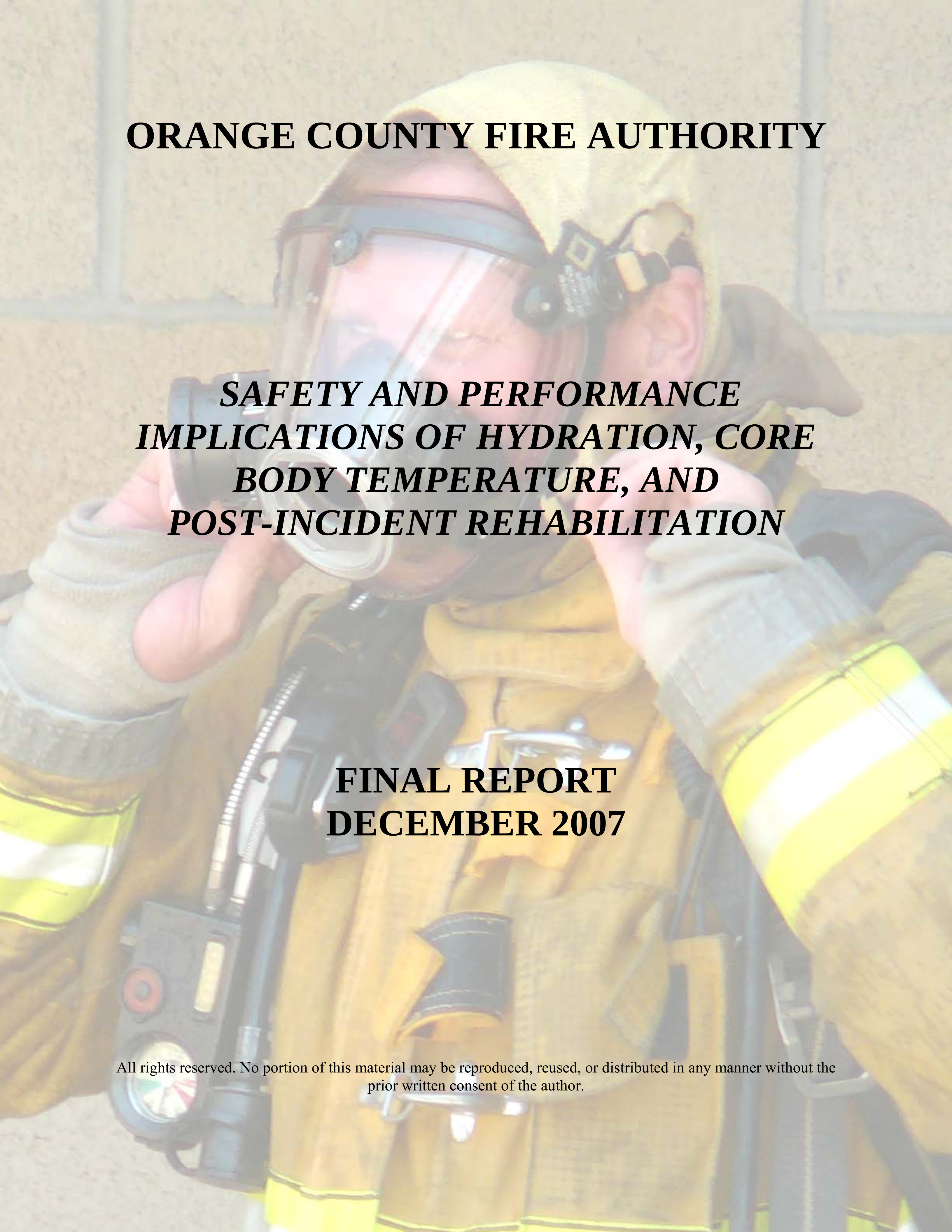

ORANGE COUNTY FIRE AUTHORITY

SAFETY AND PERFORMANCE IMPLICATIONS OF HYDRATION, CORE BODY TEMPERATURE, AND POST-INCIDENT REHABILITATION

FINAL REPORT
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ABSTRACT

Orange County Fire Authority (OCFA) undertook a research study to examine hydration status, exertion level, core body temperature, and post-incident cooling techniques. With this study, OCFA hoped to gain a better understanding of firefighter job demands. Implementing study recommendations should help minimize the inherent risks associated with the firefighting profession, resulting in a healthier, safer, and more productive workforce.

Volunteers for the study included 126 OCFA professional firefighters. It required participants to ingest a core body temperature capsule, provide a urine sample, and wear a heart rate monitoring unit. Core body temperature and heart rate readings were measured and recorded during two 15-minute firefighting-related drills. At the conclusion of the drills, participants were assigned to one of four cooling stations, where they remained for a 20-minute rehabilitation period. Final analysis included data from 101 participants.

The results indicate 91 percent of participants were dehydrated prior to commencing the study, which raises the issue of pre-incident hydration. For the majority of participants, core body temperature did not peak until five minutes into rehabilitation, which indicates core body temperature may continue to rise even after the cessation of physical activity. Even after 20 minutes of rest, few core body temperatures had returned to the initial temperature. During the rehabilitation period, wet towels and cooling chairs proved to be similarly effective at reducing core body temperature, but the wet towels were found to be more practical.

This study also shows rapid fluid loss can result from just 30 minutes of physical exertion. Given the potentially serious, adverse health consequences of inadequate hydration and re-hydration, the development and implementation of educational programs and post-incident rehabilitation protocols are necessary to maximize firefighter job safety and performance.

INTRODUCTION

Firefighting is a physically demanding and dangerous profession involving a high incidence of injury and death. In 2006, the United States alone had over 80,000 documented firefighter injuries and 106 documented on-duty firefighter deaths.[1] Orange County Fire Authority (OCFA), a career fire department serving the residents of Orange County, California, has been no exception. Between 1998 and 2004, OCFA lost one percent of its workforce to potentially preventable deaths, most of which were a result of cardiovascular events. These tragic losses served as the inspiration for the OCFA to create a program aimed at reducing firefighter injury and illness, thereby improving firefighter health and safety.

OCFA established this program, known as the Wellness and Fitness Program, in 2004 as a joint effort of labor and management to provide OCFA firefighters with knowledge, departmental support, and on-duty opportunities to improve their physical health, wellness, and fitness to enhance job performance and improve upon an overall healthy lifestyle. The guiding principle of the OCFA Wellness and Fitness Program was to create a firefighter exercise, fitness, and wellness program that was (1) created by individuals with actual, on-the-job firefighter experience; (2) based on scientifically proven principles; (3) used data collection and analysis of firefighter movements and job requirements; and (4) tailored specifically to address the unique demands of firefighter job performance. One of the unique aspects of the OCFA program was, and continues to be, its emphasis on firefighter-specific data collection and scientific analysis in creating a comprehensive, safe, and effective program.

OCFA identified physical fitness as a critical element of firefighter job performance and on-the-job safety. Accordingly, OCFA endeavored to provide firefighters with resources necessary to achieve and maintain optimal fitness levels. The desire was to move from a generic "one size fits all" fitness program to one centered on practical, research-based analysis tailored to address the specific needs of firefighter job performance. Thus, OCFA began analyzing firefighter exertion levels, physical movements, and job tasks. The objective was to create and implement a program specifically tailored to prepare OCFA firefighters for the job demands of firefighting and to reduce the incidence of musculoskeletal injuries, which account for the majority of non-fatal firefighter injuries.[2] To a large extent, this objective has been met. For example, since the inception of the Wellness and Fitness Program, OCFA has observed a 30 percent reduction in the top three musculoskeletal injuries: back, knee, and shoulder. The development and implementation of such research-based programs has resulted in reduced incidence of injuries, less work time lost due to injury, lessened severity of actual injuries, reduced workers' compensation costs, improved performance, and a healthier workforce.

OCFA continues to assess other various real-world factors that may affect firefighter health and job performance. Recently, incidences of heart disease among firefighters have been the focus of much attention. A 2007 study published in The New England Journal of Medicine identified heart disease as the cause of 45 percent of U.S. firefighters deaths over the 10-year period analyzed.[3] Similarly, the

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[1] Rita F. Fahy et al., "Firefighter Fatalities in the United States—2006," National Fire Protection Agency, Quincy, Massachusetts, June 2007, pp. 1–31.

[2] Surrey M. Walton, Ph.D., et al., "Cause, Type, and Workers' Compensation Costs of Injury to Fire Fighters," American Journal of Industrial Medicine, Vol. 43, No. 4, March 2003, pp. 454–458.

[3] Stefanos N. Kales, M.D., M.P.H., et al., "Emergency Duties and Deaths From Heart Disease Among Firefighters in the United States," The New England Journal of Medicine, Vol. 356, No. 12, March 2007, pp. 1207–1215.

National Fire Protection Association (NFPA) reported cardiac events accounted for nearly 40 percent of all U.S. firefighter deaths in 2006.[4]

The risk factors for heart disease are well known. They include age, gender, family history, obesity, and sedentary lifestyle, among others. OCFA's Wellness and Fitness Program had previously identified and addressed obesity and lack of exercise, which are two of the primary preventable risk factors for heart disease. However, other risk factors needing to be addressed remain. Being aware of these could help prevent cardiovascular events and increase the safety of OCFA firefighters.

In addition to the risk factors faced by the general population, firefighters face unique ones as a result of certain inherent job stressors. These include sudden surges in the sympathetic nervous system caused by unexpected alarms, rapid shifts from low to high levels of exertion, carrying of heavy protective gear and equipment, prolonged exposure to high temperatures, and excessive fluid loss. Each of these factors has been shown to contribute to dehydration and a rapid rise in core body temperature, which may lead to heat stress and insufficient blood flow to the heart. This can cause cardiovascular strain.[5]

To further investigate the connection between cardiovascular strain and heat stress, OCFA undertook a research study to examine certain factors—hydration status, exertion level, core body temperature, and post-incident cooling techniques—that may contribute to heat-related illnesses and self-perceived heat-related illness. One purpose of this study was to gain a better understanding of firefighter job demands. Another was to provide recommendations that should help minimize the inherent risks associated with the firefighting profession, resulting in a healthier, safer, and more productive workforce.

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[4] Rita F. Fahy et al., "Firefighter Fatalities in the United States—2006," National Fire Protection Agency, Quincy, Massachusetts, June 2007, pp. 1–31.

[5] José González-Alonso et al., "Dehydration Markedly Impairs Cardiovascular Function in Hyperthermic Endurance Athletes During Exercise," Journal of Applied Physiology, The American Physiological Society, 1997, pp. 329–343.

METHODS

Study Setting

OCFA conducted the *Hydration, Core Body Temperature, and Post-Incident Rehabilitation Study* at its Regional Fire Operations and Training Center (RFOTC) located in Irvine, California, during August 6–10, 2007. The average temperature during the week was 84°F, with an average relative humidity of 46 percent.

Participation in the study was voluntary. All data collection was anonymous, and no names were used in recording the data or reporting the findings. Each drill included one response unit consisting of three engines, one truck, and a Battalion Chief. The scheduling of all units was done in a way closely resembling a first alarm structure fire assignment for OCFA. The number of participants in each drill varied between 12 and 15, depending on staffing and unit availability.

Each response unit completed one tower drill. (Due to availability and scheduling requirements, a morning group commenced its drill at 0900 and a separate afternoon group started at 1300.) The drill tower where the study was conducted is a six-story masonry building with an attached two-story apartment prop. The temperature inside the drill tower during the live fire drill rose to 500°F.[6]

Participants

All study participants were OCFA professional firefighters. All firefighters were informed of the study procedures and advised of the associated risks before agreeing to participate in the study.

Participants reflected a range of different ages, body types, physical fitness levels, and firefighting experience levels. Table 1 summarizes the basic characteristics of the participants analyzed for this study.

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[6] A Class A fire (controlled ordinary combustibles fire) can reach or exceed temperatures of 1,000°F. However, the temperature inside the drill tower during the live fire drill was limited to 500°F because all fire activity in the drill tower is done with natural gas and not Class A materials, such as wood.

Table 1. PARTICIPANT CHARACTERISTICS

Gender Male Female	 98 3
Average Age	39.5
Average Years of Fire Service Experience	13.5
Average Fitness Level (Based on a scale of 1–7, with 1 being a low fitness level and 7 being the highest fitness level. Fitness level was determined from participant's individual resting heart rate and recovery heart rate data and self-reported activity/exercise levels.)	3.3

Test Design and Procedure

Upon arrival at the study location, participants were briefed on the study requirements and reminded of the contraindications of participating in each phase of the study. Participants were also reminded they could terminate their participation at any time. Once each participant had given his or her informed written consent to participate in the study, he or she was asked to complete a questionnaire. Gathered information included age, years of fire service experience, and fitness level. Each participant was assigned an identification number and given the equipment necessary for data collection during the study. This included a CorTemp ingestible core body temperature capsule, a Suunto t6 wrist-top heart rate monitoring device, and a plastic cup with a lid. All equipment was labeled with each participant's corresponding identification number.

Prior to commencing the drill, participants ingested the CorTemp capsule, which monitors core body temperature via a radio signal transmitted from the ingested capsule to an external data recorder. The CorTemp capsule is a nondigestible silicone-coated thermometer, which the U.S. Food and Drug Administration has tested and approved. Prior to the study, extensive research on the CorTemp capsule was conducted. Various research studies conducted on and using the CorTemp system, as well as literature describing the CorTemp capsule, were made available to all participants. Additionally, a representative from HQ Inc., the company producing the CorTemp system, was available on-site to answer questions. Any volunteer participant not comfortable proceeding with the study after having had an opportunity to review the material was permitted to continue the drill without ingesting the capsule. Participants were asked to ingest the capsule with as little water as comfortably possible and then refrain from consuming any food or liquid until the end of the drill.

Participants were then instructed to proceed to the restroom and provide a small urine sample in the provided plastic cup. The urine sample was analyzed using a PAL-10S refractometer to determine each participant's hydration level. With only a single drop of urine, the refractometer measures and immediately displays the specific gravity of the urine. Using a refractometer to measure specific gravity was chosen as the most practical and reliable measure of hydration status, based on research by the National Athletic Trainers' Association and the National Collegiate Athletic Association.[7,8] During this portion of the study, an observer remained in the restroom to ensure (a) none of the urine samples were tampered with and (b) all samples were properly disposed of after being analyzed.

Participants were then weighed (wearing undergarments only) on a Detecto 439 Physician Scale, which was tested for accuracy based on standards set forth by the U.S. Bureau of Standards. Next, each participant's vital signs—including blood pressure, tympanic temperature, heart rate, and respiration rate—were measured and recorded. Finally, all participants were advised of the proper use of the Suunto device and were then instructed to dress out in full Personal Protective Equipment (PPE). PPE included a Lion Apparel Janesville V-Force Bi-Swing Coat, a pair of Lion Apparel Janesville V-Force Bi-Swing pants, PRO-Warrington 5006 boots, a Majestic PAC II Fire Apparel Nomex Flash Hood, FireGuard protective gloves, and a Phenix structure fire helmet. Once participants were fully dressed, core body temperature was measured using the CorTemp Recorder. During certain parts of the study, participants were also required to wear a Scott Air-Pak Fifty self-contained breathing apparatus (SCBA), needed when entering a burning structure in an environment that is immediately dangerous to life and health.

Core body temperature readings were taken at specific times during the study. Because of the simplicity and ease with which readings could be taken, additional measurements were taken randomly throughout the duration of the study. Heart and respiration rate were continuously monitored using the Suunto device. All other measurements were taken at specific times—including before, during, and after the study phases.

Monitored Study Activities

Phase One: Firefighting Tasks. During Phase One of the study, participants performed two 15-minute drills. The first drill involved a live, simulated fire on the first and second floors of a building. Both floors had interior and exterior access, and each floor had four rooms. A 180-pound rescue dummy, as a victim, was placed in the rear room on the first floor.

All units were dispatched to a reported structure fire with persons trapped. The first unit arrived on-scene one minute after initial dispatch (dispatch order was randomly assigned), and additional units arrived in 30-second intervals. During the simulation, no specific tactics or strategies where given. Each company or chief officer was instructed to allocate resources based on the incident priority. Each incident commander was advised to obtain a primary "all clear"—a quick search of the building to locate any victims. Participants were assured they were not being rated on performance nor evaluated on the amount of time required to rescue the victim or extinguish the fire.

Participants spent 15 minutes tactically advancing hose lines for rescue, extinguishing the fire, and coordinating with the truck company for vertical ventilation. After 15 minutes, the first drill in

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7 Douglas J. Casa, Ph.D., et al., "National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes," Journal of Athletic Training, Vol. 35, No. 2, National Athletic Trainers' Association, June 2000, pp. 212–224.

8 Robert G. Bubb, "2001 NCAA Wrestling Rules and Interpretations," National Collegiate Athletic Association, Indianapolis, Indiana, July 2000, pp. 329–344.

Phase One was terminated, and all participants exited the building to have their core body temperature and tympanic temperatures measured and recorded.

Once all temperatures were recorded, the second 15-minute drill began. In this drill, participants removed their SCBA masks and performed 15 minutes of continuous firefighting-related movements, such as stair climbing or overhaul. Stair climbing was chosen due to its similarity to common on-the-job activities, such as climbing stairs in tall buildings or climbing ladders to gain access into buildings. Overhaul is when firefighters look for hidden fire inside attics, ceilings, and walls, which often involves moving household furniture. Monitoring participants' physiological responses to these activities provided further insight into the physical demands of the job. Due to the strenuous nature of these activities, they were also a particularly effective method of assessing firefighter fitness and analyzing the relationship between core body temperature and heart rate level.

Participants were told to proceed at their preferred pace and reminded they could terminate participation at any time if they felt uncomfortable. Once the participants had completed 15 minutes of firefighting-related movements, they exited the drill tower to have their core body temperature and tympanic temperatures measured and recorded.

Phase Two: Cooling Methods. Phase Two of the study was the recovery phase and involved ambient environmental conditions only (i.e., no fire). In this phase, participants were randomly assigned to one of four cooling stations: peripheral cooling, KoreKooler Rehab Chairs, misting fans, or wet towels. The cooling stations, which included chairs for all participants, were set up under a canopy to provide protection from the sun. This phase began once each participant was at his or her assigned cooling station and had removed all PPE (other than pants and boots). The phase continued for 20 minutes. Participants were asked not to ingest any liquids until the end of the recovery phase.

During the 20-minute recovery, core body temperature and vital signs were measured and recorded at regular five-minute intervals. The Suunto device continued to record throughout this time period, so recovery heart rate could be recorded and analyzed. At the end of the 20-minute recovery phase, participants were asked to report to the locker room so a post-activity body weight could be determined (participants wore the same apparel as when they first weighed in).

RESULTS

Number of Participants

The goal was to evaluate a minimum of 100 OCFA firefighters. An explanation of the study and a request for volunteers was sent via email to all 828 OCFA Operations Personnel. Volunteers for the study included 126 OCFA professional firefighters. Data was collected from all participants; however, for various reasons, not all participant data was used (see Table 2). The resultant analysis included 101 participants.

Table 2. RESULTANT NUMBER OF PARTICIPANTS

Total participants who volunteered and began the study	126
Number of participants who did not complete all physical aspects of the study	-4
Number of participants who did not provide all necessary personal data (e.g., age, fitness level)	-4
Number of participants for whom heart rate data was not collected (e.g., participant did not start heart rate monitor)	-7
Number of participants for whom hydration status was not measured (e.g., participant chose not to participate in hydration portion of the study)	-10
TOTAL NUMBER OF PARTICIPANTS FOR WHOM DATA WAS ANALYZED	**101**

Hydration Status

Dehydration is commonly defined as a reduction in the body's water content and a loss of important salts and minerals, which are necessary for normal body function. Emphasizing proper hydration is particularly important for firefighters because of the extreme dehydration risk factors—e.g., strenuous physical activity, exposure to high temperatures, and the use of heavy protective clothing—inherent in the occupation. These risk factors increase the sweat rate and may result in dehydration, which can lead to an increase in body temperature, low blood pressure, and a reduction in stroke volume (the total amount of blood pumped out of the heart in one beat).[9] These effects can lead to heat illnesses such as heat cramps, heat exhaustion, heat stroke, and death.

Dehydration can also have other effects, such as impaired energy output. Inadequate hydration reduces blood volume, resulting in less oxygen being delivered to the working muscles. Since water constitutes approximately 75 percent of the human body, even mild dehydration—as little as

[9] George A. Brooks et al., Exercise Physiology: Human Bioenergetics and Its Applications, 4th ed., McGraw Hill Companies, New York, 2004, pp. 511–535.

one percent of body weight—can increase muscle fatigue and impair performance.[10] Since a firefighter's job performance often depends on muscular strength and endurance, proper hydration is particularly important.

Dehydration can also affect mental performance, which is critical to on-the-job decision making. Approximately three-quarters of the brain is water, and insufficient hydration can impair the ability to think and react. Consequently, adequate hydration is vital for clear thinking and sharp reflexes.

Because dehydration can have detrimental effects on firefighter health and performance, OCFA sought to determine what percentage of firefighters were in a dehydrated state prior to beginning the drills, which would give an indication of hydration status prior to a fire. While the majority of the study volunteers reported regular exercise and good overall health, a urine analysis revealed 91 percent were dehydrated to some extent prior to commencing the study (see Table 3). Only nine percent of all firefighters were categorized as well-hydrated, as defined by the National Athletic Trainers' Association standards.[11] No significant difference in hydration status existed between the morning and the afternoon participants.

Table 3. HYDRATION STATUS PRIOR TO DRILLS

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

The discovery that over 90 percent of firefighters were already dehydrated to some extent prior to commencing the drill is alarming. Due to the nature of their work, firefighters are at an increased risk for dehydration and should ensure they are adequately hydrated prior to exposure to any additional dehydration risk factors.

While no reported firefighter deaths in 2006 were attributed solely to dehydration, it may play a role in exertion-related fatal injuries and cardiac events, which accounted for 91 percent of firefighter

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[10] Lindsay B. Baker et al., "Progressive Dehydration Causes a Progressive Decline in Basketball Skill Performance." Medicine and Science in Sports and Exercise, Vol. 39, No. 7, July 2007, pp. 1114–1123.

[11] Douglas J. Casa, Ph.D., et al., "National Athletic Trainers' Association Position Statement: Fluid Replacement for Athletes," Journal of Athletic Training, Vol. 35, No. 2, National Athletic Trainers' Association, June 2000, pp. 212–224.

deaths in the United States in 2006.[12] Dehydration, ultimately, could even have an effect on firefighter job performance. These results indicate dehydration among firefighters may be a common and potentially dangerous condition, which merits additional attention.

Heart Rate

Participants' heart rates were monitored continuously throughout the study using the Suunto t6 device (a) to analyze the exertion level required for firefighting skills and (b) to monitor recovery heart rate. Participants were required to wear a transmitter around their chest, monitoring heart rate and transmitting it to the receiver worn on the wrist. A real-time heart rate is displayed on the receiver where all data is recorded and saved. The Suunto t6 heart rate monitor was chosen because of its ability to measure the time between heartbeats, its interference-free digitally coded transmission, and its scientifically validated accuracy.[13]

As physical activity increases, the heart rate begins to rise. A strong heart, achieved through regular physical conditioning, pumps out more blood per stroke and is not required to beat as often. Consequently, a person who exercises regularly will have a lower resting heart rate and will have to work at a higher intensity to elevate the heart rate. Regular and appropriate exercise will result in a decreased resting heart rate and a faster recovery heart rate. Recovery heart rate is particularly important, because research suggests the rate of decrease in the heart rate after exercise is a good indicator of fitness level and a powerful predictor of overall mortality.[14]

Physical activity is not the only cause of an elevated heart rate. For firefighters, the increase in nervous system activity preceding the physical exertion itself can result in a rapid increase in heart rate. Based on the data collected from the heart rate monitors, participants' heart rates increased by an average of over 50 beats per minute while dressing out in their PPE. Similarly, in a previous study conducted on firefighters, the sound alone of the station alarm caused firefighters' heart rates to increase to an average of over 170 beats per minute.[15]

During the live fire drill in Phase One of this study, the average heart rate for all participants was 164 beats per minute. When data for active fire suppression participants was separated from that of those who played a less physically active role during the live fire drill (such as engineers and incident commanders), the average heart rate during the live fire drill increased to 173 beats per minute over the 15-minute period. Similarly, when data for less physically active participants was excluded from the calculation of average maximum heart rate during Phase One, the average maximum rate increased from 180 beats per minute to nearly 190. This finding is consistent with other research

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[12] Rita F. Fahy et al., "Firefighter Fatalities in the United States—2006," National Fire Protection Agency, Quincy, Massachusetts, June 2007, pp. 1–31.

[13] Suunto t6 software is built on an advanced physiological model of the human body, based on over 20 years of research by the KIHU Research Center for Olympic Sports, University of Jyvaskyla, and Firstbeat Technologies Ltd.

[14] Fulvia Seccareccia, M.Sc., et al., "Heart Rate as a Predictor of Mortality: The MATISS Project," American Journal of Public Health, 2001, pp. 1258–1263.

[15] "Physiological Assessment of Firefighting, Search and Rescue in the Built Environment: Fire Research Technical Report 2/2005," Office of the Deputy Prime Minister, London, England, December 2004.

conducted on firefighters during a 40-minute rescue drill, which reported an average maximum heart rate of 182 beats per minute.[16]

The Suunto devices were also used to record recovery heart rate after the completion of Phase One. In general, a drop in the recovery heart rate of at least 12 beats per minute within the first minute is considered favorable.[17] In this study, 68 percent of participants had a decrease of at least 12 beats per minute within the first minute of recovery. Not surprisingly, the individuals with higher fitness levels had a faster recovery time.

Table 4. AVERAGE HEART RATE

Time of Reading	Average Heart Rate (Beats per Minute)
Resting Heart Rate	77
During Live Fire Drill	164
During Fire Skills Drill	179
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

Although firefighting requires many aspects of physical fitness, firefighters may not clearly understand how to prepare for the physical demands of the job. During Phase One, participants were required to use high levels of muscular strength and endurance to perform at near maximal metabolic system capacity. The high heart rates reached during Phase One highlight the need for firefighters to thoroughly understand the physical fitness requirements and physical capability requirements of firefighting. Four percent of participants were unable to complete the study due to fatigue or physical discomfort. This is particularly alarming given the physically demanding portion of the study consisted

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[16] Clare Elgin and Michael Tipton, "Firefighter Training: Determination of the Physical Capabilities of Instructors at the End of Hot Fire Training Exercises," Office of the Deputy Prime Minister, London, May 2003, <http://www.communities.gov.uk/documents/fire/pdf/158529>.

[17] Rainer Hambrecht, M.D., et al., "Effects of Exercise Training on Left Ventricular Function and Peripheral Resistance in Patients With Chronic Heart Failure," The Journal of the American Medical Association, Vol. 283, No. 23, June 2000.

of two 15-minute drills, which is a relatively short duration in comparison to the potential length of a fire emergency. The physiological data for these individuals indicates that—after a short duration of high intensity exertion—these individuals could be too fatigued to effectively perform during a fire emergency.

The results from this study and previous OCFA data collection suggest the average heart rate response to firefighting tasks ranges between 160–200 beats per minute.[18,19,20] Not only are firefighters required to work at a high intensity, but they may also be required to maintain work levels for extended periods. The PPE worn by firefighters weighs up to 60 pounds, and the additional weight alone places an increased demand on the cardiovascular system. Given the stringent physical demands inherent in the firefighting profession, firefighters must be aware of risk factors that may affect cardiovascular health. Firefighters should also understand that introducing other factors that can increase heart rate, such as inadequate hydration and caffeine, place an increased and unnecessary demand on the heart.

Core Body Temperature

Heat injuries are a constant health concern for firefighters working in hot environments. The high temperature of fire, sometimes combined with high ambient temperatures, creates a dangerous environment for firefighters who may be required to carry up to 60 pounds of protective gear and another 40 pounds of fire suppression equipment. While most heat illnesses are preventable, firefighters may not understand there are steps that can be taken to protect themselves from heat illness.

Normal core body temperature is approximately 98.6°F, but core temperatures can vary among individuals. Factors affecting core body temperature include the rate of an individual's metabolism (people with a faster metabolism tend to have a higher core body temperature), the time of day the temperature is taken (temperature tends to be lower in the morning and higher after exercising or eating), and how the temperature is measured (tympanic, oral, rectal, etc.).[21]

Historically, rectal temperature has been recognized as the most accurate and valid measure of core body temperature. Measuring rectal temperature is not practical in the context of firefighters performing on a live fire operation. Therefore, on-the-job core body temperature data has been limited.

Existing literature shows the CorTemp system, which includes a capsule and a data-recording device, is an acceptable, accurate, and comfortable method to measure core body temperature.[22] The

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[18] Nancy Espinoza and Michael Contreras, "Orange County Fire Authority Academy 30 Final Report: Wellness and Fitness Program," Orange County Fire Authority, 2006, pp. 1–17.

[19] Nancy Espinoza and Michael Contreras, "Orange County Fire Authority Academy 31 Final Report: Wellness and Fitness Program," Orange County Fire Authority, 2006, pp. 1–20.

[20] Nancy Espinoza and Michael Contreras, "Orange County Fire Authority Academy 32 Final Report: Wellness and Fitness Program," Orange County Fire Authority, 2007., pp. 1–15.

[21] George A. Brooks et al., Exercise Physiology: Human Bioenergetics and Its Applications, 4th ed., McGraw Hill Companies, New York, 2004, pp. 511–535.

CorTemp system was used to measure the increase in core body temperature throughout Phase One of the study and to measure the core body temperature throughout the 20-minute recovery period. The goal of measuring core body temperature was (a) to determine how much a firefighter's core body temperature rose during a simulated fire and (b) to analyze the effectiveness of common post-incident cooling measures to improve OCFA's post-incident rehabilitation protocols.

While the risk factors for heat illness are well-defined (cardiovascular disease, dehydration, low fitness level, obesity, certain medications, etc.), the threshold for dangerously high core body temperatures has not been established. The World Health Organization recommends keeping core body temperature below 100.4°F to avoid heat-related illness. Other research exists that defines exertional heat stroke as a core body temperature of 104°F or higher, and in another example, a study conducted on firefighters by the Office of the Deputy Prime Minister in London selected 103.1°F as the study termination criterion.[23,24]

During the current study, participants' core body temperature ranged from 98°F to a high of 106°F. The majority of participants' peak core body temperature fell in the range of 100°F to 102°F, with 44 percent of all participants reaching a core body temperature of 102.1°F or higher (see Table 5).

Table 5. PEAK CORE BODY TEMPERATURE

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

Interestingly, for the majority of participants, core body temperature did not peak until five minutes into rehabilitation (Phase Two). This indicates core body temperature may continue to rise even after the cessation of physical activity. Caution needs to be taken to ensure firefighters do not reach a critical core body temperature before reducing their physical output or terminating their

[22] Chris Easton et al., "Rectal Telemetry Pill and Tympanic Membrane Thermometry During Exercise Heat Stress," Journal of Thermal Biology, Vol. 32, No. 2, February 2006, pp. 78–86.

[23] Douglas J. Casa, Ph.D., et al. "External Heat Stroke in Competitive Athletes," Current Sports Medicine Reports, Vol. 4, No. 6, November 2005, pp. 309–317.

[24] "Physiological Assessment of Firefighting, Search and Rescue in the Built Environment: Fire Research Technical Report 2/2005," Office of the Deputy Prime Minister, London, England, December 2004.

exposure to high temperatures. Firefighters should apply cooling measures as soon as possible after physical activities—especially intense firefighting tasks—thus possibly lowering the eventual peak core body temperature. Important to note is that even after 20 minutes of rest, few core body temperatures had returned to starting temperatures.

While the CorTemp system was very useful during this controlled study, to accurately monitor core body temperature, the capsule must be taken several hours prior to recording. This, given the unpredictable nature of fire emergency calls, tends to render the capsule impractical for use on a routine basis outside of a controlled setting.

Core Body Temperature and Tympanic Temperature

Tympanic temperature, defined as the temperature of the tympanic membrane (eardrum), is a quick and simple method of reading temperature and is often used in outdoor activities. However, tympanic temperature readings have been shown to underestimate body temperature.[25] An inaccurate reading of core body temperature can be problematic in situations in which firefighters are exposed to heat stress risk factors.

In this study, tympanic temperature was measured to determine if it could be used as a method in determining when core body temperature has risen to an unsafe level. Tympanic temperatures were measured at the same intervals as CorTemp core body temperature readings were taken. On average, tympanic temperature readings were lower than core body temperature readings by over two degrees. One of the most interesting differences between core body temperature and tympanic temperature was that during recovery, tympanic temperature began to drop immediately while core body temperature continued to rise and peaked after approximately five minutes into the 20-minute rehabilitation period.

In addition, tympanic temperature readings dropped faster to levels below that of baseline in cooling methods favoring cooling of the head and neck, such as the wet towels and the misting fan. Presumably, this occurred due to cooling of blood perfusing the tympanic membrane. Such evidence would suggest that tympanic temperature is an inaccurate indicator of core temperature.

The data also suggests that as the participants' temperatures increased, the difference between core body temperature readings and tympanic temperature readings increased. This finding merits more research to determine whether the discrepancies between core body temperature and tympanic temperature truly increase as core body temperature rises or if there is a lag in stomach temperature readings—as some research has suggested.[26,27]

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[25] A. Deschamps et al., "Tympanic Temperature Should Not Be Used to Assess Exercise Induced Hypothermia," Clinical Journal of Sports Medicine, Vol. 2, 1992, pp. 27–32.

[26] Chris Easton et al., "Rectal Telemetry Pill and Tympanic Membrane Thermometry During Exercise Heat Stress," Journal of Thermal Biology, Vol. 32, No. 2, February 2006, pp. 78–86.

[27] George A. Brooks et al., Exercise Physiology: Human Bioenergetics and Its Applications, 4th ed., McGraw Hill Companies, New York, 2004, p. 535.

Table 6. CORE BODY TEMPERATURE AND TYMPANIC TEMPERATURE

Time of Reading	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

Cooling Measures

In the fire service, the period following any physically and mentally demanding incident from which recovery is needed is referred to as rehabilitation or rehab. During rehab, firefighters attempt to recover from the physically exerting task and to allow the body to return to normal functioning. This includes reducing the heart rate, lowering core body temperature, hydrating, and ingesting enough calories to maintain the necessary energy to continue working.

Currently, no single post-incident rehab protocol exists, leaving each fire department to determine its own. Often these rehab protocols are a result of traditional practices, rather than individual needs and specific environmental concerns. This study examined some of the most common cooling measures used during rehab: misting fans, wet towels, forearm water immersion, and ambient air. Canopies and chairs were provided at each cooling station, and participants were randomly assigned to a cooling station. (The number of participants who tested the KoreKooler chairs was lower than those who tested the other cooling measures because of the limited availability of KoreKooler chairs during the study.) See Table 7 for cooling measures comparison.

Table 7. COOLING MEASURES COMPARISON

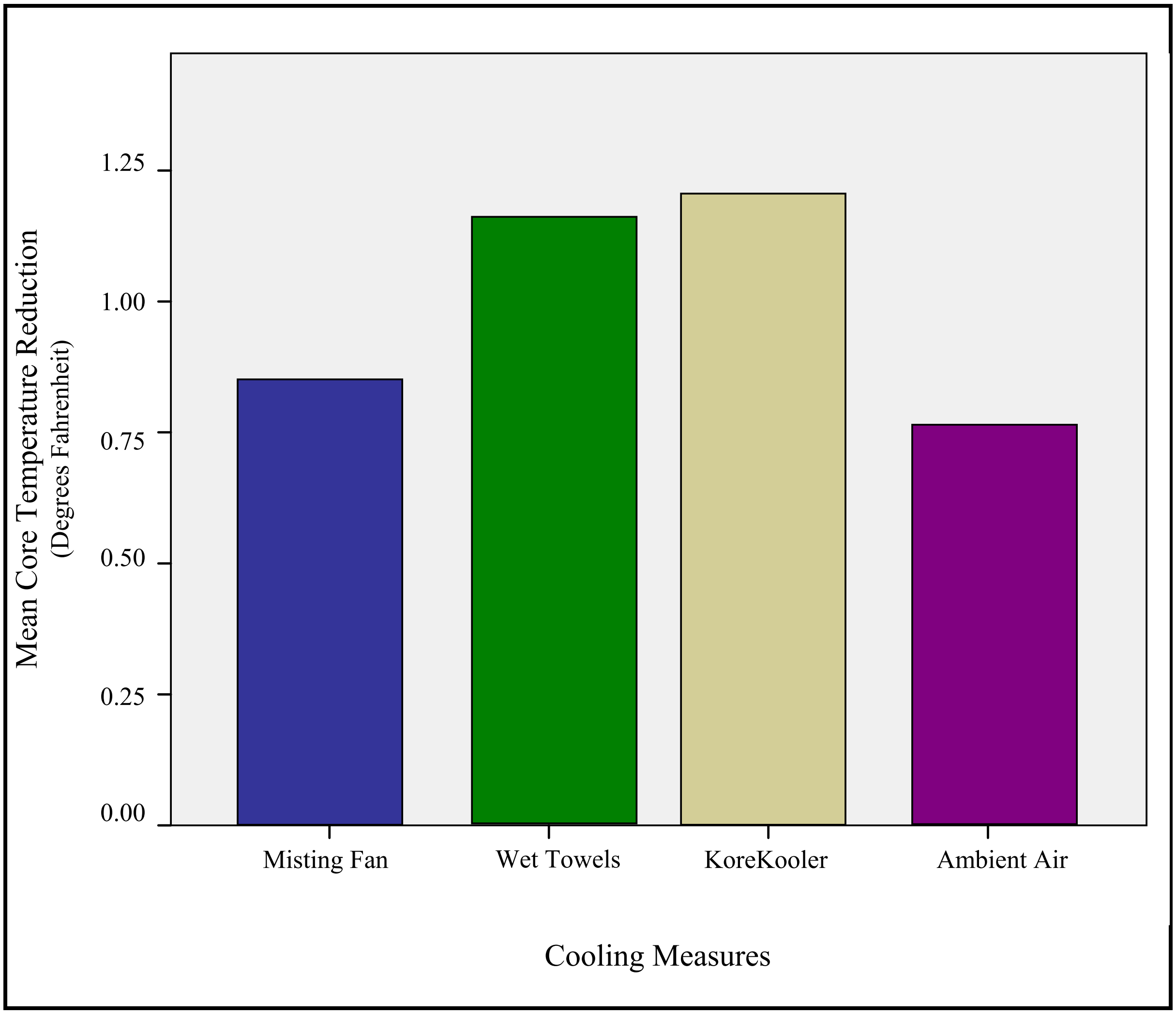
Cooling Station	Number of Participants Assigned to the Cooling Station
Misting Fan	28
Wet Towels	28
KoreKooler	17
Ambient Air	28

The misting fans used in the study were connected to a standard 3/4-inch garden hose and had misting nozzles angled out from a center panel to direct water into the air. Misting fans are thought to work best in areas with humidity levels below 70 percent. This enables the misting system to lower the surrounding air temperature (the average relative humidity during the week the study was conducted was 46 percent). Wet towels were also used as a cooling measure. The wet towels were kept in ice water until participants placed them on areas of the body with abundant blood supply, such as around the back of the neck. The KoreKooler is a chair containing plastic bags on the arm rests. The plastic bags are filled with water, and the forearms are immersed in the water during rehab. The last cooling station tested was evaporation from ambient air. Participants at this station were not provided anything other than a chair under a canopy. None of the participants were allowed to consume water during rehab to accurately monitor the effect of the cooling measure alone.

As Figure 1 shows, the wet towels and KoreKooler chairs had a similar rate of core body temperature reduction. A further analysis also revealed that—while core body temperature continued to rise in all participants during the rehabilitation period—overall, the group using the wet towels as a cooling method had the least increase in core body temperature. During the 20-minute rehabilitation period, the wet towels proved to be more practical; they required less space and set-up and were less expensive than the cooling chairs, while providing similar results.

An interesting point is that when asked which cooling measure looked most appealing, most participants responded that the wet towels looked refreshing and most effective. An in-depth analysis may reveal some added benefit from the psychological effects from this cooling method.

Figure 1. MEAN CORE TEMPERATURE REDUCTION FOR EACH COOLING MEASURE



Fluid Loss

While sweating is not the only way the body cools itself, it is the body's most effective method of cooling. When body temperature rises, the body reacts by increasing sweat production on the surface of the skin. The sweat then evaporates off the skin, removing some heat with it.[28]

Age, genetics, hydration level, physical exertion level, fitness level, clothing, and environmental conditions, such as temperature and humidity, all play a role in the rate at which an individual sweats. For firefighters—whose job often requires performing strenuous work in high temperatures while wearing heavy protective clothing—a high degree of fluid loss usually occurs.

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[28] J. R. Stofan et al., "Sweat and Sodium Losses in NCAA Football Players: A Precursor to Cramps?," International Journal of Sport Nutrition and Exercise Metabolism, Vol. 15, No. 6, 2005, pp. 641–652.

High rates of fluid loss can result in dehydration, fatigue, and mild to severe heat illnesses. Firefighters are usually not aware of how much fluid they lose during an incident and are often not well-informed about how much fluid is required to re-hydrate after an incident. Improper re-hydration can negatively affect performance and decision making, both of which are critical components of the firefighting profession.

According to the American College of Sports Medicine, just a one percent loss of body weight may cause a disproportionate elevation of heart rate during exercise, increasing cardiovascular strain and hampering performance.[29] Weight losses of three to four percent impair physical capacity and begin to affect concentration and the ability to focus. At five percent, the body may stop sweating, and the temperature regulation system may become impaired or even fail.

During the OCFA study, 59 participants lost at least two percent body weight during the 30-minute drill (see Table 8). Most participants were aware they had lost a significant amount of fluid; however, none knew of the adverse effects a relatively small percentage of weight loss could have on their bodies. The average weight loss among participants was slightly over three pounds, and the highest individual loss was seven pounds.

A rapid amount of weight loss is cause for concern. Most disturbing is that, when asked, very few participants had any idea how much fluid was required to re-hydrate. Most participants responded that they would just "drink a lot of water" to replenish the fluid they lost during the drill.

Table 8. FLUID LOSS

Fluid Loss	Number of Participants	Percentage of Participants	Potential Effect
1% body weight	3	3	↓ heat transfer from contracting muscles to skin surface where heat can be dissipated to the environment
1–2 % body weight	39	39	↑ heart rate; ↓ blood pressure (including the one above)
2–3% body weight	54	53	↓ muscle endurance; ↓ energy level (including the two above)
> 3% body weight	5	5	↓ concentration and ability to focus (including the three above)

[29] Victor A. Convertino, Ph.D., et al. "American College of Sports Medicine Position Stand. Exercise and Fluid Replacement.," Medicine and Science in Sports and Exercise, Vol. 28, No. 1, January 1996, pp. i–vii.

DISCUSSION AND RECOMMENDATIONS

Introduction

This study was conducted to investigate the connection between cardiovascular strain and heat stress. OCFA sought to examine modifiable risk factors for heat stress and cardiovascular strain, including hydration status, exertion level, physical fitness level, and post-incident cooling techniques. These factors were examined to gain a better understanding of what can be done to minimize the increase in core body temperature during an incident and to improve post-incident rehabilitation for firefighters. The following are areas for improvement for fire departments.

Actions

Take a Proactive Stance. Overall, the results from this study suggest that, due to the risks associated with the firefighting profession, fire departments must become more proactive in researching and implementing strategies to ensure firefighter health and safety. An example is that rather than focusing only on re-hydrating firefighters after an incident, departments should educate firefighters on the signs of dehydration and the potentially detrimental health and performance effects to help firefighters understand the importance of being properly hydrated prior to an incident, as well as maintaining an optimal hydration level both during and after an incident.

The severe potential consequences associated with inadequate health and fitness should serve as motivation for fire departments to provide firefighters with information, departmental support, and opportunities to improve their physical health, wellness, and fitness to enhance job performance and an overall healthy lifestyle.

Educate Firefighters on Proper Hydration. Dehydration—whether mild or severe—can have a significant impact on performance and health. Fire departments should actively educate firefighters on proper hydration. Conducting educational classes, distributing informational materials, and addressing the topic of proper hydration in required firefighting-related classes (e.g., multi-company classes) are all ways fire departments can help to decrease the incidence of dehydration among firefighters.

Educate Firefighters on Overall Fitness. Educating firefighters may also be the key to increasing firefighter fitness. Most firefighters understand the firefighting profession is physically demanding—not all firefighters understand how the body responds to the physical demands of the job, particularly how these demands can affect health and performance. For example, having a clear understanding of how a less than optimal fitness level can increase an individual's risk for heat illness and heart strain may motivate firefighters to maintain a healthy lifestyle.

Additionally, a more thorough understanding of how to prepare effectively for the physical demands of firefighting may help firefighters select appropriate exercise modes, manipulative exercises, and fitness plans to achieve the desired goal. In a profession requiring all aspects of physical fitness, individuals must receive the necessary support and education to help them excel in their physically demanding job. OCFA research has shown an effective way to motivate firefighters to be physically active and maintain a high level of physical fitness is to quantify the physical demands of the job by measuring intensity through heart rate monitors and tailoring workouts to mimic the workloads of the profession.

Develop Fitness/Wellness Programs. OCFA recommends all fire departments develop or adopt fitness programs based on the demands and movements of the job. New evidence may contradict some of the common and traditional exercise programs currently in place. Appropriately trained and qualified professionals should design physical training programs to ensure the programs are safe, scientifically valid, and effective. Accurately documenting fitness data is an important element in determining a program's effectiveness, assessing injury risks and fitness levels, and measuring cost effectiveness.

While exposure to certain heat stress risk factors is unavoidable for firefighters, much can be done to prepare for such conditions. Dehydration, low fitness levels, and being overweight are all modifiable risk factors for heat illness. Individuals who are overweight are less effective at losing heat and are at a higher risk for increased core body temperature and heat strain.

Being physically fit is not only important to job performance, but it also aids in the body's ability to cope with increased heat demands. As demonstrated in this study, individuals who are physically fit are better able to tolerate an increase in core body temperature and are less likely to experience heat stress.

Establish Medical Screening for Firefighters. For fire departments, particularly those located in areas of high ambient temperatures, identifying individuals at increased risk will minimize the likelihood of heat illness. Research has shown heat-related incidents are not random and unpredictable; the patterns are usually consistent. Educating firefighters on the risk factors for increased core body temperature and heat illness is the first step in helping prevent future incidents. Additionally, establishing thorough medical screening for firefighters and departmental heat and hydration protocols are crucial steps in achieving individualized risk reduction among firefighters.

Develop Rehabilitation Protocols. The relative effectiveness of the various rehabilitation and post-incident cooling techniques is perhaps the most important finding of this study. Fire departments should develop or adopt comprehensive rehabilitation protocols that include rest, hydration, active cooling, medical monitoring, and refueling. OCFA also recommends additional research be conducted on the issues identified by this study.

Adequate hydration is an important element of optimal physical performance. This study shows rapid fluid loss can result from just 30 minutes of physical exertion. Due to the potentially serious adverse health consequences, firefighters should be well-versed on how to adequately replenish fluid lost through sweat. To accomplish this, firefighters should drink approximately 24 ounces of water for each pound of body weight lost.[30] Importantly, firefighters should be aware that (1) certain nutrients—such as sodium, potassium, and calcium—are also lost through sweat and (2) the loss of these nutrients can also have detrimental effects on health and performance (e.g., loss of sodium can increase the risk of muscle cramps). Depending on an individual's sweat loss, sweat sodium rate, exertion level, and duration of exertion, replenishment of these nutrients may be required.

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[30] E. Randy Eichner, M.D., "Heat Stroke in Sports: Causes, Prevention, and Treatment," Sports Science Exchange, Vol. 15, No. 3, 2002.

Educate Firefighters on Dietary Intake. Depending on the incident type and duration, carbohydrate intake also becomes increasingly important. Performance is, in part, a function of fuel availability. Carbohydrates are the body's most important fuel source for energy production. Insufficient carbohydrate availability may limit exercise performance by decreasing the time for the body to reach a level of fatigue. Carbohydrate intake can have a significant impact on the ability to exercise for longer periods of time; therefore, proper and appropriate carbohydrate intake should be included in a thorough rehab protocol.

Conclusion

Developing and implementing a comprehensive program for educating firefighters on health and fitness can result in healthy employees and lower costs, including reduction in lost time due to injuries and lower workers' compensation costs. Creating a health and fitness culture can improve morale and result in a positive outlook on job performance. Healthy and fit firefighters are able to perform their job requirements more effectively, thus providing a higher level of service.

Although not all health problems can be predicted and prevented, educating firefighters regarding the importance of proper fitness, hydration, and safety and rehabilitation protocols is an important step in enabling firefighters to maintain optimal health, maximize job performance and job satisfaction, and improve overall equality of life.

APPENDIX A:
PROPOSED HEAT AND HYDRATION PLAN FOR OCFA

OBJECTIVE: To reduce the risk factors for heat illness and to manage the consequences of heat exposure among OCFA firefighters

1. GOAL: Train and educate firefighters on the importance of hydration and the warning signs of dehydration

ACTION:

i. Deliver a presentation during Training Activities Group (TAG)
ii. Provide overview of this study and its results
iii. Discuss implications and practical applications of findings

FOLLOW-UP:

i. Produce and deliver an instructional DVD on proper hydration
ii. Create and post signage and other visual reminders regarding dehydration for posting in station restrooms, kitchens, and common areas
iii. Deliver hydration announcements during high water sheds and red flag warnings

2. GOAL: Increase physical fitness levels of OCFA firefighters to maximize job performance and safety

ACTION: Implement a plan ensuring all OCFA firefighters are able to reach and maintain a heart rate of 160–200 beats per minute for 15 minutes continuously

FOLLOW-UP:

i. Provide support for members not meeting the required threshold
ii. Ensure all members have access to a comprehensive fitness facility and appropriate exercise equipment
iii. Highlight the importance of a complete medical and fitness exam and ensure department-wide support and encouragement for individuals seeking to obtain an exam

3. GOAL: Reduce the percentage of body fat composition among OCFA firefighters in accordance with national standards

ACTION: Provide OCFA firefighters with the opportunities for regular measurement of body composition

FOLLOW-UP:

i. Deliver regularly scheduled nutrition classes

ii. Create and distribute an OCFA healthy eating cookbook
iii. Create and post signage and other visual reminders regarding portion control in station kitchens
iv. Deliver healthy cooking demonstrations

4. GOAL: Implement detailed post-incident rehabilitation protocols and ensure all OCFA firefighters are aware of such protocol

ACTION: Deliver a presentation during TAG

FOLLOW-UP:

i. Produce and distribute an instructional DVD on new rehabilitation protocols
ii. Post signs at the rehabilitation sites describing the new rehabilitation protocols
iii. Review signs and symptoms of heat illness and the appropriate protocols for dealing with it

APPENDIX B:
PROPOSED POST-INCIDENT REHABILITATION PLAN FOR OCFA

Rehabilitation protocol applies when one or more of the following occur:

- Any second alarm incident or greater
- Any incident requiring 30 minutes or longer of continuous activity
- At the discretion of the incident commander

Equipment/supplies needed:

- Ice chests
- Ice
- Water
- Towels
- Signs
- Canopies
- Buckets
- Drinks
- Dietary supplements

Steps for wet towel use:

1. Fill ice chests with water and ice (ideal water temperature for most effective results to be determined).
2. Place towels in the ice chests for a minimum of 5 minutes.
3. Remove coat and helmet of firefighter.
4. Cease all activity and stand/sit under a canopy.
5. Take one wet towel at a time from the ice chest and place on areas of the body with abundant blood supply (such as the back of the neck) and areas with efficient heat transfer (such as the head).
6. Place used towel in a separate bucket, not in the ice chest, when done.

Steps for fluid replacement:

1. During the first 30 minutes of an incident, provide only water.
2. After approximately 30 minutes, provide water and an electrolyte replacement drink.
3. After approximately 60 minutes, provide water and an electrolyte and glucose replacement drink.
4. After approximately 120 minutes, provide all fluids mentioned above and a meal replacement drink/bar containing essentials vitamins, minerals, and calories.

Note: All fluids, other than water, and all other drinks and/or bars shall be selected based on the recommendations of a qualified nutrition professional.

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