, and the metabolic heat generated from the heavy exertion. Hostler and Suyama add that when you combine these

conditions with heavy thermally protective clothing, thermoregulation is impaired and core body temperature begins to rise.

According to the Office of the Deputy Prime Minister [ODPM] (2004), all firefighting and other rescue activities are dependent to a great extent upon the physiological capabilities of the firefighters. Dickinson and Weider (2004) cite that some incidents extend far beyond the safe operating period for many firefighters. Although the ODPM (2004) asserts that the limitations of firefighters must be considered when planning for incidents, currently there is limited information available to fire and rescue service incident commanders on whether the activities assigned to firefighters will exceed their capability to complete the assignment safely within the physiological limitations.

No matter how well conditioned firefighters are, each one has a point where fatigue and exhaustion reduce effectiveness and increase the likelihood of a stress or fatigue-related injury (Dickinson and Wieder, 2004). Although a high percentage of incidents end before any firefighter reaches the point of exhaustion, many do not. Both Dickinson and Wieder, and the USFA (1992) assert that firefighters who extend beyond their safe operating capability are at high risk for a stress or fatigue-related illness or injury being unable to complete an operation because of fatigue, or making poor decisions in a high-risk environment due to fatigue. In 1998 the incidence of work-related injury in the fire service was over four times that for private industry with one of every three firefighters injured in the line of duty (Walton, Conrad, Furner, and Samo, 2003). Some of these injuries include heat exhaustion, dizziness, fainting or weakness, dehydration, nausea, and cardiac symptoms (Kartner, 2007).

Hostler and Suyama (2007) assert there is a common thread between baking, athletics and firefighting. According to Hostler and Suyama all of these professions have had members die of

heat related illnesses. Heat illness is inherent to physical activity and its incidence increases with rising temperature and relative humidity (Binkley, Beckett, Casa, Kleiner, and Plummer, 2002). In sports, one of the most severe stresses an athlete can encounter is exercise in heat. Exercise performance is almost invariably impaired during hot weather, and at worst, the heat imposes a serious threat to the athlete's health (Maughan and Shirreffs, 1997). In the sport of track and field, the Canadian Track and Field Association recommended that distance races be cancelled if the wet bulb global temperature. The ability to delay an activity is not an option in firefighting (Binkley et al.). (WGBT, the Wet Bulb Global Temperature is a composite temperature used to estimate the effect of temperature, humidity, and solar radiation on humans) is greater than 80° Fahrenheit (F) (Binkley et al.). The American College of Sports Medicine guidelines from 1996 recommend that a race should be delayed or rescheduled when the WBGT is greater than 80°F.

Heat stress placed on firefighters is both intrinsic, meaning produced by the individual, or extrinsic, such as heat from exposure to fire, open flame, or the environment (Hostler and Suyama, 2007). About 75 percent of the energy turnover during exercise is wasted as heat, inevitably causing body temperature to rise (Maughan and Shirreffs, 1997). Under normal conditions heat is lost from the body by radiation, conduction, convection, evaporation, or respiration (Hostler and Suyama, 2007, Binkley et al., 2002). Of these, evaporation of sweat, and convection to air or circulating water are the most efficient (Hostler and Suyama). In cool air, much of body heat can be readily transferred to the air. However, when the environmental temperature exceeds the skin temperature, heat is gained from the environment and body temperature can rise to dangerous levels (Maughan and Shirreffs, Binkley et al.).

The environmental factors that influence the risk of heat illness include ambient temperature, relative humidity, air motion, and the amount of radiant heat from the sun and other

sources (Binkley et al, 2002). Environmental conditions can influence the risk of heat illness and magnify heat stress during an incident (Binkley et al., Hostler and Suyama, 2007). Hostler and Suyama assert that thermal burden is increased with rising temperature and relative humidity. Warm air is capable of holding more moisture than cooler air, intensifying the threat of heat problems during warm weather (Hostler and Suyama). Binkley et al. affirm that high relative humidity inhibits heat loss from the body through evaporation placing additional physiological stresses on an athlete and increasing the probability of a heat related illness.

As the environmental heat stress increases, there is greater dependence on sweating and evaporative cooling. Sweat evaporation provides the primary avenue of heat loss during vigorous activity in hot weather, therefore sweat loss can be substantial (Sawka et al., 2007). According to Sawka et al., individual characteristics such as body weight, genetic predisposition, heat acclimatization state, and metabolic efficiency will influence sweat rates for a given activity. As a result, there is a large range in sweat rates and total sweat losses among individuals performing the same task (Sawka et al.). If not appropriately replaced, dehydration and electrolyte imbalances can develop and adversely impact the individual's physical performance and perhaps health (Sawka et al.).

Evaporation of sweat and convection to air are the bodies two most efficient cooling mechanism (Binkley et al. 2002). Barriers to evaporation can interfere with this mechanism. Athletic equipment and rubber suits used for weight loss do not allow water vapor to pass through, and inhibit evaporative, convective, and radiant heat loss (Binkley et al.). Football players who wear protective gear have markedly greater sweat rates and heat stress risks compared to cross country runners training in the same hot environment for the same duration

(Sawka et al., 2007). Binkley et al. noted that helmets are also limiting because a significant amount of heat is dissipated through the head.

Although firefighter's protective clothing is always improving, it still impairs both the evaporation and convection process (Hostler and Suyama, 2007). Hostler and Suyama emphasize that even in conditions where air is moving across the firefighter, the thick layers of the garment hamper effective convective cooling. Additionally, Hostler and Suyama assert that as the evaporation process is impeded, the firefighter's protective turnout clothing becomes laden with sweat increasing the weight of the gear and adding additional physical stress. Impairing this thermoregulation ultimately results in a rising core body temperature. Even if heat stress doesn't progress to exertional illness, a firefighter usually suffers some consequences from the additional heat burden (Hostler and Suyama).

The impact of heat related stress on the ability of firefighters to complete assignments was confirmed in a study conducted in Great Britain by the Officer of the Deputy Prime Minister in 2004. The study was conducted in three phases. The first phase was to investigate the physiological demands of simulated firefighting, and search and rescue operations in ambient conditions (ODPM, 2004). This phase involved ambient conditions only with no fire and total visual obscuration. There were three routes into the building. Teams of two firefighters were assigned to fight a fire and to search and rescue a victim. In this phase, none of the teams were successful on the first attempt before running out of breathing air. Only 12 percent of all occasions produced a successful outcome and this was contingent on adequate support from firefighters in ancillary roles (ODPM).

The second phase of the ODPM (2004) study involved attacking live fires on various floors between the basement and the fourth floor. One firefighter team and one search and rescue

team were monitored per entry. The total weight being carried by each firefighter including protective clothing was 72.6 pounds, equating to approximately 41 percent of the individual's mean body mass (ODPM). Forty events were conducted on six floor conditions. The live scenario duration averaged 31-minutes for the firefighting, and 33-minutes for the search and rescue (ODPM). In only 9 (22.5 percent) of the scenarios did both the firefighting and search teams rescue the victim and return to the entry control point safely and under control. According to the study, the participants reported both feeling exhausted and hot. The ODPM (2004) states that the physiological data collected supported this. The ODPM found heat related problems were by far the most prevalent. Fifteen of the scenarios were stopped due to the firefighter's core temperature exceeding 103.1°F. Another 15 (40 percent) were stopped for safety reasons, either by the safety officers or by the firefighters themselves. Most of the stops were heat related (ODPM).

The third phase of the Office of the Deputy Prime Minister study examined the physiological load associated with climbing up 28 floors to explore the vertical component of firefighting and rescue operations. The study did not evaluate the component of returning to the building access level (ODPM, 2002). Two separate assessments were conducted in personal protective equipment both with and without carrying breathing apparatus and hose. The study found that when carrying breathing apparatus and hose it took approximately 30-seconds and body core temperature rose by .3°F per floor. When climbing unloaded it took approximately 15-seconds and core temperature rose by approximately .1°F per floor. The ODPM study concluded that in all three scenarios performed in the study, heat strain among the firefighters was the greatest single source of performance limitation causing premature termination of approximately 65 percent of the scenarios.

In a study conducted by the Fire Research Division of the Office of the Deputy Prime Minister the aim was to determine whether firefighter instructors were capable of performing a simulated rescue after participating in live fire training exercises (Elgin and Tipton, 2003). In this study ten fire instructors participated in two simulated rescues which involved dragging a 177 pound dummy 905 feet along a flat floor and down two flights of stairs (Elgin and Tipton). Prior to the first simulated rescue the instructors had not been exposed to heat within the previous 12-hours. The second simulated rescue was attempted approximately 10 minutes after the instructors had performed as safety officers in a hot fire training exercise lasting approximately 40-minutes (Elgin and Tipton). According to Elgin and Tipton (2003) all the instructors were able to complete both of the simulated rescues. During the first scenario the heart rate of the instructors ranged from 146 to 178 beats per minute. During the second scenario the heart rate of the instructors ranged from 165 to 195 beats per minute and their rectal temperatures from 99.8 to 101.3°F.

In a third scenario conducted by Elgin and Tipton (2003), seven fire instructors performed a simulated rescue which involved dragging a 187 pound dummy 1200 feet along a flat floor approximately 79-seconds after being in a hot fire exercise lasting an average of 41-minutes. According to Elgin and Tipton, six out of the seven instructors were able to complete the first simulated rescue. One instructor was not able to complete the first simulated rescue, being able to only drag the dummy 798 feet, 402 feet short of the objective. All of the instructors were able to complete a rescue simulating a worse case scenario at the end of the first hot fire exercise, however according to Elgin and Tipton they experienced a greater physical strain the second hot fire scenario. In the final scenario the heart rate of the instructors range from 162 to 202 beats per minute and their rectal temperatures from 99.6 to 102.1°F.

Elgin and Tipton (2003) maintain that fire instructors are capable of performing a rescue at the end of a hot fire exercise. However, the rescue tasks resulted in near maximal heart rates suggesting the instructors had very little spare physical capacity. Therefore in less favorable conditions such as higher body core temperatures, greater levels of dehydration, less fit or experienced instructors, or a victim weighing more than 190 pounds, a rescue may not be possible (Elgin and Tipton).

The physiological response to exercise in heat is determined in part by the intensity of the activity and in part by the degree of heat stress. At the same power output, exercise in the heat results in a higher heart rate and a higher cardiac output, as well as higher core and skin temperature compared with the same exercise in a cooler environment (Maughan and Shirreffs, 1997). Heat exhaustion and heatstroke are part of a continuum of heat-related illnesses. Both are common and preventable conditions affecting a diversity of patients. Recent research has identified a cascade of inflammatory pathologic events that begins with mild heat exhaustion and, if allowed to go unchecked, can eventually lead to multiple organ failure and death (Glazer, 2005).

Binkley et al. (2002) stress that heat related illnesses are inherent to physical activity and their incidence increases as temperatures rise. While recognition of heat illness has improved, the subtle signs and symptoms associated with heat illnesses are often overlooked resulting in more serious problems (Binkley et al.). The traditional classification of heat illnesses defines three categories: heat cramps, heat exhaustion, and heat stroke. However, Binkley et al. contends heat syncope (a transient loss of consciousness due to decrease blood flow to the brain) and exertional hyponatremia (a decreased concentration of sodium in the blood) must also be included. Eichner

(2002) asserts that heat illnesses can advance quickly. Over-motivated athletes can overheat by doing too much too fast, or trying to endure too long (Eichner).

Rosenstock and Olsen (2007) stress that firefighting is a high-hazard job, and the work is at times extremely physically demanding. It is not surprising that firefighters face an increased risk of illness and death due to cardiovascular disease during periods of intense physical and even psychological stress at work. However, Rosenstock and Olsen find that although numerous mortality studies have shown evidence of an increased risk of some cancers and non-malignant respiratory diseases, they have not shown any consistent evidence of an increased risk of death from cardiovascular disease. Rosenstock and Olsen contend that firefighters are a healthy work group. By their very nature they generally have high levels of fitness and health. On average a firefighter's risk of dying from cardiovascular disease is slightly lower than that of others in the general population. Thus, firefighters overall may not have an excess risk of dying from heart disease, or if they do, the excess risk is small (Rosenstock and Olsen). Therefore, Rosenstock and Olsen ask if firefighters have little or no excess risk of death from cardiovascular disease, why are they dying from sudden cardiac death. Rosenstock and Olsen assert there is a need to understand why these deaths occur, including those that occur on the job. Kales, Soteriados, Christophi, and Christiani (2007) agree, stating various biologically plausible explanations for the high mortality from cardiovascular event among firefighters have must be explored.

Rosenstock and Olson (2007) contend that cardiovascular events that occur while firefighters are on duty appear to cluster around specific activities, most notably fire suppression and emergency response. Kales et al. (2007) agree, stating that elevated risks of death were associated with fire suppression, alarm response, and physical training. Kales et al. found that while fire suppression only represents about one to five percent of firefighters' professional time

each year, it accounted for over 32 percent of deaths caused by coronary heart disease. As compared with the odds of death from coronary heart disease during non-emergency duties, the odds were 12.1 to 136 times as high during fire suppression (Kale et al.).

Rosenstock and Olsen (2007) note that numerous studies over decades have shown the role of heavy exertion, from snow shoveling to recreational exercise, in triggering sudden myocardial events. Firefighters have episodic exposure to extreme levels of physical exertion, and they face occupational hazards that may add to or amplify their risk of death due to cardiovascular disease (Rosenstock and Olsen). These hazards include thermal and emotional stress. The ODPM (2004) confirmed these findings noting that physical activity is not the only cause of elevated heart rate in firefighters. An increase in central nervous system activity prior to physical exertion itself can result in an increase in heart rate. Kales et al., (2007) agree, stating the most likely explanation for these findings is the increased cardiovascular demand associated with fire suppression.

During competition in hot environments, endurance athletes perform at intensities that stress their cardiovascular system to its absolute limit, reaching 90 to 100 percent of maximal heart rate (Gonzalez-Alonso, Mora-Rodriguez, Below and Coyle, 1997). Exercise can elicit high sweat rates and substantial water and electrolyte losses during sustained exercise, particularly in warm or hot weather (Sawka et al., 2007). Although evaporation is impaired when a firefighter is wearing turnout gear, sweat is still produced at these elevated levels as blood moves from the body core and travels to the skin surface (Hostler and Suyama, 2007). The production of sweat removes water from the plasma, thus reducing the effective blood volume (Hostler and Suyama). During intense exercise, especially in the heat, sweat rates can be one to two and one-half liters, or two to five pounds of body weight per hour, resulting in dehydration (Binkley et al. (2002).

Individuals can become dehydrated while performing at high levels of physical activity (Sawka et al., 2007). Gonzalez-Alonso et al. (1997) maintain that when subjects exercise in the heat at moderate intensities, they experience hyperthermia because of reduced heat dissipation. This stress produced by dehydration and hyperthermia elicits cardiovascular strain during exercise characterized by a markedly reduced cardiac output up to three liters/minute, and an increased systemic resistance up to 13 percent (Gonzalez-Alonso et al.). Hostler and Suyama (2007) affirm this finding stating that dehydration reduces the stroke volume of every cardiac contraction. Dehydration increases the physiological strain as measured by core temperature, heart rate, and perceived exertion during heat stress. Sawka et al. maintains the greater the body water deficit, the greater the increase in physiological strain for a given task.

Research with players from the National Basketball Association (NBA) indicated that inadequate hydration practices are common in this group of athletes (Baker, Dougherty, Chow, and Kenny, 2007). Baker et al. found that NBA players were inadequately hydrated prior to and during preseason practices and summer league games. While Sawka et al. (2007) found that dehydration levels greater than 2 percent of body weight degraded aerobic exercise, and cognitive and mental performance in temperate-warm-hot environments Baker et al. discovered that athletic events do not have to take place in a hot environment for dehydration to have a detrimental impact on performance.

Sawka et al. (2007) found that greater levels of dehydration will further degrade performance. According to Sawka et al. the critical water deficit (which is greater than 2 percent of body weight for most individuals) and the magnitude of performance decrement are likely related to the environmental temperature, exercise task, and the individual's unique characteristics such as tolerance to dehydration. The study by Baker et al. (2007) supported this

standpoint finding that there was a progressive deterioration in performance as dehydration progressed from 1 to 4 percent of overall body weight. Decrement reached significance when water loss reached 2 to 3 percent of overall body weight (Baker et al.).

Sawka et al. (2007) contend physiological factors that contribute to dehydration-mediated aerobic exercise performance decrements include increased core body temperature, increased cardiovascular strain, increased glycogen utilization, altered metabolic function and perhaps altered central nervous system function. Sawka et al. adds although each factor is unique, evidence suggests that they interact to contribute in concert, rather than in isolation, to degrade aerobic exercise performance. Gonzalez-Alonso et al. (1997) confirm this finding, stating that cardiovascular instability results from the synergistic effect of dehydration combined with hyperthermia on reducing cardiac output.

In a study conducted by Gonzalez-Alonso et al. (1997), it was found that the individual effects of hyperthermia and dehydration were similar, each one reducing stroke volume by seven to eight percent and increasing heart rate by four to six percent. However, when compared to the individual effect of hyperthermia, the addition of dehydration caused a significantly greater decline in stroke volume (19 to 21 percent) which was not fully compensated for by the eight to ten percent rise in heart rate, and thus reducing cardiac output by 11 to 15 percent. Gonzalez-Alonso et al. argue that because stroke volume was markedly reduced with a heart rate close to maximal (approximately 96 percent), it appears that the cardiac output generated was the highest possible. However, Gonzalez-Alonso et al. found when exposed to the combination of dehydration and hyperthermia, this highest possible cardiac output was inadequate for maintaining cardiovascular function due to falling blood pressure and increased systemic vascular resistance despite the fact that the exercise intensity still elicited only 72 percent of

$VO_{2max}$ . ( $VO_{2max}$  represents the maximal oxygen consumption. This is the highest volume of oxygen a person can consume during exercise; maximum aerobic capacity).

In a study by Sawka et al. (2007), they confirmed that when subjects are dehydrated, they become exhausted sooner even at lower body core temperatures when compared to hydrated subjects. The study found that dehydrated subjects experience lower cardiac output and blood pressure and greater vascular resistance, making them potentially more prone to ischemic injury (Sawka). Sawka et al. asserts that at a given body core temperature, dehydrated subjects experience lower cardiac output and blood pressure, and greater vascular resistance, making them potentially more prone to ischemic injury. The study emphasizes that hyperthermia should be considered more serious in a dehydrated subject compared to a hydrated subject and not assume that hyperthermia is an acceptable occurrence in a dehydrated subject (Sawka et al.).

Declining stroke volume is the primary problem encountered with both hyperthermia and dehydration because general cardiovascular strain develops when declines are large enough to elicit near-maximal heart rate and cardiac output (Gonzalez-Alonso et al., 1997). Hostler and Suyama (2007) agree stating that additional dehydration will result in a loss of cardiac output if a rise in heart rate and a falling stroke volume can't keep up with the needs of the firefighter's body. When this condition is compounded by additional heat load, the combination of stressors makes the heart endure near-maximal heart rates for extended period time intervals (Hostler and Suyama). According to Seccareccia et al. (2001) heart rate can be considered an important indicator of mortality. It represents one of the most independent predictors of cardiovascular, noncardiovascular, and overall mortality in that, all other risk factors being equal, death risks increase about 50 percent for each 20-beat per minute increment (Seccareccia et al.).

The two physiological systems most frequently monitored during firefighting research is heart rate and body core temperature (Durnad, 2007). Heat stress refers to the combination of factors that increase core body temperature; these are environmental conditions, clothing, and metabolic rate (Petersen, 2008). When the environment is hot, blood vessels near the surface open to facilitate the transfer of body heat to the environment so the body's core temperature can be maintained (American Council on Exercise [ACE], 2003). This causes a reduction in both venous return and stroke volume. At any given exertion level the heart rate will be higher than usual as the cardiovascular system attempts to maintain cardiac output to meet the oxygen demands of the muscles (ACE).

Our bodies try to achieve a balance between heat gain and heat loss, but when this balance is compromised the body is unable to function at its optimal level (Petersen, 2008). Durand (2007) reports that in one research study, firefighters wearing standard protective clothing were asked to advance a hose line and chop wood while inside a fire training structure. At the completion of the test, including both tasks, the average heart rate of the firefighters was 182.3 beats per minute and their body core temperature was 104.1°F.

Performance is almost invariably impaired during hot weather, and at worst, the heat imposes serious threats to health (Maughan and Shirreffs, 1997). A major finding from all of the scenarios performed in the studies conducted in Great Britain by the Office of the Deputy Prime Minister (2004) was that rising core temperature was a main factor limiting firefighter performance. Many of the firefighters in this study withdrew from the fire scenarios complaining of feeling too hot, and demonstrated classic signs of excessive heat exposure (ODPM). Of all the scenarios conducted in this study, 65 percent were terminated before successful completion due to rising body temperature (ODPM).

Firefighters are required to work in temperatures well over the normal body core temperature of 97.7 to 99.5 °F (Doherty, 2002). The human body will only tolerate a drop in body core temperature of 14°F and an increase of 6°F. (Binkley et al., 2002) Failure to regulate within these limits may cause death. Sustained workloads can increase the metabolic rate to 20 to 25 times the resting level. This can theoretically increase core body temperature about 1.8°F every five minutes (Petersen, 2007). High heat conditions combined with high work loads under stressful conditions can lead to rapid body core temperature increases that can be lethal (Petersen, 2008).

When the body gains heat from increased metabolism during physical activity from a hot environment, from impaired dissipation of heat to the environment, or a combination of these, the brain's temperature regulatory center, the hypothalamus, activates the body's cooling mechanisms (ACE, 2003). ACE finds that when the ambient temperature approaches 100°F that the convection of heat from the body, one of the body's cooling mechanisms, will cease and core body temperature will begin to rise. Petersen (2007) contends that if the body's cooling mechanism cannot dissipate heat thermo-regulation will be compromised and core body temperature will rise. The most common symptom from this rise in core temperature is heat stress or heat exhaustion resulting from a mild-to-moderate dysfunction of temperature control associated with elevated ambient temperature and strenuous work resulting in dehydration and salt depletion (Hoppe, 2006). Other symptoms of heat stress include persistent muscle cramps, weakness, fainting, nausea, and diarrhea (ACE, 2003). Binkley et al. (2002) asserts that heat exhaustion is also accompanied by decreased urine output, and body core temperature that generally ranges from 97 to 104°F.

Heat stress can also affect blood clotting and clot resolution (Hostler and Suyama, 2007). Hostler and Suyama find that heat stress co-activates coagulation (the process of blood clotting) and fibrinolysis (makes blood thinner). As the body temperature returns to normal, fibrinolysis down-regulates to its normal level while coagulation remains active for a period of time. This results in the blood being thicker than normal. Hostler and Suyama assert that this condition, combined with an increased endogenous (produced or arising from within the cell) epinephrine surge associated with the strenuous work involved with fire suppression, can accelerate the progression to myocardial infarction, resulting in a heart attack or sudden death.

Binkley et al. (2002) emphasizes that when the temperature regulation system is overwhelmed due to excessive endogenous (arising from within a cell or organism) heat production or inhibited heat loss in challenging environmental conditions, there can be complete thermoregulatory failure resulting in exertional heat stroke. ACE (2003) agrees, affirming this condition is a true medical emergency. Exertional heat stroke patients will have an elevated core temperature of greater than 104°F associated with signs of organ system failure (Binkley et al.). According to Hoppe (2006), during the early stages of heat stroke the victim may experience dizziness, headache, nausea, weakness, and a bounding pulse. Binkley et al. cautions that at its worse it is often difficult to distinguish heat exhaustion from heat stroke without measuring body core temperature rectally. As thermoregulatory collapse persists, the patient will display tachycardia (an abnormal rapidity of the heart), hypotension (a decrease in systolic and diastolic blood pressure below normal), sweating, hyperventilation (increased inspiration and expiration of air), altered mental status, vomiting, diarrhea, seizures, and coma (Binkley et al., Hoppe). The risk of morbidity (state of being diseased) and mortality are greater the longer the patient's body core temperature remains above 106°F (Binkley et al., ACE, 2003).

According to Binkley et al. (2002), the pathophysiology of exertional heat stroke is due to the overheating of the organ tissue that may induce malfunction of the temperature control center in the brain, circulatory failure, endotoxemia (a bacteria confined within the blood), or a combination of the three. Hoppe (2006) finds that individuals may begin to sustain cellular damage anywhere from 45-minutes to 8-hours after body core temperatures of 107.6°F. Other symptoms associated with exertional heat stroke include severe lactic acidosis (the accumulation of lactic acid in the blood), hyperkalemia (an excess of potassium in the blood), acute renal failure, rhabdomyolysis (a destruction of the skeletal muscles), and disseminated intravascular coagulation (a bleeding disorder characterized by diffuse blood coagulation), among other medical conditions (Binkley et al.).

Wearing firefighters down until they are physically unable to continue operations is not much better than leaving them injured or dead (Dickinson and Wieder, 2004). Dickinson and Wieder add that either alternative produces firefighters who are unable to contribute to the positive outcome of the emergency incident. The USFA (1992) agrees, and adds emergency personnel who are not provided adequate rest and rehydration during emergencies or training exercises are at increased risk for illness or injury, or may jeopardize the safety of others. On the other hand, firefighters who receives adequate rest, nourishment, and medical attention before reaching complete exhaustion will be able to resume their duties and make safe decisions (Dickinson and Wieder, USFA). This process is known as rehabilitation or rehab (Dickinson and Wieder).

On-scene rehabilitation can be described as an intervention to mitigate against physical, physiological, and emotional stress of firefighting, improve performance, and decrease the likelihood of on-scene injury or death (Smith and Haigh, 2006). Rehabilitation is an essential

part of any incident to prevent more serious injuries (USFA, 1992). The National Fire Protection Association (NFPA) 1584 Standard states that rehabilitation should, at a minimum, include relief from climatic conditions, rest and recovery, active and/or passive cooling or warming, rehydration, and calorie and electrolyte replacement. While the bulk of responders' needs can be addressed with these five functions, some incidents may require expansion or adjustment to meet specific needs of the incident.

A key element in determining rehabilitation needs is the current weather condition (Dickinson and Wieder, 2004). Most agencies automatically associate hot temperatures with the need for rehab. Although the USFA (1992) recommends that rehab be initiated whenever the heat index is about 90°F, Dickinson and Wieder assert that cooler temperatures can present just as many dangers. The rehabilitation area should ensure that adequate space, based on the environmental conditions, be established to conduct rehab of personnel (NFPA, 2008).

The NFPA (2008) identifies two forms of cooling, passive and active. NFPA Standard 1584 (2008) defines the passive process as using natural evaporative cooling such as sweating, removing personal protective equipment, or moving to a cool environment to reduce elevated core body temperature. NFPA defines active cooling as the process of using external methods or devices such as misting fans, ice vests, or hand and forearm immersion to reduce elevated body core temperature.

Typically, most departments provide passive cooling (Ross, McBride, and Tracy, 2004). Hostler and Suyama (2007) emphasize that the first step in the passive cooling of personnel is to remove the protective clothing and be sheltered from the environment. Optimally, both the turnout coat and pants should be removed to aid in passive cooling. If this isn't possible, the

turnout pants should be pushed down below the knees while the firefighter is seated (Hostler and Suyama).

Ross et al. (2004) assert that military, industrial, and municipal fire departments have recognized that passive cooling does not reduce core temperature. Hostler and Suyama (2007) agree, stating that passive cooling is inefficient especially in dehydrated individuals. McLellan and Selkirk (2006) have the same opinion, citing a study conducted with the Toronto Fire Department found that passive recovery did little to cool firefighters when they continued to be exposed to hot ambient conditions. In their study and those they cited, McLellan and Selkirk maintain that rectal temperature continues to rise five to ten-minutes into the recovery process after work in firefighter protective clothing. McLellan and Selkirk's study also revealed that heart rate should not be used as an index of the heat strain being experienced by a firefighter during recovery. Ross et al. agreed, adding that heart rate recovery and subjective feeling of comfort cannot be used to determine when it is safe to return to work. Decrease in heart rate during recovery would not predict or indicate the continued rise in rectal temperature during exposure (McLellan and Selkirk).

The implementation of work and rest cycles has helped to increase total work time, assuming that environmental conditions allow for cooling during rest periods (Selkirk, McLellan and Wong, 2004). Selkirk et al. found that at higher ambient temperatures when wearing self-contained breathing apparatus (SCBA), and protective clothing, and when the wearer did not open the garments during rest, the work and rest schedules did not allow for more work to be accomplished. However, even removing restrictive clothing during rest periods may not be adequate to extend total work times at higher ambient conditions or metabolic rates (Selkirk et al.).

In a similar study by McLellan and Selkirk (2006), firefighters who followed a similar work protocol to Selkirk, McLellan, and Wong's study produced tolerance times of 67-minutes with a rectal temperature increase of 3.15°F with an outdoor temperature of 95°F and 50 percent relative humidity. Given that the rectal temperature cut-off for the study was a conservative 102.2°F, and that seven of the nine subjects reached rectal temperature cut-off, the subjects' tolerance times would have been increased by .29 hours or 17-minutes if they have been allowed to continue until their rectal temperature values equaled 103.1°F, a more acceptable cut-off rectal temperature (McLellan and Selkirk). This would have created tolerance times of 84-minutes while performing continuous work at similar work rates and ambient environmental conditions.

In contrast to McLellan and Selkirk's study, Selkirk et al. (2006) found in their study that working intermittently with passive cooling (removing upper body protective gear) produced an average tolerance time of 108-minutes, of which 78-minutes represented actual work time. In comparing these findings to those of McLellan and Selkirk, tolerance time was extended with passive rest although the total amount of work performed was reduced (78-minutes versus 84-minutes). McLellan and Selkirk concluded that alternative cooling strategies were necessary to help reduce core temperature during periods of recovery even when the firefighter was able to remove most of their protective clothing. Ross et al. (2004) agreed, stating that passive cooling will not alleviate heat stress. Ross et al. (2004) also supported these findings stating that passive cooling is inadequate much of the time, particularly when more than two air cylinders are used or in conditions that significantly increase thermal loads.

As noted in other literature, Bull (2008) concurs that passive cooling alone may not manage core cooling for temperatures that have accelerated into dangerous territory within the first 30-minutes of firefighting. Bull states the big problem with passive cooling is that it losses

effectiveness as temperature and humidity rise, just when it is most critical. Bull contends that a cold towel is a simple, low cost active core-cooling system that can be used. Armsrong, Casa, Millard-Stafford, Moran, Pyne, and Roberts (2007) agree, stating that a cold towel works by conductive cooling which is effective in all temperature and humidity conditions. Cold towels are a simple, compact, expandable, and sustainable core-cooling system that is inexpensive to use (Bull). Armstrong et al. add that ice water and cold towels are the most effective. Binkley et al. (2002) also champion the finding that cold towels may be applied to the head and trunk because these areas of the body have demonstrated through thermography (a device for registering variation of heat) for having the most rapid heat loss.

On July 25<sup>th</sup> through 27<sup>th</sup>, 2007, the Littleton (CO) Fire and Rescue Department conducted an exercise to measure the effectiveness of cold towels in reducing core body temperature. The exercise was conducted with firefighters in full turnouts and SCBA (Bull, 2008). The two main elements to the exercise were exterior roof ventilation and an interior hose attack with self-rescue. According to Bull, 11 identical exercises were conducted and the crews worked until all tasks were completed. The time range during the event was 16 to 27-minutes using one tank of air. The air temperature on the first day was 97°F, on day two, 87°F, and on the third day, 83°F. A lightning storm and rain cancelled the last training evolution (Bull).

When all tasks were completed the firefighters were directed to the rehab area and tympanic temperatures were taken. Bull (2008) states that 62 firefighters were monitored for core temperature rise. Thirty-three firefighters were found to have a temperature greater than 101°F. Of those 33, twelve were found to have temperatures above 102°F, four were above 103°F, and two firefighters had a temperature of 103.3°F (Bull).

In the rehab area the firefighters removed their turnout jackets and pants and were provided a cold towel soaked in ice water, and cold water to drink (Bull, 2008). The firefighters were allowed to self-regulate their own cooling by drinking all the water they wanted and using as many towels as they pleased. According to Bull, this process resulted in reducing the temperature of the 33 firefighters who began the rehab process with temperatures above 101°F, to an average temperature of 98.5 °F after 15-minutes of rehab. All 62 members were cooled to 99°F or lower, and all were deemed fit for duty after rehab (Bull). Of the 62 firefighters involved, Bull emphasizes that 53 highly recommended and 9 recommended cold towels as a comfort aid.

Armstrong et al. (2007) agreed with the effectiveness of cold towels in the reduction of core body temperature. Armstrong et al. cite that an aggressive combination of rapidly rotating cold water-soaked towels to the head, trunk, and extremities, and ice packs to the neck, axilla (arm pit), and groin provide a reasonable rate of cooling between .21 and .28°F per minute. This technique is currently used in the Twin Cities, Chicago, and Marine Corps marathons (Armstrong et al.). Binkley et al. (2002) agree, stating that when ice packs or bags are being used they should be directed to as much of the body as possible, especially the major vessels in the armpit, groin, and neck regions. Binkley et al. assert ice packs should also be directed to the hands and feet as well.

Misting fans have become prevalent active cooling devices for rehabilitation (Hostler and Suyama, 2007). Hostler and Suyama claim that although moving air around a person in need of cooling will enhance convective heat loss, the application of water mist will only be effective if the relative humidity is low. Armstrong et al. (2007) agreed, citing that air mist and fanning techniques provide slower whole body cooling rates and are most effective when the relative humidity is low since this method depends primarily on evaporative cooling. Selkirk et al. (2004)

confirmed these findings, stating that the effectiveness of the mister depends on the ability to exchange the humidity in the microenvironment with the ambient environment. In a study conducted by Selkirk et al., the mister affected heat transfer in several ways. First, the increased air velocity of the fan promoted greater evaporative and convective heat transfer. Second, the rapid evaporation of the fine water mist led to a reduction in local temperature from 95 to 86°F, which also promoted greater convective heat transfer (Selkirk et al.). However, Selkirk et al. found that the mister fan led to a 20 percent increase in relative humidity and an increase in local environmental vapor pressure from 2.8 to 3.1 kPa, this reducing the evaporative potential of the environment. (kPa = kilopascal which is a meteorological measurement of air-pressure).

Hostler and Suyama (2007) assert that even under optimal conditions, the misting fan will reduce core body temperature less than 1.8°F during a 30-minute exposure. Selkirk et al. (2004) agreed, stating that while mister fans helped to increase tolerance time, there was a limited reduction of thermal strain as depicted in skin and rectal temperatures, and heart rates. Potentially, the mister rest period could be extended to further reduce rectal temperatures, however, this would reduce work time and hinder productivity (Selkirk et al.). Another concept investigated by Selkirk et al. is incorporating more than one mister in a large space to increase the cooling effects. Selkirk et al. discovered, however, that using more than one mister would be self-defeating due to additional increases in ambient vapor pressure. It is possible that in a closed space the use of fans alone may be just as effective. Another suggestion by Selkirk et al. is to use ice water in the mister water container to increase cooling power.

Applying active cooling modalities directly to the responder are the most effective methods for cooling (Hostler and Suyama, 2007). According to Hostler and Suyama, some level of evidence supports the effectiveness of cooling vests in treating mildly hyperthermic

individuals. A study by Godek, Bartolozzi, Burkholder, and Sugarman support this assertion (2005), citing an National Football league player who was rapidly cooled when an ice-water-soaked vest, neck collars, and caps after his body core temperature rose to 105.6°F. However, Lopez, Clearly, Jones, and Zuri (2008) disagree with Hostler and Suyama's statement based on their findings. In the study conducted by Lopez et al., the conclusions did not support the use of microclimate cooling vest for the rapid reduction of body core temperatures in mildly hyperthermic individuals. While the participants in their study had reduced core body temperatures in a shorter period than participants with no vest, the findings were not statistically significant. Additionally, Lopez, et al. found that the time to recover recorded for those who wore the vest would not be sufficient for treating an athlete with a dangerously high body core temperature.

Lopez et al. assert that the cooling vest provided a convective heat gradient that cooled the skin, but increased blood flow in the skin may have warmed the thin layer of the vest closest to the skin. Unlike liquid cooling garments in which re-chilled coolant is continuously perfused against the skin, the cooling vest absorbing the heat from the skin may have prevented effective cooling during the recovery period (Lopez et al.). The study by Lopez et al. also concluded that surface temperature must also be considered. In the case of the cooling vest, Lopez et al. assert that it is the cooling vest that is determining the body's conductive heat exchange.

Lopez et al. (2008) suggest that the cooling vest was no more effective for rapidly reducing body core temperature than resting in a thermoneutral environment. Lopez et al. maintain their findings were consistent with the results of other researchers who found that a cooling garment was not successful in rapidly decreasing elevated body core temperature. In the case study presented by Godek et al, (2005), Lopez et al. assert that the cooling vest was most

likely successful in reducing the NFL player's core temperature because it was soaked in ice water, and an ice-water-soaked garment also covered the head and neck, which is a technique similar to ice-water immersion. Binkley et al. (2002) note that ice-water immersion is the fastest way to decrease body core temperature.

Binkley et al. (2002) state that cooling over vital superficial blood vessels, such as those in the head and neck regions, is another means of decreasing elevated core temperature when ice-water or cold-water immersion is not available. Hasegawa, Takatori, Komura, and Yamasaki (2005) found that a cooling jacket with ice packs inserted anteriorly and posteriorly did effectively decrease thermal and cardiovascular strain while participants cycled in an environmental chamber. In their study, Hasegawa et al. noted that the cooling garment worn by the cyclist was tight fitting. In the study conducted by Lopez et al. (2008) the cooling vest was worn over a dry t-shirt per the manufacturer's instructions, and was placed on the wearer after the body core temperature was already elevated.

Lopez et al. (2008) conclude that although the use of superficial microclimate cooling garments to rapidly cool individuals may not be appropriate, there may be some justification in the practical application of these garments. Although they did not record data on the physiological effect of wearing the cooling garments, researchers have reported positive psychological effects of wearing cooling garments after exercise in hot, humid environments (Lopez et al.). Lopez et al. add that the cooling vest used in their study could be used as an adjunctive cooling method when body core temperatures remain normal.

Forearm submersion is clearly effective in reducing heat strain as well as extending total work time, although thermal equilibrium is not attained (Selkirk et al., 2004). Forearm immersion takes advantage of many superficial arm veins by placing the forearms and hands into

cold water, enhancing the convective transfer of heat from the blood to the water (Hostler and Suyama, 2007). The British Royal Navy documented the effectiveness of using hand and forearm submersion to lower core body temperatures for shipboard firefighting during the Falklands War (Ross et al., 2004). The report clearly showed that without hand and forearm immersion (active cooling), the subjects were unable to cool, and that immersion of the hands in water temperatures of 50, 68, and 86°F significantly reduced body core temperature within 10-minutes (Ross et al.). Ross et al. also noted that the British study reported that the process did not lead to vasoconstriction.

Hand and forearm submersion in cool water produces a vasoconstriction of the arteriovenous anastomoses (AVA) (a communication between two vessels) through centrally mediated temperature receptors in order to maintain thermal equilibrium. However, like the findings of Ross et al., Selkirk et al. (2004) also found that when the body is in a hyperthermic state, it has been shown that vasodilation of AVAs is not compromised in water temperatures ranging from 50 to 86°F. Selkirk et al. assert that the optimal water submersion temperatures have been found to be between 50 and 68°F, with cooler water producing rates of body cooling at the onset, with a subsequent plateau observed after 20 to 30-minutes of submersion.

During the study by Selkirk et al. (2004), there was a greater transfer of heat to the bath water during the first 10 minutes of submersion compared with the period between 10 and 20-minutes. Selkirk et al. assert this can be attributed to an elevated heat transfer gradient at the beginning of the submersion. As the core temperature approaches normal, peripheral perfusion decreases due to responses of the AVA (Selkirk et al.). At the same time, the temperature of the bath water increased, decreasing the heat transfer gradient and subsequent heat transfer.

McLellan and Selkirk (2006) found that passive recovery did little to cool the firefighters when they continued to be exposed to warm ambient conditions. It was found that in their study and others, core temperature continued to rise five to ten minutes into recovery increasing the risk of heat injury. Selkirk, et al. (2004) note that by incorporating an active cooling strategy during designated rest periods, work time was increased by 25 percent with the use of mister fans, and 60 percent when using forearm submersion. Not only did forearm submersion extend tolerance time and work times by 60 percent, compared with passive cooling, and 30 percent compared with the mister trials, there was a significant reduction in thermal strain associated with the given workload (Selkirk, McLellan and Selkirk). Selkirk et al. (2004) also found that while it may not be practical in the field, one way to increase the effectiveness of submersion is to use a combination of hands and feet.

Fluid replacement is the single most important component of an effective rehabilitation program (Smith and Haigh, 2006). Individuals can become dehydrated while performing physical activity (Sawka et al., 2007). Sawka et al. continue, stating that dehydration is a risk factor for both heat exhaustion and exertional heat stroke. Dehydration can increase the likelihood or severity of acute renal failure consequently leading to exertional rhabdomyolysis. In a study conducted by Sawka et al. it was discovered that many individuals often start an exertional task with normal body water weight, but dehydrate over an extended duration. However in some activities a person may initiate an activity dehydrated.

The goal of drinking during physical activity is to prevent excessive dehydration (greater than two percent body water loss from water deficit) and excessive changes in electrolyte balance to avert compromised physical performance (Sawka et al, 2007). The traditional fluid used for rehydration is water since it is inexpensive and easy to store (Hostler and Suyama,

2007). Sawka et al. asserts that the amount and rate of fluid replacement depends on the individual sweating rate, duration of the activity, and the opportunities to drink.

Individuals should drink periodically during physical activities (Sawka et al., 2007). After physical activity, the goal is to fully replace any fluid or electrolyte deficit (Sawka et al.). For every pound of body fluid lost, a pound must be replaced (Hostler and Suyama, 2007). Hostler and Suyama recommend that for every two pounds of water weight lost by a working firefighter, it will require 34 ounces of water to ensure full rehydration. Sawka et al. agrees, stating that an individual looking to achieve rapid and complete recovery from dehydration should drink 1.5 quarts of fluid for each two pounds of body weight lost. When possible, these fluids should be consumed over time, and with sufficient electrolytes, rather than being ingested in a large bolus in order to maximize fluid retention (Sawka et al.).

Hostler and Suyama (2007) contend that caffeinated beverages are perhaps the most misunderstood fluid in the context of rehydration and performance. It is widely believed that caffeine exerts a diuretic effect that will impair performance in heat (Hostler and Suyama). Armstrong, Casa, Maresh, and Ganio (2007), confirm this belief stating that there is a widespread belief that caffeine exerts a diuretic effect, prompting medical, exercise physiology, and nutrition communities to recommend that caffeine not be consumed before or during exercise. Contrary to this belief, there is no evidence that caffeine consumption results in water-electrolyte imbalance or reduced heat tolerance (Hostler and Suyama, Armstrong et al.). Armstrong et al. confirm this assertion stating that caffeine intake exerts little or no influence on human thermal balance, circulatory strain, and exercise time to exhaustion. Armstrong et al. continue stating that restricting dietary intake of caffeine is not scientifically and physiologically

supported. Both Hostler and Suyama, and Armstrong et al. note however, that caffeine can raise the heart rate which is not helpful in the context of rehabilitation.

Hostler and Suyama (2007) assert that sport drinks are often ignored by emergency service organizations due to a misconception of rehydration. There is a belief that sport drinks cause gastric distress and lead to further dehydration by extracting water from the cells (Sawka et al., 2007). Hostler and Suyama contend that a drink that includes glucose and sodium chloride should be considered for prolonged incidents. Sawka et al. agree, stating that consuming sodium during the recovery period will help retain ingested fluids and help stimulate thirst. Sawka et al. add that failure to replace sodium will prevent the return to a hydrated state and stimulate excessive urine production.

Hostler and Suyama (2007) state that intravenous (IV) rehydration with normal saline has produced mixed reviews in terms of athletic performance. Casa et al. (2000), found a lack of significant difference in exercise time to exhaustion when comparing IV and oral hydration. In the study conducted by Casa et al., it was found that subjects who rehydrated orally avoided exhaustion for an additional five-minutes, or 14 percent longer as compared to those who were rehydrated via IV. Additionally, the study demonstrated a decreased cardiorespiratory strain during the oral rehydration as compared to that during intravenous rehydration. Casa et al. also found that oral hydration significantly decreased rectal temperature and skin temperature response as compared to IV rehydration. The response to oral rehydration was the result of either a decrease in heat accumulation or an enhanced ability to dissipate heat (Casa et al.).

During an incident it will be necessary to provide some form of nutrition to working firefighters (Hostler and Suyama, 2007). Food is used to fuel the human body and is critical for continued physical exertion over extended periods of time (Smith and Haigh, 2006). For years,

well meaning groups have provided support to the fire service with food on an emergency scene but have focused little on the benefits or detriment of certain nutritional items (Smith and Haigh, 2006). During these incidents, firefighters have been given donuts, cake, pizza, fried chicken, hamburgers, and French fries. These well meaning groups have focused on feeding large groups, not on providing food that improves firefighter performance or assists in recovery (Smith and Haigh).

Smith and Haigh (2007) stress that calorie replacement should come from foods high in carbohydrates and protein, and low in fats. Hostler and Suyama (2007) agree, stating that most nutritionist recommend snacks that are primarily complex carbohydrates to maintain blood glucose level with some protein and a lesser amount of fat. Meal consumption is critical to ensure full hydration (Sawka et al., 2007). Many of the individually wrapped sport snacks meet these requirements and have the advantage of a long shelf life (Hostler and Suyama).

The literature identified other methods that impact firefighter rehabilitation. Armstrong et al. 2007 assert the effect of athletic uniforms on body heat storage is significant. Fire departments have also recognized the effect uniforms have on heat storage, and have replaced traditional uniforms with modern gear that provides a higher level of protection from fire (Malley et al, 1999). Although the new uniforms afford superior burn protection, Malley et al. assert they may reduce work time. Malley et al. study compared the exercise times of firefighters wearing the traditional uniform (a shirt and long pants), to a modified uniform (T-shirt and short pants). Although exercise time was extended from 15 to 17-minutes when shorts were worn, there was no increase in body core temperature during this exercise (McLellan and Selkirk, 2006). Malley et al. concluded the lower production of heat reduces heat strain and extends tolerance times.

In firefighting one of the concerns in replacing uniform pants with shorts is whether the level of protection offered is compromised (McLellan and Selkirk, 2006). In tests conducted by the Fire Department of New York (FDNY) they concluded that there were no significant increases in upper and lower extremity burns when wearing the traditional versus the modified uniform (Prezant, Malley, Barker, Guerth, and Kelly, 2001). McLellan and Selkirk note that in the FDNY study, that lost work time due to heat exhaustion was significantly reduced when shorts were worn instead of pants. Taken collectively, the findings from the studies of Malley et al. and Prezant et al. support replacing uniform pants worn by firefighters with uniform shorts (McLellan and Selkirk).

In summary, the literature review provided research pertinent to the intrinsic physical demands and stress firefighting operations place on firefighters, and the connection between cardiovascular strain and heat stress. The research also established a relationship between hydration status, levels of exertion and core body temperature on firefighter performance.

## **PROCEDURES**

This Applied Research Project utilized the descriptive research method for gathering information on specific physiological factors that influence firefighter job performance. The descriptive methodology focused on research which studied current information impacting the safety and performance of firefighters, and providing recommendations for reducing these impacts.

The first part of this research project began with a review of existing research and literature on the subject. The reviewed materials consisted of a selection of text books, journal articles, periodicals, and Internet sources. Literature searches were conducted initially at the University of California, Irvine, Grunigen Medical Library located at the University of

California, Irvine Medical Center in Orange, CA. Based on the nature of the research, an additional search was conducted at the Chapman University Leatherby Library located in Orange, CA. The researcher used the catalogs at both libraries and searched by typing “exertional illness,” “heat illness,” “exercise stress,” “dehydration,” “cardiovascular illness,” “overexertion,” “injury,” “rehabilitation,” “cooling,” and various combinations of these to locate journal articles and references.

A comprehensive search for related information was conducted in the Internet. Several search engines were used. These included google.com, eMedicine.com, and MEDLINE.com. These articles were very beneficial in researching the physiological effects of firefighting, implications and conditions associated with exertional and heat related illnesses, the physiological implications of hydration levels on performance, rehydration, and cooling techniques. The researcher sought literature and journals on these issues within the fire service, and outside, focusing on athletics as well.

The second part of the research process was a study to examine hydration status, exertion level, core body temperature, and post-incident cooling techniques. This study looked at factors that may contribute to exertional or heat related illnesses.

Research was conducted at the Orange County Fire Authority’s Regional Operations and Training Center (RFOTC) in Irvine, CA. The research was administered under the direction of the OCFA’s exercise physiologist, Nancy Espinoza, and fire captain, Michael Contreras, both directly responsible for the OCFA’s wellness and fitness program. This research was conducted the week of August 6<sup>th</sup> to 10<sup>th</sup>, 2007. The average temperature during the research period was 84°F, with an average relative humidity of 46 percent.

Participation in the research was voluntary. Each drill conducted consisted of a first-alarm structure fire assignment that included three engine companies, one truck company, and one battalion chief. The arrival of the companies during the drills was timed to be consistent with arrival times on an actual fire response. The number of participants in each drill ranged from 12 to 15, based on the number of personnel assigned to the companies. The collection, recording and reporting of data, and findings were done anonymously.

Each company completed one tower drill. The research was broken into two groups, one in the morning beginning at 0900 hours, and one in the afternoon beginning at 1300 hours. The structure used for the research was a six-story masonry training tower with an attached simulated two-story apartment on one end, and two-story simulated industrial building attached on the opposite end.

All the research participants were OCFA professional firefighters. There were 126 volunteers for the research. Of those, data was analyzed for 101 participants (Table 1). The participants reflected the ages, body types, physical fitness levels, and firefighting experience levels consistent with a profile of the OCFA (Table 2).

Upon arrival at the RFOTC the research participants were provided instructions for the research (See Appendix A), briefed on the elements of the research and informed of contraindications of participating. The participants were reminded that participation was voluntary and that they could end their participation at any point in the process. The participants were briefed on the CorTemp body core temperature capsule and provided access to various research studies performed on using the device, as well as literature describing the device. Additionally, a representative from HQ Inc., the company that produces the CorTemp system,

was available on site to answer questions. At the conclusion of the briefing, each participant signed an informed consent to participate.

Each participant was asked to complete a brief questionnaire (See Appendix B). The questionnaire gathered information on the participant's age, years of fire service experience, and fitness level. Each participant was assigned an identification number and issued the equipment that would be utilized to collect data during the research. This included a CorTemp non-digestible silicone-coated ingestible core body temperature capsule, a Suunto t6 wrist-worn heart rate monitor, and a 100-cc plastic sample cup with lid. Each item was labeled with the participant's corresponding identification number.

Prior to beginning the research activities, each participant ingested the CorTemp capsule. The capsule monitors body core temperature and transmits the data to an external receiver. The participants were asked to ingest the capsule with minimal water and then refrain from consuming any additional food or liquid until the end of the research.

The participants were then escorted to the restroom and directed to provide a small urine sample in the plastic sample cup provided. The urine sample was analyzed using a PAL-10S refractometer to determine the hydration level of each participant by measuring the specific gravity of the urine sample. The refractometer was selected based on recommendations by the National Athletic Trainers' Association (Casa et al., 2000). This process was monitored by an observer to ensure the samples were not tampered, and that they were properly disposed after analysis.

The participants were then weighed wearing only undergarments using a Detecto 439 Physician Scale. The scale had been confirmed for accuracy based on standards set by the U.S. Bureau of Standards (National Institute of Technology and Standards, 2007). The participant's

vital signs were measured next, including blood pressure, heart rate, respiratory rate, and tympanic temperature.

In the final steps prior to starting the monitored activities, the participants were instructed in the proper use of the Suunto heart monitor and directed to don the device. The participants were then directed to don their firefighter personal protective equipment (PPE). The PPE worn consisted of a Lion Apparel Janesville V-Force Bi-Swing coat, Lion Apparel Janesville V-Force Bi-Swing pants, PRO-Warrington 5006 boots, a Majestic PAC II Fire Apparel Janesville Nomex flash hood, FireGuard gloves, and a Phenix structure style helmet. During the research the participants were also required to wear a Scott Air-Pak Fifty self-contained breathing apparatus when entering immediately dangerous to life and health (IDLH) environments.

Once the participants were fully dressed, core body temperature was recorded using the CorTemp recorder. Core temperatures were taken at two minute intervals throughout the research. Due to the simplicity of obtaining these readings, additional measurements were taken randomly throughout the research. Heart and respiratory rate were continuously monitored throughout the research using the Suunto device. All other measurements were taken prior to, during, and after the research phases.

The monitored research activities consisted of two phases. The first phase involved firefighting tasks and consisted to two 15-minute drills. The first drill involved a live simulated fire on the first and second floor of the training tower. Both floors had interior and exterior access, and each floor had four rooms. A 180-pound rescue manikin was placed in the rear room of the first floor as a simulated victim.

The first drill began with companies being dispatched to a reported structure fire with persons trapped. The first unit arrived on-scene after the initial dispatch, and the additional units

arrived in 30-second intervals. During the scenario no specific tactics or strategies were given to the participants. Each company was instructed to allocate resources based on the reported and observed conditions. The participants were assured they were not being evaluated on times or fireground performance.

The planned duration of the drill was 15-minutes. During this time period the participants advanced hose lines to extinguish the fire, rescued the simulated victim, and coordinated vertical ventilation with other companies. The drill was concluded at 15-minutes. Upon termination of the exercise, the participants exited the building and had core body temperature recorded and were directed to have their tympanic temperatures measured and recorded.

After the temperature measurements were completed, the participants began the second 15-minute drill. This drill focused on the participants' performing firefighting related movements. In this drill the participants removed their SCBA masks and performed 15-minutes of continuous movements such as climbing stairs and overhaul (overhaul is a process where firefighters look for hidden fire inside close walls and attic spaces, and often move furniture and other household items). Physiological monitoring was performed during this exercise. The participants were directed to proceed at their preferred pace during this drill and were again reminded that they could terminate their participation at any time. When the participants had completed 15-minutes of firefighting related movements, they were directed to leave the drill tower and their core body temperature was recorded and they were directed to have their tympanic temperatures measured and recorded.

The second phase of the research focused on recovery. This phase was conducted for 20-minutes in ambient environmental conditions. In this phase the participants were randomly assigned to one of four cooling stations. The stations were passive cooling, KoreKooler

rehabilitation chairs, misting fans, and wet towels. The misting fans were connected to three-quarter inch standard garden hose with misting nozzles angled out from the center panel to direct water into the air. The wet towels were kept in ice water until provided to the participant. The wet towels were placed around the areas with abundant blood supply such as the arms, and the back of the neck. The KoreKooler chairs had plastic bags filled with water on the arms. The number of participants assigned to the cooling chairs was lower than the other methods due to the limited availability of the cooling chairs. The remaining three cooling stations provided standard chairs for all participants, and all stations were under a canopy to provide protection from direct sun. The participants were directed not to ingest any liquids until the end of the 20-minute recovery phase.

During the recovery phase both core body and tympanic temperature, and other vital signs were measured and recorded every five minutes. The use of the CorTemp recorder was continued along with the tympanic thermometer due to post-exercise differences between core temperature and tympanic measurements (Easton, Fudge, and Pitsiladis, 2006). The participants continued to wear the Suunto device so that heart rate data could continue to be recorded. At the end of the 20-minute period the participants were directed to the locker room for a post-activity body weight measurement. The participants again were weighed in the same undergarments worn during the initial weigh-in.

This research project had one limitation. The CorTemp telemetry pill was ingested 45-minutes prior to the beginning of the research. Easton et al. (2007) emphasis that the telemetry pill should be ingested eight to twelve hours prior to measurements for a more accurate core temperature reading. The researchers attempted to compensate for this condition by not allowing the participants to ingest any water or food after swallowing the telemetry pill.

## RESULTS

Through descriptive research, which included exploring the connections between exertional illness, body core temperature, and cardiovascular strain, and the reviews of many written resources, the researcher found considerable information to answer the four research questions.

Question 1: What are the effects of physical exertion on firefighters' performance?

The literature review found that firefighters are likely to endure levels of exertion that can exceed their physical capabilities (USFA, 1992). Firefighting and rescue activities are highly dependent upon the physiological ability of the firefighters (Dickinson and Weider, 2004). Regardless of conditioning, firefighters reach a point where fatigue and exhaustion reduce their performance (Dickinson and Wieder). Firefighters who continue beyond their safe operating capability are at high risk for a stress or fatigue-related illness or injury, or may make bad decisions in a high-risk environment (USFA).

Heat illness is inherent to the physical exertion levels associated with firefighting, and its likelihood increases with elevated temperatures and relative humidity (Binkley et al., 2002). Heat stress is one of the most severe stresses an individual can encounter. A firefighter's physical performance is impaired during hot weather, and at worst, the heat imposes a serious threat to firefighter health and safety (Maughan and Shirreffs, 1997).

During heavy physical activity like that associated with firefighting, about 75 percent of a person's energy turnover is wasted as heat, causing body temperature to rise (Maughan and Shirreffs, 1997). In cool air, most of this wasted body heat can be transferred to the air, but when the environmental temperature exceeds the skin temperature, the body gains heat and body temperature can rise to unsafe levels (Maughan and Shirreffs, Binkley et al.).

As heat stress increases, the body is dependent on sweating and evaporative cooling. (Sawka et al., 2007). Sweat evaporation is the primary avenue of heat loss for the body; during firefighting activities, sweat loss can be substantial. If fluids are not appropriately replaced, dehydration and electrolyte imbalances can develop and adversely impact a firefighter's physical performance (Sawka et al.).

Barriers to evaporation interfere with the body's cooling mechanism (Binkley et.al, 2002). Individuals who wear protective clothing have markedly greater sweat rates and heat stress risks. Binkley et al. also noted that helmets add to heat stress due to the significant amount of heat dissipated through the head.

While firefighters' protective clothing has improved, it still impairs the evaporation and convection process (Hostler and Suyama, 2007). Impeding the evaporation process not only causes a retention of heat, it causes the firefighters' protective turnout clothing to become weighed down with sweat, increasing the weight of the gear and adding additional physical stress. This condition further impairs the body's thermoregulation ability and results in a rising core body temperature (Hostler and Suyama). Even if this additional heat doesn't result in an exertional illness, a firefighter's physical performance typically suffers some detriment from the additional heat burden (Hostler and Suyama).

The impact of heat related stress on firefighter performance was confirmed in a study conducted in Great Britain by the Officer of the Deputy Prime Minister in 2004. The physical exertion caused the participant's body temperatures to rise (ODPM, 2002). The ODPM found heat related problems were by far the most common. Of the 40 scenarios conducted, 15 were stopped due to the firefighters' core temperatures exceeding 103.1°F. Another 15 (40 percent) were stopped for safety reasons, most of which were heat related (ODPM).

In other studies conducted by the Fire Research Division of the Office of the Deputy Prime Minister, the outcome of heavy physical exertion was noticeable physiologically in the form of elevated heart rate and body core temperature (Elgin and Tipton, 2003). During one scenario, the heart rate of the participants ranged from 146 to 178 beats per minute. During a second scenario heart rates ranged from 165 to 195 beats per minute, and rectal temperatures ranged from 99.8 to 101.3°F. During a final scenario heart rates ranged from 162 to 202 beats per minute, and rectal temperatures from 99.6 to 102.1°F (Elgin and Tipton).

The literature emphasized heat exhaustion and heat stroke as an effect on firefighters from high levels of physical exertion (Glazer, 2005). Both are common and preventable conditions. Heat related illnesses generally start mild then through a series of inflammatory pathological events that begins with heat exhaustion, and goes on to multi-organ failure and death if permitted to go unrestricted (Glazer, 2005). Heat illnesses can advance quickly. An over-motivated firefighter can quickly overheat by doing too much too fast, or trying to endure too long (Eichner, 2002).

Although firefighters are seen as a healthy group and do not show any consistent evidence of increased risk from cardiovascular disease, they face an increased risk of injury and death due to cardiovascular events during periods of intense physical and stress (Rosenstock and Olsen, 2007). The cardiovascular events are grouped around fire suppression and emergency response while firefighters are on duty (Kales et al., 2007). Kales et al. found that although fire suppression only represents about one to five percent of firefighters' professional time each year, it accounts for over thirty-two percent of on-duty deaths. Numerous studies have demonstrated the relationship between heavy exertion and sudden cardiac events (Rosenstock and Olsen, 2007).

The research conducted for this Applied Research Project began with 126 volunteer participants. Four participants were unable to complete all the physical aspects of the research due to reaching exhaustion. Four participants did not provide all the necessary data on the initial questionnaire. This included age, fitness level, and years of fire service experience. There were seven participants who did not properly start the Suunto t6 heart rate monitor so no heart rate data was collected. There were ten participants for whom hydration status was not measured prior to beginning the study (Table 1).

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Table 1 –Final number of research participants

Total participants who volunteered and began the research	126
Number of participants who did not complete all physical aspects of the research	-4
Number of participants who did not provide the necessary personal data	-4
Number of participants where heart data was not collected (failed to start heart rate monitor at beginning of research)	-7
Number of participants where hydration status was not measured (the participant chose not to participate in the hydration portion of the research)	-10
Total number of participants for whom data was analyzed	101

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There were 101 final participants in the research for whom data was analyzed. There were 98 men and 3 women with an average age of 39.5 years. The research participants averaged 13.5 years of fire service experience. The average fitness level of the participant group was 3.3, based on a scale of one to seven. The fitness level was determined from the participant's

individual resting heart rate and recovery rate data, and from self-reported physical activity and exercise levels (Table 2).

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Table 2 – Final research participant data

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Gender	
Male	98
Female	3
Average age	39.5
Average years of fire service experience	13.5
Average fitness level	3.3

(Based on a scale of 1-7, with 1 being a low fitness level and 7 being the highest)

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The average resting heart rate during the research was 77 beats per minute. It was noted that participants who ranked their fitness level higher displayed a much lower resting heart rate than those participants who were less fit. During the live fire portion of the first phase of the research, the average heart rate for all the participants was 164 beats per minute. When the data for the participants who were actively engaged in fire suppression was separated from those who participated in a less physical roll, such as operating the engine pump or commanding, the average heart rate during the first phase increased to 173 beats per minute over the 15-minute period (Table 3).

During the fire skills portion of the first phase, the average heart rate for all the participants was 179 beats per minute (Table 3). When the data for the less physically involved participants was excluded from those physically involved in the activities, the average heart rate increased to 190 beats per minute. The average maximum heart rate during the research was 179

beats per minute (Table 3). During the research several participants reached heart rates either at or exceeding their 100 percent maximum heart rates. The research found maximum heart rates of over 200 beats per minute and one participant reached a maximum heart rate of 204 beats per minute. It was observed that participants who rated themselves with higher levels of fitness displayed significantly lower maximum heart rates, and completed the drill scenarios with a lower level of verbalized exhaustion than participants with a lower rated level of fitness.

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Table 3 – Average heart rates observed during research

Time of reading	Average heart rate (beats per minute)
Resting heart rate	77
During live fire drill (all participants)	164
During live fire drill (involved in suppression)	173
During fire skills drill (all participants)	179
During fire skills drill (involved in suppression)	190
After 5 minutes of rest	162
After 10 minutes of rest	148
After 15 minutes of rest	121
After 20 minutes of rest	102
Average maximum heart rate	180

The research discovered that participants who indicated a higher level of physical fitness in the initial questionnaire had lower maximum heart rates when compared to participants who indicated a lower level of fitness.

The Suunto devices were used to measure and record recovery heart rate during the second phase of the research. Heart rate recovery of the participants was monitored. After five minutes of rest the average heart rate had decreased from an average of 190 beats per minute to 162 beats per minute (Table 3). Table 3 demonstrates the recovery heart rate average during the second phase of the study. The participants were initially observed for a heart rate decrease of at least 12 beats per minute for the first minute. A heart rate recovery of a least 12 beats per minute within the first minute is considered favorable (Meszaros, 2001). In the research, 68 percent of the participants experienced a decrease of at least 12 beats per minute within the first minute of recovery. It was observed that the individuals with higher fitness levels experienced a faster recover time.

The research noted that physical exertion was not the only cause of an increased heart rate. Based on the data collected from the Suunto t6 monitors, the participants' heart rates increased an average of 50 beats per minute during the donning of the personal protective gear.

Question 2: What are the impacts of hydration levels on a firefighters' performance?

The literature noted that hydration status can impact firefighter performance. High levels of physical activity result in high sweat rates and substantial water and electrolyte losses (Sawka et al., 2007). Even though sweat evaporation is impaired by firefighter turnout gear, sweat is still produced at high levels (Hostler and Suyama, 2007). The elevated production of sweat removes water from the plasma and reduces blood volume (Hostler and Suyama). During intense levels of activity, especially in the heat, sweat rates can be one to two and one-half liters, or the equivalent of two to five pounds of body weight per hour, resulting in dehydration (Binkley et al. (2002).

Firefighters can become dehydrated while performing at high levels of physical activity (Sawka et al., 2007). Dehydration can result in hyperthermia because of reduced heat dissipation.

The stress produced by dehydration and hyperthermia results in cardiovascular strain during exercise and markedly reduced cardiac output up to three liters per minute. Inadequate levels of hydration increase body core temperature, heart rate, and perceived exertion during heat stress.

The ARP research measured hydration status prior to beginning the research activities (Table 4). The research found nine percent of the participants were well hydrated prior to beginning the exercise, having a specific gravity of urine less than 1.010. Sixty-five percent of the participants were minimally dehydrated. Twenty-two percent were found to be significantly dehydrated, and four percent were seriously dehydrated. Of the 101 participants, the research found 91 percent did not begin the research activities properly hydrated (Table 4).

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Table 4 - Hydration status prior to research

Hydration status	Specific gravity of urine	Number of participants	Percentage of participants
Well hydrated	Under 1.010	9	9
Minimally dehydrated	Between 1.010-1.020	66	65
Significantly dehydrated	Between 1.020-1.030	22	22
Seriously dehydrated	Over 1.030	4	4

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Studies conducted on NBA players found inadequate hydration levels were common during preseason practices and summer league games (Baker et al., 2007). Critical water deficit is considered to be greater than two percent of overall body weight for most individuals. There is a noted decrease in performance as dehydration increases from one to four percent of body weight. Significant deficits are noticed in performance when water loss reached two to three percent of body weight (Baker et al.).

During the research, three percent of the participants lost one percent or less of their body weight. This group was primarily those participants assigned to less physical tasks during the research (Table 5). Fifty-eight percent of the participants lost at least two percent body weight during the 30 minute drills (Table 5). The majority of participants reported being aware they had lost a significant amount of fluid through sweat loss. Five percent of the participants in the research lost greater than three percent of their body weight. The average weight loss among the participants in the research was slightly over three pounds, and the highest individual weight loss was seven pounds.

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Table 5 – Body fluid loss of participants during research

Fluid loss	Number of participants	Percentage of participants	Potential effects
1% body weight	3	3	Decrease heat transfer to skin for dissipation
1-2% body weight	39	39	(all the above plus) Increase heart rate Decrease blood pressure
2-3% of body weight	54	53	(all the above plus) Decrease muscle endurance Decrease energy level
>3% body weight	5	5	(all the above plus) Decrease concentration and ability to focus

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Diminished levels of hydration can impact physical performance, increase body core temperature, increase cardiovascular strain, increase glycogen utilization, alter metabolic function, and possibly alter central nervous system function. Evidence suggests each of these factors interact to contribute in concert, rather than independently, to degrade aerobic exercise performance (Sawka et al., 2007).

The individual effects of dehydration and hyperthermia are similar each one reducing stroke volume by seven to eight percent and increasing heart rate by four to six percent when compared alone. Adding dehydration to hyperthermia results in a decreased in stroke volume of 19 to 21 percent. Although this causes heart rate to increase by eight to ten percent, cardiac output still decreases by eleven to fifteen percent. When exposed to the combination of dehydration and hyperthermia, cardiac output will be inadequate for maintaining cardiovascular function due to falling blood pressure.

When firefighters' are dehydrated, they become exhausted more quickly even at lower body core temperatures. Dehydrated firefighters experience lower cardiac output, lower blood pressure, and greater vascular resistance, making them potentially more prone to ischemic injury. Hyperthermia should be considered to be more serious in a dehydrated person compared to a hydrated person.

Additional dehydration results in an additional loss of cardiac output when the rise in heart rate and fall in stroke volume cannot keep up with the needs of the firefighter's body. Severe levels of dehydration can cause the heart to endure near-maximal heart rates for extended periods time (Hostler and Suyama, 2007). Heart rate is considered an important indicator of mortality. All other risk factors being equal, death risks increase about 50 percent for each 20-beat per minute increase (Seccareccia et al., 2001).

Question 3: What effects do changes in body core temperature have on firefighter performance?

The literature review found that body core temperature is one of the most frequently monitored conditions during firefighting (Durnad, 2007). In hot environments, blood vessels near

the skin open to facilitate cooling so the body's core temperature can be maintained (ACE, 2003). This causes a reduction in venous return and stroke volume.

The human body attempts to maintain a balance between heat gain and heat loss (Petersen, 2008). When the balance is compromised, the body is unable to function at its optimal level (Petersen). Increased body core temperature poses serious threats to firefighter performance and health (Maughan and Shirreffs, 1997). During the fire scenarios performed in the studies conducted in Great Britain, rising body core temperature was a main factor limiting firefighter performance (ODPM, 2004). In this study, 65 percent of the scenarios were stopped before being completed due to rising body temperature (ODPM).

The human body will only tolerate a drop of 14°F and an increase of 6°F. (Binkley et al., 2002). Failure to stay within these limits may cause death. Firefighter workloads can result in metabolic rates 20 to 25 times higher than resting level. These workloads can increase core body temperature approximately 1.8°F every five-minutes (Petersen, 2007).

During the research conducted for the ARP, the participants' body core temperatures ranged from 98 to 106°F. The largest number of the participants' peak core body temperatures, 57 percent, fell between the range of 100 to 102°F (Table 6). Forty-four percent of the participants' peak core body temperatures were above 102.1°F (Table 6). Two of the participants attained body core temperatures above 105°F, with one reaching 106°F. For the majority of the participants in the research, body core temperatures did not peak until five minutes into phase two, the rehabilitation phase of the research.

Table 6 – Peak core body temperatures during the research

Peak core body temperature (Degrees Fahrenheit)	Number of participants	Percentage of participants
Between 100 -102	57	56
Between 102.1 – 103	33	33
Between 103.1 – 104	8	8
Between 104.1 – 105	1	1
Above 105	2	2

The most common symptom experienced by firefighters due to a rise in body core temperature is heat exhaustion. Symptoms of heat exhaustion include persistent muscle cramps, weakness, fainting, nausea, and diarrhea (ACE, 2003). Heat exhaustion can also be accompanied by decreased urine output, and body core temperatures that generally range from 97 to 104°F (Binkley et al., 2002).

Elevated body core temperatures associated with heat exhaustion can also affect blood clotting (Hostler and Suyama, 2007). This condition, associated with the strenuous work involved with fire suppression, can accelerate the progression to myocardial infarction resulting in a heart attack or sudden death.

When the temperature regulation system is overwhelmed due to excessive heat production or inhibited heat loss, there can be complete thermoregulatory failure resulting in exertional heat stroke (Binkley et al., 2002). Exertional heat stroke patients can have body core temperatures greater than 104°F associated with signs of organ system failure (Binkley et al.). As the body core temperature increases, the patient will display elevated heart rate, decreased blood pressure, sweating, rapid breathing, altered mental status, vomiting, diarrhea, seizures, and coma

(Binkley et al., Hoppe, 2006). The likelihood of long-term injury or death increase the longer the patient's body core temperature remains above 106°F (Binkley et al., ACE, 2003). Other conditions associated with elevated body core temperature and exertional heat stroke include severe lactic acidosis, hyperkalemia, acute renal failure, and (Binkley et al.).

Question 4: What are the most effective methods of rehabilitating firefighters following firefighting operations?

Effective rehabilitation includes relief from climatic conditions, rest and recovery, active and/or passive cooling or warming, rehydration, and calorie and electrolyte replacement (NFPA, 2008). There are two forms of cooling, passive and active. Passive cooling relies on natural evaporation of sweat, removal of personal protective equipment, or movement to a cool location (NFPA, 2008). Active cooling is the process of using external methods or devices to reduce elevated body core temperature.

Most fire departments use passive cooling (Ross et al., 2004). The first step in the passive cooling is to have firefighters remove their protective clothing and seek shelter from hot environments (Hostler and Suyama, 2007). Passive cooling is inefficient and does not reduce core temperature (Ross et al., 2004). This is especially true in dehydrated individuals. Passive cooling does little to cool firefighters. Studies demonstrated that rectal temperature continues to rise five to ten minutes into recovery increasing the risk of heat related injury (McLellan and Selkirk, 2006). Passive cooling alone does not reduce temperatures that have soared into dangerous territory as a result of the first 30-minutes of firefighting (Bull, 2008).

Implementation of work and rest cycles increases total work time, and rehabilitate firefighters. During rest periods, firefighters need to open garments and remove restrictive equipment to enhance cooling (Selkirk et al., 2004).

Alternative cooling strategies are necessary to help reduce core temperature during rehabilitation (McLellan and Selkirk, 2006). A simple, low cost active core-cooling system is the cold towel (Bull, 2008). Cold towels work by conductive cooling which is effective in all temperature and humidity conditions (Armstrong et al., 2007). Placing towels in ice water makes them the most effective. Cold towels can be applied to the head, body, and arms since these areas have demonstrated the ability for rapid heat loss (Binkley et al, 2002).

The literature noted that the Littleton (CO) Fire and Rescue Department measured the effectiveness of cold towels in reducing core body temperature. Of the 33 firefighters who began the rehab process with temperatures above 101°F, body core temperatures were reduced to an average temperature of 98.5 °F after 15-minutes of rehab using cold towels (Bull, 2008). Of the 62 firefighters involved, 53 highly recommended and 9 recommended cold towels as a comfort aid. An aggressive combination of rapidly rotating cold water-soaked towels to the head, trunk, and extremities, and ice packs to the neck, arm pit, and groin provide an acceptable cooling method (Armstrong et al., 2007).

Misting fans have become common active cooling devices for firefighter rehabilitation (Hostler and Suyama, 2007). A combination of water mist and fans are most effective when the relative humidity is low since this method depends primarily on evaporative cooling. The literature noted that a mister fan can lead to a 20 percent increase in relative humidity, reducing evaporation potential (Selkirk et al., 2004). Under ideal conditions, misting fans can reduce core body temperature approximately 1.8°F during a 30-minute exposure. While mister fans did help increase the time firefighters could tolerate the heat, there was only limited reduction of thermal strain (Selkirk et al.)

Applying active cooling techniques directly to the responder are the most effective methods for cooling (Hostler and Suyama, 2007). The literature review found contradicting data on the effectiveness of cooling vests in treating mildly hyperthermic individuals. Godek et al. (2005) supported the use of cooling vest, citing an example where an NFL football player was saved using one. However, Lopez et al. (2008) stated the cooling vest was no more effective for rapidly reducing body core temperature than resting in a thermoneutral environment.

Forearm submersion is effective in reducing heat stress, extending work time, and rehabilitating firefighters (Selkirk et al., 2004). Forearm immersion takes advantage of numerous superficial arm veins by placing the forearms and hands directly into cold water (Hostler and Suyama, 2007). Ideal water submersion temperatures are between 50 and 68°F. Cooler water produces more rapid rates of cooling initially, then plateaus after 20 to 30-minutes of submersion (Selkirk et al.). A greater transfer of heat to the cold water is noted during the first 10-minutes of submersion compared with the period between 10 and 20-minutes.

When using forearm submersion, work time is increased by 60 percent compared with passive cooling, and by 30 percent when compared to cooling with mister fans. Submersion also produces a significant reduction in thermal strain (Selkirk et al., 2004). While not practical in the field, one way to increase the effectiveness of submersion is to use a combination of hands and feet (Selkirk et al.).

The Applied Research Project research examined some of the most common cooling measures used during firefighter rehabilitation. This included passive cooling, misting fans, wet towels, and forearm water submersion (cooling chairs) (Table 7). The participants were randomly assigned to a cooling station. Each station had 28 participants except the submersion; due to the limited availability of the chairs, only 17 participants were assigned to this station.

Table 7 – Cooling station assignments in research

Cooling station	Number of participants assigned to the station
Passive cooling	28
Misting fan	29
Wet towels	28
Forearm submersion (KorKooler chair)	17

As Table 8 demonstrates, the wet towels and cooling chairs had a similar rate of reduction in body core temperature, with a difference of only .05°F. Analysis of the research found that the group using the wet towel cooling method experienced the smallest increase in core body temperature compared to the other methods.

Table 8 – Average core temperature reduction for each cooling measure

Cooling measure	Passive	Misting fan	Wet towels	KoreKooler
Mean core temp reduction	.75°F	.88°F	1.18°F	1.22°F

During the second phase of the research, temperature readings were taken from both the CorTemp telemetry device, and tympanic thermometer (Table 9) Tympanic measurements were taken at the same time intervals as the CorTemp readings. On average, the tympanic temperature readings were lower than the core body temperature readings by more than two degrees. During the recovery period the tympanic temperature began to drop immediately while the core temperature continued to rise and peaked after approximately 20-minutes.

Table 9 – Core body and tympanic temperature comparisons

Time of recording	Average core body temperature (Degrees Fahrenheit)	Average tympanic temperature (Degrees Fahrenheit)	Difference (Degrees Fahrenheit)
After 5 minutes of rest	101.8	100.3	1.5
After 10 minutes of rest	102.0	99.2	2.8
After 15 minutes of rest	101.6	98.2	3.4
After 20 minutes of rest	101.1	98.0	3.1

During the research the tympanic temperature readings dropped quicker than baseline temperatures when the participants were being cooled by methods that focused on the head and neck, such as the misting fans and wet towels.

Fluid replacement is the single most important component in the rehabilitation of firefighters (Smith and Haigh, 2006). Dehydration is a risk factor for both heat exhaustion and exertional heat stroke. Fluids lost through sweat during firefighting must be replaced to prevent excessive dehydration and excessive changes in electrolyte balance (Sawka et al, 2007). The traditional fluid used in the fire service for rehydration is water since it is inexpensive, and easy to carry and store (Hostler and Suyama, 2007).

The goal of rehydration is to fully replace any fluid or electrolyte deficits. Individuals should drink periodically throughout and following physical activities (Sawka et al. 2007). For every kilogram of body fluid lost, a kilogram must be replaced (Hostler and Suyama, 2007). When possible, fluids should be replaced over time, not in large amounts all at once. Replacement fluid should also have sufficient electrolytes to maximize fluid retention (Sawka et al.).

There is a widely held belief that drinking beverages with caffeine during firefighting activities will exert a diuretic effect and impair performance in heat (Hostler and Suyama, 2007). Contrary to this belief, there is no evidence that caffeine consumption results in water-electrolyte imbalance or reduced heat tolerance (Hostler et al.). While caffeine has little or no influence on thermal balance, it can raise the heart rate which is not helpful in the context of rehabilitation (Armstrong et al., 2007, and Hostler and Suyama).

Many fire service organizations avoid sport drinks due to a misconception of rehydration (Hostler and Suyama, 2007). There is a belief that sport drinks cause gastric distress and lead to further dehydration by extracting water from the cells. This is unfounded (Sawka et al., 2007). Fluid replacement for extended incidents should include drinks that contain glucose and sodium chloride (Hostler and Suyama). Consuming sodium during recovery helps retain ingested fluids as well as stimulate thirst (Sawka et al.). Failure to replace sodium loss can cause the body to return to a dehydrated state as well as stimulate excessive urine production (Sawka et al.).

The use of intravenous rehydration has produced mixed reviews (Hostler and Suyama, 2007). It was found that subjects who rehydrated orally avoided exhaustion for an additional five minutes, or 14 percent longer than a person who was rehydrated using the intravenous route (Casa, et al., 2000). Additionally, the study demonstrated decreased cardiorespiratory strain and a significant decrease in rectal temperature and skin temperature with oral rehydration.

During proper rehabilitation it is important to provide some form of nutritional replacement to working firefighters (Hostler and Suyama, 2007). Food is the fuel for the body and is critical for continued physical exertion. Calorie replacement should come from foods high in carbohydrates and protein, and low in fats (Smith and Haigh, 2007). Replacement foods should be primarily complex carbohydrates to maintain blood glucose levels, with some protein,

and a lesser amount of fat. Meal consumption is critical to ensure full hydration (Sawka et al., 2007).

Fire departments have acknowledged the effects uniforms have on heat storage. Some departments now allow members to wear shorts and t-shirts in place of long pants and long-sleeve shirts (Malley et al, 1999). The shorts and t-shirt result in a lower production of heat, reduce heat strain, and extend work times. One of the concerns in replacing uniform pants with shorts is the level of thermal protection. The Fire Department of New York (FDNY) concluded that there were no significant increases in upper and lower extremity burns when wearing the shorts and t-shirt combination (Prezant et al., 2001)

## **DISCUSSION**

As supported in the literature review, and confirmed in the research conducted for this Applied Research Project, firefighters are often required to tolerate extreme physical demands while working in hot, humid environments (Pye, 2006). Since firefighting is highly dependent upon the physical ability of the firefighter, when firefighters are exposed to these conditions too long they reach a point where fatigue and exhaustion set in and begin to reduce their ability to perform (Dickinson and Wieder, 2004).

This assertion was supported in the research. During the first phase of the research, the participants were required to use high levels of muscular strength and endurance to perform at near maximal metabolic system capacity. Four percent of the research participants were unable to complete the research due to fatigue or physical discomfort. This result particularly is concerning given that the physically demanding portion of the research consisted of only two 15-minute drills. This is a relatively short duration when compared to the potential length of actual fireground operations.

The literature noted that as firefighters become more fatigued they can make poor decisions. This is of particular concern while working in the high-risk fire environment and can result in increased injuries. This was supported by Walton et al., (2003) who reported in 1998 that work-related injuries among firefighters was over four times higher than those experienced by private industry. While the research was conducted in a controlled environment, it was apparent that the level of fatigue would have impacted the participants' abilities to perform in a less safe environment.

The literature noted that firefighter protective clothing impairs the evaporation cooling process and results in increased sweat rates (Binkley et al., 2002). Although modern firefighting gear is much lighter than its predecessor, it still becomes saturated with sweat which increases the weight of the gear, further adding to the firefighter's physical and thermal stresses (Hostler and Suyma, 2007). This declaration was affirmed in the research. The PPE worn by the research participants weighed approximately 60 pounds. The participants commented on the noted additional weight at the end of the research phases. It is critical that firefighters recognize the impacts this additional weight has on their physiological health.

The literature review identified numerous studies that supported the effects that the physical demands of firefighting and working in hot environments can have on firefighters (ODPM, 2002, Elgin and Tipton, 2003). In one study conducted, heat strain was the greatest single source of performance limitation (Elgin and Tipton, 2003). During these studies, Elgin and Tipton noted that the heart rate of the participants averaged 162 beats per minutes. During a second scenario lasting 40 minutes, average heart rates reached 180 beats per minute. During a final scenario, average heart rates reached 182 beats per minute, with one heart rate recorded as high as 202 beats per minute (Elgin and Tipton).

The research conducted for this ARP produced similar results to those of Elgin and Tipton. During the live fire drill in the first phase of the study, the average heart rate of all the participants was 164 beats per minute. This rate was two beats higher than the average heart rate noted in the first phase of the study conducted by Elgin and Tipton. However, when the data for those who were actively involved in the fire suppression activities were separated from those who performed a less physical role such as controlling the pump panel or a command position, the average heart rate for the first exercise increased to 173 beats per minute.

During the firefighter skills drill portion of the first phase, the average heart rate of all the participants was 179 beats per minute. Again, this was consistent with the average heart rate of 180 beats per minute noted in the second portion of the Elgin and Tipton study. Similar to the first exercise, when the data for those who were actively involved in the fire suppression activities were separated from those performing a less physical role, the average heart rate for the participants in the second portion of the first phase increased to 190 beats per minute.

The research produced very similar results with several participants reaching maximum heart rates. One of the participants reached a heart rate of over 200 beats per minute, and one participant reached a frightening maximum heart rate of 204 beats per minute. These two high heart rates were noted in individuals who had indicated a lower level of physical conditioning and were slightly overweight. This observation serves to re-emphasize the importance of maintaining a high level of fitness to meet the physical demands of the job. Being physically fit is not only critical to job performance, it also allows the body to cope with increased thermal demands. The research participants who rated their level of fitness higher also described a lower level of exhaustion at the completion of the events, and began the research drills with a lower initial heart rate.

Consistent with the findings of Kales et al. (2007) noted in the literature, the research also demonstrated that the central nervous system response prior to physical activity could increase heart rate. The research noted an average increase of 50 beats per minute in heart rates before the activities were started. During this time the research participants were simply getting dressed in firefighter turnouts.

During the research it was observed that the participants were surprised by the heart rates observed during the activities. Many of the participants commented that they were shocked by high heart rates observed.

The literature review noted that cardiovascular events which occur while firefighters are on duty most commonly centered on fire suppression activities and on emergency response (Rosenstock and Olson, 2007). Kales et al. (2007) noted that while firefighters only spend between one and five percent of their time fighting fires, these duties accounted for over 32 percent of cardiac deaths. Although firefighters have lower than average risk factors from cardiovascular disease, they are still dying from heart attacks. The literature attributed the higher death rate in firefighters to the extreme levels of physical exertion they face (Rosenstock and Olson). When looking at the physical demands and the heart rates of firefighters involved in the studies of Elgin and Tipton, and the research results, this finding is not surprising.

Hydration levels are critical to firefighting operations. Diminished levels of hydration degrade performance (Sawka et al., 2007). When water loss for most individuals exceeds two percent, the magnitude of the harm to the individual increases. The research found that 53 percent of the participants experienced body weight loss of over two percent.

Baker et al. (2007) noted that when body water loss reaches two to three percent of body weight, significant physiological impacts can occur. These impacts include increased body core

temperature, increased cardiovascular strain, and altered central nervous system functions. This assertion was validated in the research. As body fluid loss increased, the researcher noted changes in the participants' physiological and mental capabilities. While the majority of the participants experienced body weight loss between two and three percent (53 percent), five percent of the participants experienced body weight loss exceeding three percent.

During the research the majority of the participants were aware that they had lost a significant amount of fluid during the 30-minute exercises however, all of them stated that they were not aware of the adverse impacts a comparatively small percentage of body weight loss would have on their performance. During firefighting operations rapid weight loss is a concern. What was most disturbing in the research was that when asked how much fluid would be required for the participants' rehydration, only a few individuals had any idea. The normal response was that they would "Just drink a lot of water."

In a study by Baker et al. (2007) on NBA players it was noted that they began the basketball season inadequately hydrated. Since hydration is an important component of firefighter performance, the research sought to determine hydration levels prior to conducting the research that would also provide an indication of hydration levels before responding to a fire. Surprisingly, the urinalysis revealed that 91 percent of the participants were dehydrated to some extent prior to beginning the research. The researchers found that this was consistent between both the morning and afternoon groups.

As noted in the literature, the research also demonstrated that when firefighters are dehydrated they become exhausted earlier in a fireground operation; this is true even at lower body core temperatures. The literature also noted that dehydrated subjects with decreased cardio output are more prone to cardiac events (Sawka et al., 2007).

A firefighter who is dehydrated is in a dangerous condition. Dehydration results in decreased stroke volume and reduced cardiac output. As they worsen, the rising heart rate and falling stroke volume will be unable to keep up with the needs of the firefighter's body (Hostler and Suyama, 2007). When this continues, the heart has to maintain near-maximal heart rates for extended periods of time. Saccareccia et al. (2001) note that heart rate is an important indicator of mortality.

Elevated body core temperatures can significantly impact a firefighter's performance. A dehydrated firefighter exposed to stressful work environments can develop elevated body core temperatures. During a study conducted by the ODPM, heat related problems were the most predominant. During 40 scenarios performed, 15 were stopped due to the firefighter's core body temperature exceeding 103.1°F (ODPM, 2002).

The human body attempts to maintain a balanced heat level; when this balance is compromised, the body is no longer able to function at its best (Petersen, 2008). The human body will only tolerate a temperature increase of 6°F. Failure to manage body core temperature is serious and can result in death.

During the ARP research the participants' body core temperatures ranged from 98 to 106°F. The research participants were shocked by the high temperatures resulting from the research activities. The majority of the participants' peak body core temperatures fell in the range of 100 to 102°F with 44 percent reaching a core body temperature of 102.1°F or higher. Two percent of the participants reached body core temperatures above an alarming 105°F.

The most common symptom related to elevated body core temperature is heat exhaustion (ACE, 2002). When this condition is not managed, or when the thermoregulatory system is overwhelmed, exertional heat stroke results. This can result in body core temperatures above

104°F, and organ system failures (Binkley et al., 2002). Exertional heat stroke is a true medical emergency and must be managed at once.

The literature provided insights on various methods of rehabilitating firefighters during firefighting operations. The intent of rehabilitation is to improve firefighter performance and decrease the likelihood of an injury or death (Smith and Haigh, 2006). Effective rehabilitation includes climate relief, rest and recovery, cooling or warming, rehydration, and calorie replacement (NFPA, 2008).

There are two forms of cooling, passive and active (NFPA, 2008). Passive cooling relies on the natural evaporation of sweat, and the removal of personal protective equipment. Active cooling is the process of using external methods or devices such as misting fans, ice vests, or hand and forearm immersion to reduce body core temperature (NFPA, 2008).

Most fire departments in Orange County (CA) do not have a policy for cooling firefighters during rehabilitation, leaving each department to determine its own approach. While most departments use passive cooling, it is not sufficiently effective. In most agencies, passive cooling involves removing the firefighter's turnout coat, sitting in the shade, and drinking some water. (Ross et al., 2004) notes that removing both the coat and the pants is most effective. Ross, et al. added that even this form of passive cooling is not effective. This is especially true if the person is dehydrated as well. This assertion was supported based on feedback from the research.

The research examined some of the most common cooling methods noted in the literature review. This included passive cooling, wet towels, misting fans, and forearm water submersion. In the literature review, Armstrong et al. (2007) stated that cold towels were effective in reducing core body temperature. The results of the research support this statement, gaining a reduction in the core body temperature of almost 1.18°F. The literature also indicated the effectiveness of the

forearm submersion. The research again affirmed this finding, lowering body core temperature almost 1.25°F. One interesting observation noted during the research occurred when the participants were asked which cooling method looked the most appealing. The majority of the participants responded stating that the wet towels looked refreshing and the most effective. However, the data indicated while only by a small amount, the forearm submersion was more effective than wet towels in lowering body core temperatures.

During the research, the group using the cold towel cooling method experienced the smallest increase in core body temperature compared to the other methods. This fact, combined with their effectiveness, is an encouraging finding given that towels are easy to carry and set-up, and much less expensive than forearm submersion cooling chairs.

During the second phase of the research, temperature was monitored at identical intervals with both the CorTemp system and tympanic thermometer. Easton et al. (2006) noted that during recovery from heat exposure, tympanic temperatures recorded are lower than body core temperatures. The research found this assertion to be true. On average, the tympanic temperatures were lower than core temperatures taken by the CorTemp device by over two degrees. As the resting time increased, so did the difference between the temperature measurements.

During the recovery phase of the research tympanic temperatures began to drop almost immediately while core temperature continued to rise and peak after approximately five minutes into the 20-minute rehabilitation phase. After five minutes of recovery, the data indicated a 1.5°F difference between the core temperature reading and the tympanic reading. However, after 20-minutes the difference between the core temperature and the tympanic temperature had increased to over three degrees. This is a notable observation. While this observation might be contributed

to the fact that these cooling methods focus on the head and neck, it also suggests that tympanic temperature is an inaccurate indicator of body core temperature. While the rectal or telemetry pill method is the most accurate measurement of core body temperature, it is impractical in the field. The research suggests that additional options should be evaluated and considered.

Fluid replacement is the single most important component in the rehabilitation of firefighters (Smith and Haigh, 2006). Both the literature and the research emphasized that dehydration is a risk factor for both heat exhaustion and exertional heat stroke. The fluids lost through sweat must be replaced to prevent excessive dehydration and excessive changes in electrolyte balance (Sawka et al, 2007).

Traditionally, the fire service has used water for rehydration. However, the literature suggests that water is not necessarily the most effective method, especially in cases of larger volume loss. Swaka et al. (2007), assert that both fluids and electrolytes must be replaced. For the best results, fluids should be replaced over time, not in large amounts all at once.

Replacement fluid should have electrolytes to maximize fluid retention (Sawka et al., 2002). Drinks should contain glucose and sodium chloride (Hostler and Suyama, 2007), and also should be consumed cold. While some of the research participants were aware of the benefits of consuming sport drinks during rehabilitation, most were not. Consuming sodium during recovery helps retain ingested fluids as well as stimulate thirst (Sawka et al.). Failure to replace sodium loss can cause the body to return to a dehydrated state as well as stimulate excessive urine production (Sawka et al.). While they may appear attractive in cold weather, caffeine drinks should be avoided. Although caffeine does not impair performance in heat, it can raise the heart rate which is not desirable during rehabilitation (Armstrong et al., 2007, and Hostler and

Suyama). The literature review also demonstrated that intravenous rehydration is no more effective than oral rehydration.

Providing some form of nutritional replacement during rehabilitation is important (Hostler and Suyama, 2007). The body will require some form of food in order to continue physical performance. While hamburgers and other fast foods are tasty, and have been the norm for the fire service, they should be avoided. Calorie replacement during rehabilitation should come from foods high in carbohydrates and protein, and low in fats, and is best if served in the form of snacks (Smith and Haigh, 2007). These snacks should consist primarily of complex carbohydrates to maintain blood glucose levels, with some protein, and a lesser amount of fat. While not a well-known fact, food replacement is critical to ensure full hydration (Sawka et al., 2007). During the research, almost all the participants were not aware of the importance of nutritional replacement in proper rehydration.

The results of this Applied Research Project clearly demonstrate a connection among physical exertion, levels of hydration, and changes in body core temperature on firefighter performance. The implications of these findings is the need for the Orange County Fire Authority to formally address fireground rehabilitation as an essential component of any incident. The research has provided an in-depth understanding of the physiological factors that affect firefighter performance, as well as steps that can be taken during an incident to rehabilitate firefighters.

The project implied the continued importance of the OCFA physical fitness program. While it is clear from the literature review and the research that certain risk factors associated with firefighting are unavoidable, levels of fitness and weight are risk factors that can be modified through proper diet and exercise. Being physically fit is not only critical to job

performance, it also improves the body's ability to manage increased heat stress. The research demonstrated the connected between physical fitness and firefighter performance. Research participants who rated their level of fitness higher began the process with lower initial heart rates, and produced lower maximum heart rates at sustained exertion levels. They also described a lower level of exhaustion at the conclusion of the research exercises. Currently, participation in the OCFA fitness program is mandatory but not punitive. The research supports the need to implement changes in the program and require participation and, and minimum fitness performance standards as conditions of continued employment.

The research implied a need to educate firefighters on the necessity of hydration and nutrition. The research demonstrated that a firefighter could experience significant fluid loss in only 30-minutes of physical exertion. Firefighters need to be educated regarding the critical need for proper hydration, appropriate rehydration fluids, and the importance of proper nutrition both during rehabilitation and afterwards. The literature review emphasized the importance of hydration on mental and physical performance. The findings in the research that 91 percent of the participants began the research dehydrated, indicate a potential pattern of improper hydration within the Orange County Fire Authority. The research also noted that firefighters are unaware of proper fluid replacement needs following an incident.

The research and literature review demonstrated the most effective methods of cooling firefighters during rehabilitation. Both cold towels and forearm submersion not only produced clinical evidence in the form of reduced body core temperatures. Research participants also reported feeling the positive effects of the two cooling methods.

## RECOMMENDATIONS

The research in this Applied Research Project has clearly demonstrated the need for the Orange County Fire Authority to take action toward providing proper firefighter rehabilitation during emergency incidents. Based on the literature review, and the research on physical exertion, hydration levels, and body core temperature, it is clear that these factors have a direct impact on firefighter performance. The research demonstrated that the majority of OCFA firefighters are unaware of many of the risks associated with heat stress, as well as the methods to reduce those risks. The OCFA should take the necessary steps to develop and implement a comprehensive program that addresses emergency incident rehabilitation, and the prevention of exertional illnesses and injuries. In order to correct this condition, the following recommendations are provided:

1. Develop a fireground rehabilitation policy for the Orange County Fire Authority. This policy should identify recovery techniques such as the use of cooling towels, forearm submersion, fluid replacement with liquids containing electrolytes, especially sodium, and nourishment that includes foods high in carbohydrates, protein, and low in fats. The policy also should address work/rest cycles, incorporate heat stress indexes, along with medical evaluations, and contain accountabilities that ensure that each crew member participates in the rehabilitation process. In the development of this policy, the OCFA should also investigate practical, accurate methods for measuring body core temperature in the field. The research conducted and the literature review demonstrated the need for a rehabilitation policy. NFPA 1584, Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises should be consulted.

2. Require mandatory participation in the OCFA's WEFIT Program by all new employees. Starting January 1, 2009 all new OCFA employees will be required to participate in a mandatory physical fitness program and WEFIT fitness evaluation at whatever physical abilities they possess. The research demonstrated that higher levels of fitness enable a firefighter to better perform their duties, and decrease the risk of exertional and heat related illnesses.

3. Provide training to OCFA command officers on the importance of firefighter rehabilitation during both emergency incidents and training. The research project demonstrated that many firefighters will continue working until they either drop, or are directed to rest. The training will educate OCFA command officers on rehabilitation needs of firefighters including rest, rehydration, and proper types of nourishment. In order to make the new rehabilitation policy more effective, those required to implement and enforce the policy must understand the benefits and consequences.

4. Provide training to all OCFA firefighters on proper hydration. The training should start with recognizing the importance of proper hydration. Firefighters should be educated on the importance of consuming liquids that contain electrolytes, particularly sodium. Since meal replacement was also identified as an important component of rehydration, this training should include the importance of proper eating and meal replacement during and following incidents. Training should stress the importance of carbohydrates in both rehydration, and the increasing of work times. Emphasis also should include the need for rehydration and meal replacement in training exercises as well. The research clearly demonstrated a need to educate firefighters on proper methods of rehydration during incidents; these methods include the type and quantity of fluids to consume.

5. Develop criteria for post-fighting follow-up after fire-ground rehabilitation for firefighters who experienced hyperthermia (body core temperature above 102°F) and or experienced heart rates greater than 175 beats per minute during firefighting activities.

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Format changes have been made to facilitate reproduction. While these research projects have been selected as outstanding, other NFA EFOP and APA format, style, and procedural issues may exist.

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## APPENDIX A

### INSTRUCTIONS

Hydration/core temp/heart rate research August 6 – 10, 2007

1. Read and sign volunteer notice
2. Pick up bag
3. Ingest pill
4. Urinate into cup
5. Weigh in (in underwear)
6. Proceed to drill ground bleachers
7. Get blood pressure and pulse taken
8. Wait until everyone is done
9. Give directions
10. Get in turnout and ready in fire engine
11. Take temperature readings and start watches
12. Dispatch units
13. 45 seconds apart
14. 15 minutes of continuous fire fighting
15. Horn will blow

16. Drop everything and proceed to exit or get off the roof  
(TO's) evacuate smoke
17. Once out the door line up with personnel on your unit  
Tympanic and core temps will be read
18. Proceed to salvage and overhaul prop
19. Do simulated tasks for 15 minutes
20. Horn will blow again
21. Initial reading 9start stop watch
22. Drop everything and proceed to four cooling stations  
Cool towels  
Coolie chair  
Shade  
Misting fan
23. If you need water swish around in mouth and spit out
24. 5 minute reading temp and BP
25. 10 minute reading temp and BP
26. 15 minute reading temp and BP
27. 20 minute reading temp and BP
28. Once complete proceed to scale to weigh in
29. Once weigh in is complete exercise is over

## **APPENDIX B**

### **Hydration Research Questionnaire**

**Complete following the exercises**

**1. Position of arrival**

**1<sup>st</sup> engine    2<sup>nd</sup> engine    3<sup>rd</sup> engine    4<sup>th</sup> engine    Truck**

**2. Fire ground actions**

**Nozzle    Assist    engineer    IC    Truck**

**3. Cooling measures used**

**Misting fan    Kooler chair    Cool towel    Ambient air**

**4. Perceived personal conditioning level**

**Unconditioned    1    2    3    4    5    6    Elite**

**5. During the fire attack, did you feel nauseous or light headed at any time from exertion?**

**Yes            No**

**6. During the stair climb, did you feel nauseous or light headed at any time?**

**Yes            No**

**7. Did you do try to hydrate (different than normal) prior to the evolutions?**

**Yes            No**

**8. Did you feel that you were able to rehydrate well upon returning to quarters?**

**Yes            No**

**9. Were you physically sore following the evolution? What area of the body?**

**10. What did you drink the morning of the study**

**Soda      Coffee      energy drink (Red Bull, Monster)      Water      Other**

**11. What type of beverage do you drink on a regular basis?**

**Soda      Coffee      energy drink (Red Bull, Monster)      Water      Other**

**12. What did you wear under your turnouts**