Advancing Technology to Promote Health & Safety in the Fire Service

SKIDMORE COLLEGE

First Responder Health and Safety Laboratory

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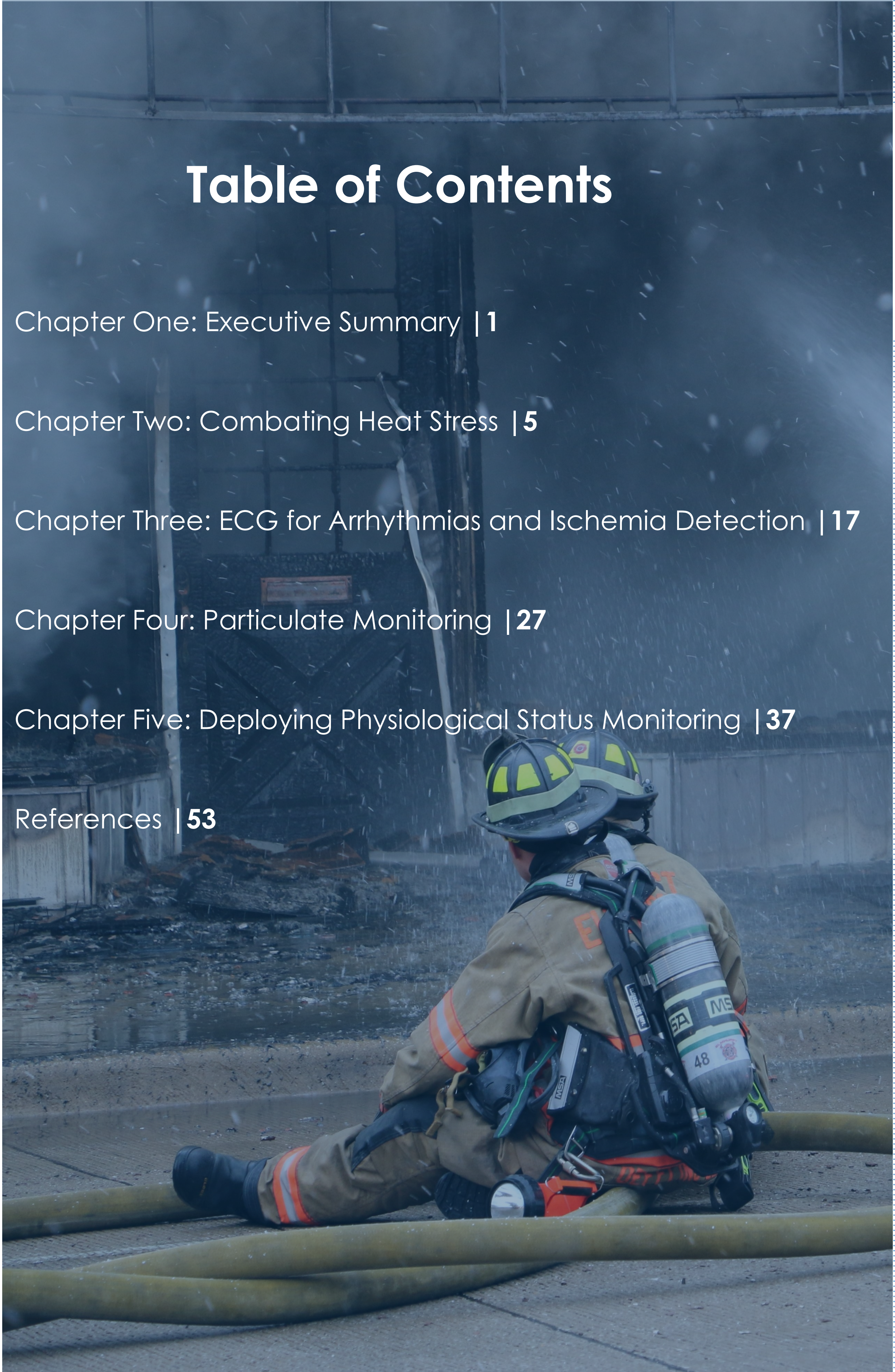

EXECUTIVE SUMMARY

INTRODUCTION

Despite numerous dangers on the fireground, it is the pathophysiological response to firefighting that causes most line-of-duty injuries and deaths. Too many firefighters experience a cardiac event, heat stroke, or musculoskeletal injury during or shortly after firefighting operations, and during training. Early detection of physiological abnormalities and real-time monitoring of toxic particulates offer tremendous opportunities to address these risks to first responders.

The SMARTER (Science Medicine And Research & Technology for Emergency Responders) research team sought to employ scientific advances, medical knowledge, research findings, and technological solutions to reduce firefighter injuries and fatalities. The project was specifically focused on the use of technology to address firefighter health issues and was organized into four (4) topic areas:

1. An improved algorithm to accurately estimate body temperature;
2. ECG Monitoring for detection of arrhythmias and ischemic changes;
3. A low-cost portable monitor to assess air contaminants;
4. Deployment of a physiological monitoring system in the fire service.

During the SMARTER project, a multi-disciplinary team collaborated to create appropriate use models and advance targeted technologies. They then tested those technologies for applicability and feasibility for use by the fire service, and made recommendations to foster their adoption when appropriate.

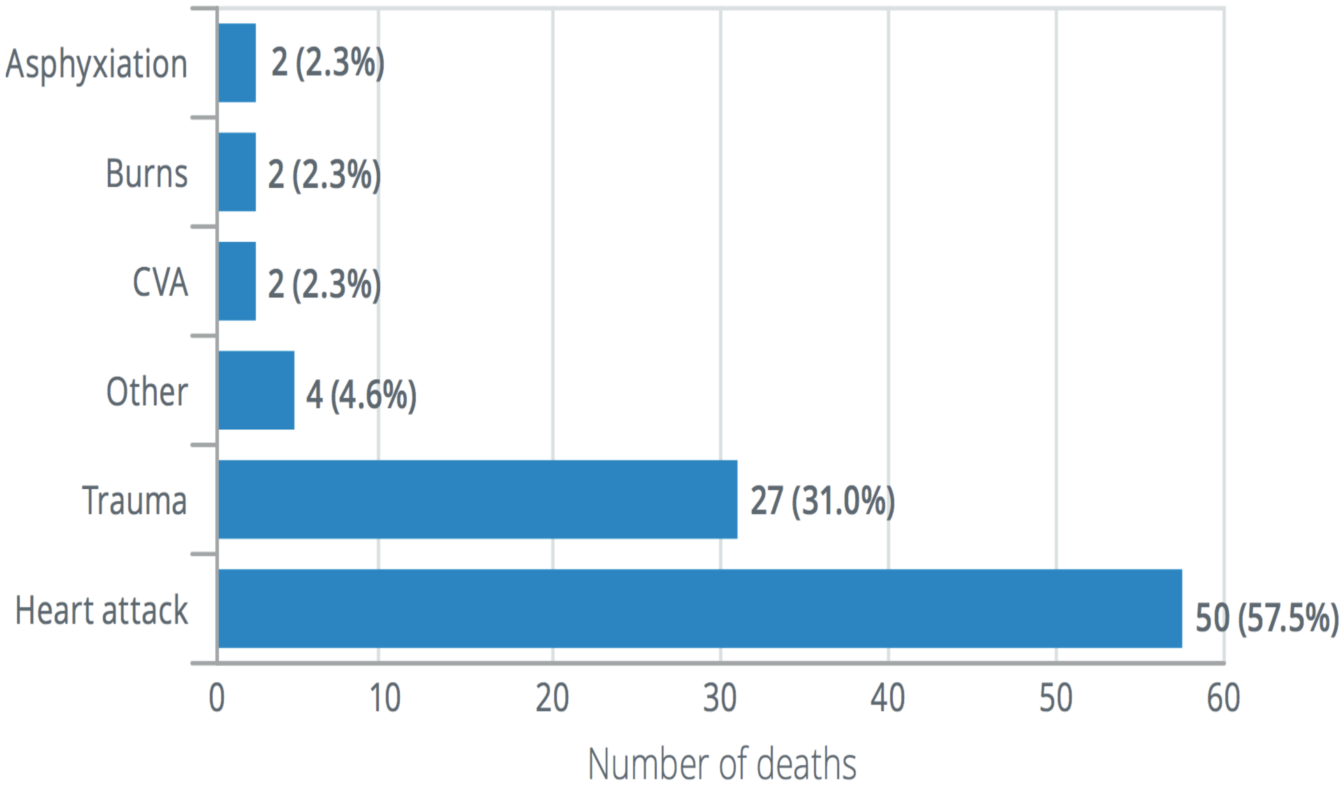

FIGURE 1.1. FIREFIGHTER FATALITIES BY NATURE OF FATAL INJURY DURING 2017 (UNITED STATES FIRE ADMINISTRATION 2018).

PHYSIOLOGICAL VULNERABILITIES OF FIREFIGHTERS

1. Cardiac Events

Despite all the on-scene hazards, nearly half of firefighter fatalities result from cardiac events (Fahy et al., 2018). As seen in Figure 1.1, 57.5% of fatal injuries among firefighters in 2017 were caused by heart attack (United States Fire Administration, 2018). Additionally, about 800-1,000 duty-related injuries are attributed to non-fatal cardiac events annually (Evarts, 2018). Firefighting involves strenuous work, the use of heavy personal protective equipment (PPE), and is performed in hot and hostile environments often under time urgency. The heavy work, encapsulating PPE, and high temperatures associated with firefighting lead to activation of the sympathetic nervous system, dehydration, heat stress, and increased cardiovascular strain.

Firefighting increases heart rate, cardiac output, and blood pressure. It also leads to vascular and coagulatory changes. Taken together, these cardiovascular changes can trigger arrhythmias and ischemic changes that can cause a sudden cardiac event in individuals with underlying cardiovascular disease (Smith, Barr, & Kales, 2013; Soteriades et al., 2011). To address cardiac vulnerability, we evaluated the use of commercially available single-lead ECGs.

2. Heat-Related Injuries and Fatalities

Heat stress is common on the fireground. Because of the physical work performed and the heavy encapsulating PPE, firefighting causes a rapid increase in core temperature (Horn et al., 2017). Among the most distressing line-of-duty fatalities are incidences of heat stroke that occur during training. These cases are especially heartbreaking because they are preventable and occur when there is no actual emergency. The fire service has an obligation to protect the health and safety of trainees.

Training can result in other types of heat-related injuries including heat exhaustion. Research indicates that the physical strain of firefighting, use of PPE, and high temperatures increases heat stress, cause dehydration, and exacerbate cardiovascular strain (Fehling et al., 2015; Horn et al., 2013). Recruits are more susceptible to heat-related injuries and fatalities because they are often required to perform physical training at the beginning of the day and then engage in multiple training evolutions.

To address heat stress vulnerability, we worked with leading experts from the military to advance an algorithm to estimate **core temperature**. It is expected that the updated algorithm can be incorporated into existing physiological status monitors to provide a real-time evaluation of **thermal strain**. Physiological monitoring systems (PSMs) that can calculate an accurate estimate of core body temperature may assist safety and training officers in making critical decisions about the physiological status of firefighters, and ultimately save lives.

3. Air Contamination Levels on the Fireground and in Structures After Firefighting

Dangerously elevated gas and particulate matter levels are commonly detected on the fireground, and often persist after the fire is extinguished. These forms of air contamination increase the risk of developing cancer, irritate the respiratory system, and can also trigger fatal arrhythmias and ischemia (Soteriades et al., 2011). The overall increased risk of cancer in the fire service is approximately 15%, but the risk of certain cancers may be 40-100% greater than the general population (Daniels et al., 2015). The increased risk due to smoke and products of combustion has not been quantified, but medical research indicates that contaminants reduce the availability of oxygen within the body and produce free radicals that promote a pro-coagulatory state (Soteriades et al., 2011). Air contamination is an important vulnerability, both for cardiac risk and carcinogenic exposure. We addressed this vulnerability by advancing the development of a low-cost, easy-to-deploy monitor that may be used to quantify air contamination levels after the fire is extinguished.

Firefighters and fire officers need to know when respiratory protection is needed. To facilitate that determination, research partners from UCLA have developed and tested a novel device suitable for real time detection of particulate matter. Their device, the c-Air, is portable and utilizes lens-free microscopy and provides state-of-the-art measurement. The information obtained from the c-Air device may help firefighters to more effectively assess the environment in which they are working. The increased availability of air quality information could help with the development of improved safety protocols.

The remaining chapters of this report address each of the project's focus areas (see page 1) in greater detail. These topics were chosen because they present major health and safety concerns for the fire service and because there are technologies that are commercially available or in development that may help us address these vulnerabilities. It is our sincere hope that this information will serve to educate and promote a healthier and safer fire service.

COMBATING HEAT STRESS

HEAT STRESS

Heat stress is a familiar sensation for firefighters given their demanding work and challenging work environment. Common aspects of firefighting, including hot environments, use of heavy and fully-encapsulating PPE, and strenuous tasks, cause increases in core temperature that can lead to serious heat illnesses, exaggerated cardiovascular strain, impaired cognitive function, and the early onset of fatigue. These physiological consequences may impair job performance, and if severe enough, may progress to life-threatening challenges. Perhaps because it is so common, we often fail to recognize the devastating consequences that accompany heat stress.

Using evidence from over 20 years of research, Smith et al. developed a model to represent the central role that heat stress, and accompanying dehydration, play in causing increased physiological strain and serious medical conditions that firefighters may face on the fireground (see Figure 2.1). Specifically, the model details how **hyperthermia (and dehydration)** can cause physiological consequences that, if left untreated, may result in serious, life-threatening consequences. These outcomes are devastating for firefighters, and for other the affected firefighter, as well as for other responders on the scene and the public they serve.

The following chapter will describe the causes of heat stress, potential consequences of untreated heat stress, and work that the SMARTER team is doing to address this vulnerability.

FIREFIGHTING WORK

Though firefighters are involved in a variety of duties, specific aspects of their work contribute to thermal strain. These factors are detailed below and shown in Figure 2.1A.

Heavy Work

Firefighting involves strenuous work. The labor that a firefighter performs during emergency response increases metabolic heat production and causes body temperature to increase. The magnitude of the increase in body temperature is affected by the amount, type, and duration of work. The ef-

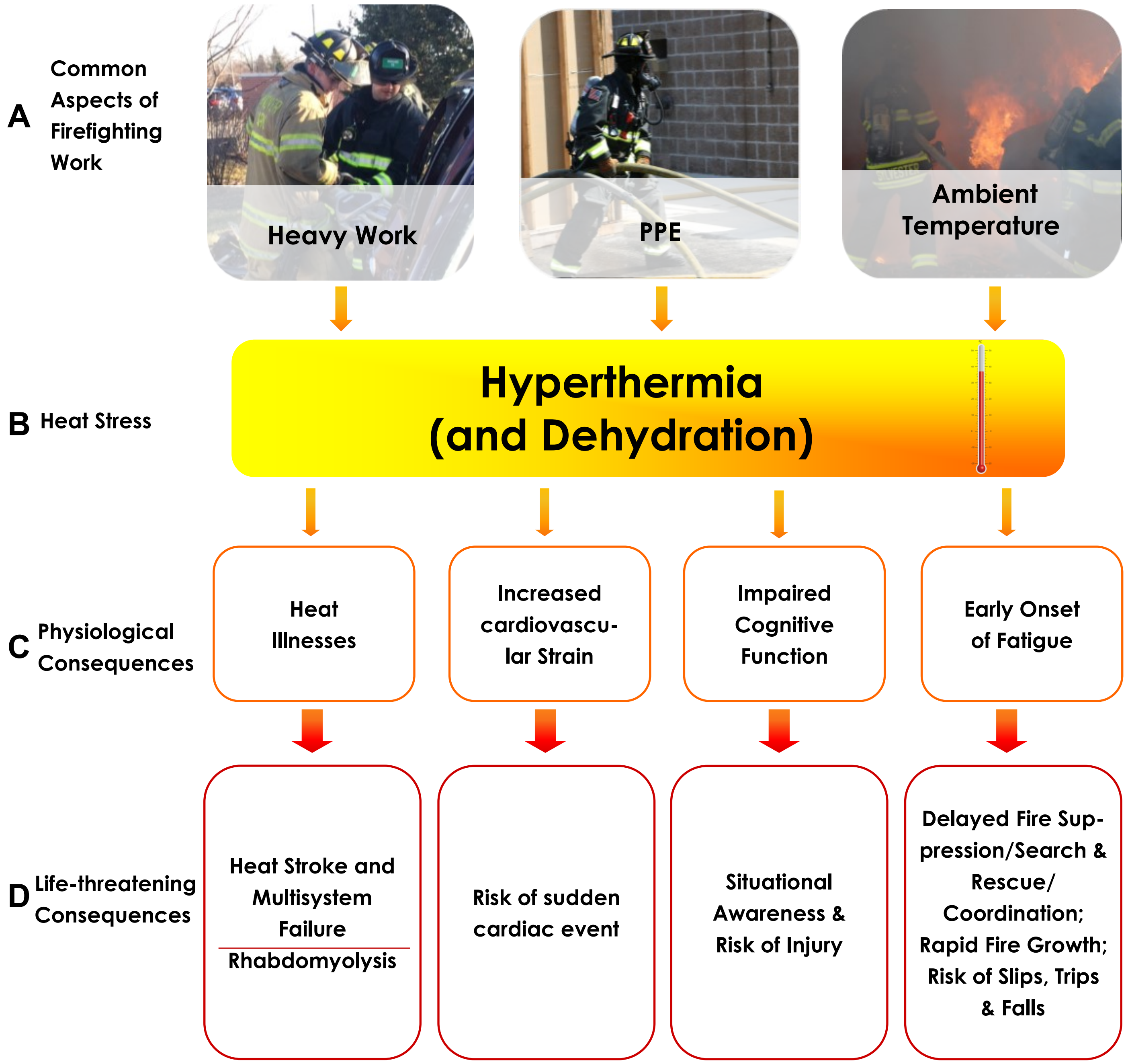

FIGURE 2.1. THEORETICAL MODEL OF THE CAUSES AND CONSEQUENCES OF HYPERTHERMIA. Figure modified from *Surviving the Fire Ground* in press

fect of different job assignments on core body temperature has been investigated by the University of Illinois Fire Service (Horn et al., 2017). These researchers had firefighters complete fire suppression activities in a residential structure by comparing crews that performed different tasks; incident command and pump operators; engine crew on hose line; search and rescue teams; outside ventilation teams; and overhaul activities. Somewhat surprisingly, these researchers found that the firefighters with the highest temperatures were those that performed outside ventilation (which involved manually chopping a roof) and those who performed overhaul activity. This data reinforces the role that heavy muscular work plays in causing body temperature increases (for full details about this study, visit https://bit.ly/2JAYLUY).

PPE

Though PPE is necessary for safety, it also plays an important role in increasing heat strain. PPE contributes to heat stress in several important ways. It adds weight to the firefighter, which then increases the amount of muscular work that must be performed. Bunker gear is encapsulating, and interferes with evaporative cooling. Because sweat cannot readily evaporate, the body is not able to cool itself and a microclimate develops around firefighters that is equivalent to 100% humidity. Finally, the gear is restrictive, which can decrease range of motion and increase the amount of musculoskeletal work required to move. An important concern for firefighters is cooling as soon as possible, including removing bunker gear. Although a firefighter may feel cool once the helmet and face piece are removed, core body temperature continues to increase. The sooner firefighters can remove PPE following fire suppression, the quicker the body can begin to cool.

Environmental Conditions

Firefighters are regularly exposed to high ambient temperatures during fire suppression. Average structural fires produce heat well above 300° F and firefighters often operate in far higher temperatures. Importantly, however, ambient temperatures encountered during firefighting differ greatly based on job assignment and in most cases, exposures to high temperatures are relatively short because firefighters seek to suppress the fire immediately. Nevertheless, operating at even moderately high temperatures, such as during overhaul or performing a vehicle extrication on a hot day, can have profound effects on core temperature. This is especially true when heavy work is performed while wearing PPE, and when recovery time is limited.

Multiple environmental conditions affect heat stress, including: ambient temperatures, environmental temperatures, direct sunlight, and relative humidity. It is important to consider the effects of exposure to high temperatures over several days. Researchers have found that the risk of exertional heat illness is associated with environmental conditions not only during an event, but also the day prior to the event (Garzon Villalba et al., 2016; Wallance et al., 2005).

HEAT STRESS & DEHYDRATION

As shown in Figure 2.1B, the combination of the factors described in the previous section lead to an increase in body temperature (hyperthermia) and dehydration.

Heat Stress

The average temperature of a healthy individual is approximately 98.6°F (37°C). When this temperature is disrupted, our bodies make adjustments (thermoregulate) in an attempt to re-establish normal body temperature. The body's main ways of cooling itself are through the evaporation of perspiration and by increasing blood flow to the skin. Both of these methods are largely ineffective when wearing PPE.

When the body gains more heat (through metabolic heat production or from the environment) than it can dissipate through normal processes, then body temperature rises (hyperthermia). Even relatively small increases in body temperature can exacerbate cardiovascular strain; large fluctuations in body temperature can lead to life-threatening heat illnesses.

Dehydration

Dehydration is a physiological challenge that regularly accompanies heat stress. Dehydration can result if too much body water is lost through perspiration. In turn, dehydration also interferes with the ability to continue sweating and increases blood flow to the skin. Thus, heat stress and dehydration are twin challenges that should be considered together. Unfortunately, there is ample evidence that firefighters are often dehydrated before they begin firefighting (Horn et al., 2012; Espinoza & Contreras, 2007) and they certainly become increasingly dehydrated during the response. In 2012, Horn et al. found that only 9% of firefighters were properly hydrated at the start their shifts. This high rate of dehydration is especially troubling considering the large volume of fluids that are lost during firefighting.

On-site rehabilitation is designed to help cool and rehydrate firefighters. During rehab, caffeine-free beverages such as water or sports drinks should be used for fluid replacement; caffeine can potentially cause further dehydration.

FIGURE 2.2. SIGNS AND SYMPTOMS OF HEAT STRESS.

CONSEQUENCES OF HEAT STRESS

Hyperthermia creates a cascade of biological events that lead to consequences in all systems of the body. These consequences range from concerning (Figure 2.1C; heat illnesses, increased CV strain, impaired **cognitive function**, and early onset of fatigue) to life-threatening (Figure 2.1D; heat stroke and multisystem failure, risk of sudden cardiac event), decreased situational awareness, and increased risk of injury. Unfortunately, the sense of purpose and drive of many firefighters can lead them to ignore the less severe, treatable symptoms that progress to medical emergencies. Instituting and maintaining formalized rehabilitation is one way to ensure that early signs and symptoms are identified and treated.

Heat Illnesses

Heat illnesses range in severity from an annoying heat rash to painful heat cramps, debilitating exertional heat exhaustion, and deadly exertional heat stroke. While it may be unavoidable, every firefighter should attempt to minimize heat stress as much as possible in order to mitigate the detrimental effects of heat illness. (Figure 2.2). Figure 2.2 shows some of the common signs and symptoms associated with heat stress. Firefighters should be alert to these and take early action. Medical monitoring during incident rehabilitation should also address these signs and symptoms.

Table 2.1 provides information for different

TABLE 2.1. HEAT ILLNESSES.

Classification	Cause	Signs and Symptoms	Treatment
Heat Cramps	Profuse sweating coupled with failure to replace electrolytes that are depleted from the body.	Evident cramping and pain in muscle(s) following work.	Individuals should remove PPE, consume fluids containing electrolytes (sports drinks). Rest and stretching are also recommended .
Exertional Heat Exhaustion	Profuse sweating and dehydration that disrupts electrolyte balance. Elevation in core body temperature.	Fatigue, fainting, and minor alterations in cognitive function (headache, dizziness, confusion).	PPE and excess clothing should be removed to facilitate cooling. Cooling should be aided by fans and ice towels if possible. Individuals should also consume fluids containing electrolytes (sports drinks).
Exertional Heatstroke	Drastic elevation in body temperature as a result of the body's inability to respond to heat stress (high temperatures and heavy work).	Core body temperature > 40.5°C (105°F) and central nervous system dysfunction. Disorientation, confusion, dizziness, irritability, irrational or unusual behavior, collapse, delirium, and loss of consciousness are all indications of heatstroke. Sweaty, pale skin at the time of collapse are distinct signs of exertional heat stroke.	**Individuals exhibiting signs of heatstroke should be transported to a medical facility immediately.**

types of heat illnesses. Treatment for heat cramps and exertional heat exhaustion generally includes cooling and aggressive hydration in a shaded environment. Fortunately, most crews are equipped to handle early heat-illness treatment on sudden cardiac event. Nevertheless, early signs and symptoms of heat illness are often overlooked. Gone untreated, these physiological consequences can lead to medical emergencies like exertional heat stroke and multisystem failure.

Exertional Heatstroke & Multisystem Failure

Exertional heatstroke is the most serious in the progression of heat illness. This life-threatening condition disrupts functions of the central nervous system (CNS) and leads to rapid decline in all bodily functions. Common diagnostic criteria of exertional heatstroke consist of a core temperature of 40.5°C (105°F) and altered CNS function, including, but not limited to: disorientation, changes in behavior, and decline in proprioception (Binkley et al., 2002). Immediate attention and transport to a medical facility is paramount when individuals exhibit signs and symptoms of heatstroke, and aggressive cooling strategies should be initiated as soon as possible.

Rhabdomyolysis

Rhabdomyolysis (rhabdo) is a specific concern for firefighters (Figure 2.1D). This life threatening condition can occur when muscles are damaged due to heavy exercise/work, and is exacerbated by working in a hot environment and/or in a state of dehydration. Muscle injury and some medications also increase the risk of rhabdo. Rhabdo becomes dangerous as it progresses because proteins and electrolytes leak into the blood stream, negatively affecting multiple organs, and can lead to kidney failure.

Kidney failure is a particular problem. Along with the renal system, the gastrointestinal and cardiovascular systems become dysfunctional with heatstroke. A complex series of physiological events leads to decreased blood flow in the intestines, which promotes increased temperature in the gut and tissue death from lack of oxygen (Binkley et al., 2002).

Signs and symptoms of rhabdo include muscle pain, cramping, swelling, weakness, and muscle fatigue, a decreased range of motion, dark-colored urine, and increased levels of muscle proteins in the blood. Creatine kinase (CK) is a muscle protein that is found at high levels in the blood of individuals with rhabdo. When firefighters present with any signs and symptoms of rhadomyolysis, it should be treat-

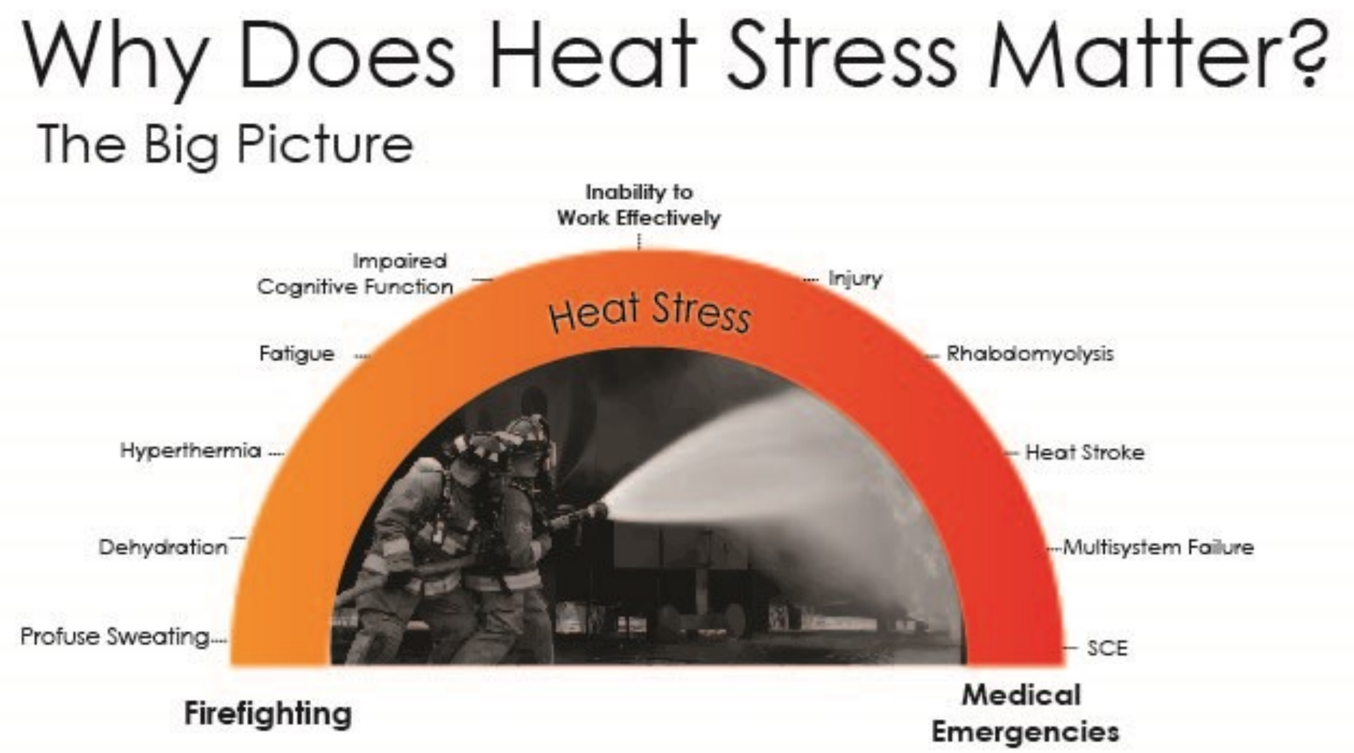

FIGURE 2.3. HEAT STRESS CONTINUUM.

ed as a medical emergency. As shown in Figure 2.3, rhabdo is a severe physiological consequence that can occur in response to firefighting.

Increased Cardiovascular (CV) Strain

As seen in Figure 2.1C&D, heat stress exaggerates cardiovascular strain, resulting in higher heart rates and lower ventricular stroke volumes (volume of blood pumped with each heart beat).

Risk of Sudden Cardiac Event

High levels of CV strain coupled with thermal stressors can trigger sudden cardiac event in individuals with underlying conditions such as atherosclerosis and/or an enlarged heart (cardiomegaly) or thickened left ventricle (left ventricular hypertrophy) (Figure 2.1D). These factors are concerning given the high incidence of sudden cardiac events among firefighters, the leading cause of line-of-duty death in the U.S. fire service.

Impaired Cognitive Function

Mental confusion is a primary symptom of progressing heat illness (Figure 2.1C). Tunnel vision, tunnel hearing, or an inability to focus can result from poorly regulated core temperature. While these symptoms of heat illness are easily identifiable in a general population, diagnosis among firefighters is more difficult because of their stressful work environment.

Decrease in Situational Awareness

Impairments to cognitive function are particularly distressing because of the degree of focus required to perform during emergency operations; failure to think clearly can negatively affect success of fire suppression and other operations (Figure 2.1D). For the individual firefighter, a reduction in situational awareness can result in a compromised ability to perform critical risk analysis calculations, and increases likelihood of injury or death.

Early Onset of Fatigue

Heat stress resulting from both the environment and internally from increased metabolic work causes fatigue to occur more quickly. This increases time necessary to complete work, increasing the exposure risk for firefighters and occupations, and the risk of slip, trip, and fall injuries (Figure 2.1C).

Risk of Injury

Slips, trips, and falls are one of top two causes of injury on the fireground (Figure 2.1D), and constitute approximately 20% of reported injuries (Evarts and Molis, 2018). Because fatigue increases the risk of these type of injuries, it is important to try to lessen fatigue when possible or delay its onset. This challenge is primarily addressed by the fire service with shorter and less frequent bouts of work; however, recognizing this factor remains critical. It is important that firefighters adhere to a formalized rehabilitation protocol both between and following bouts of activity. Protocols should include removal of PPE to allow for evaporative cooling, hydration to replenish body fluids, and monitoring of vital signs (including cognition) to ensure health and safety.

With impaired cognitive function and early onset of fatigue comes slower completion of work. An inability to suppress fires results in rapid growth and changing conditions, which leads longer periods of heavy work under extreme temperatures, thereby exacerbating physiological strain.

ENHANCING AN ALGORITHM TO ACCURATELY ESTIMATE CORE TEMPERATURE

Because heat stress and elevated body temperature present so many challenges to firefighters, there is considerable interest in measuring body temperature. Unfortunately, this is a difficult thing to do given limitations of currently available devices. However, technology may provide a way to accurately estimate core temperature on the fireground.

Challenges of Measuring Core Temperature

As described in Figure 2.4, commonly used devices provide inaccurate and misleading data. Oral temperatures are falsely low because of ingestion of fluid and/or heavy

COMMON CHALLENGES OF MEASURING HEAT STRESS ON THE FIREGROUND

- *Oral measurements* are affected by fluid intake, smoking, and use of chewing tobacco products.
- *Infrared measurements* are altered by ambient temperature and inaccurate during work.
- *Rectal measurements* are not practical.

FIGURE 2.4. CHALLENGES OF MEASURING HEAT STRESS.

breathing. Infrared tympanic thermometers underestimate core temperature, the degree of which varies depending on work that is done and environmental temperature. Rectal temperatures are accurate but it is not feasible to collect core temperature this way on the fireground. However, technological advances in research equipment offer the opportunity to measure the thermal strain experienced during firefighting.

Algorithm Development

Accounting for past challenges, Mark Buller of U.S. Army Research Institute of Environmental Medicine (USARIEM) developed an improved algorithm using computational physiology that requires only an accurate measure of heart rate to estimate core temperature (Buller et al., 2010). Figure 2.5 displays a comparison of observed core temperature measurements and those estimated by Buller's initial algorithm. This initial algorithm provided estimates of core temperature that were within 0.5°C of the observed temperature 94.5% of the time. Though the algorithm is able to accurately estimate core temperature in military cadets, firefighters differ significantly from the military population in average age, body composition, and work activities. One of the primary aims of the SMARTER project is to enhance USARIEM algorithm and validate it for use in the firefighter population. Preliminary tests with a small number of firefighters have been promising; however, additional testing is still needed. Testing will continue with firefighters who have a broader range of descriptive characteristics (age, body mass index, gender, etc.) to ensure that the algorithm is broadly applicable. Once the algorithm is validated, appropriate cut-off points for rest and return to duty can be established. Additionally, the algorithm must be incorporated into low-cost, portable devices that are suitable for firefighting to facilitate widespread use. Further challenges include creating a sufficiently accurate system that can be used to determine when firefighters are at risk for heat illness, and when they have recovered. Liability issues and firefighters' fears of being taken off-line must also be addressed. In the future, technologies that accurately measure heart rate may be able to incorporate the final improved algorithm to estimate heat stress. This data can then be transmitted to the incident commander, who can use it to inform actionable decisions.

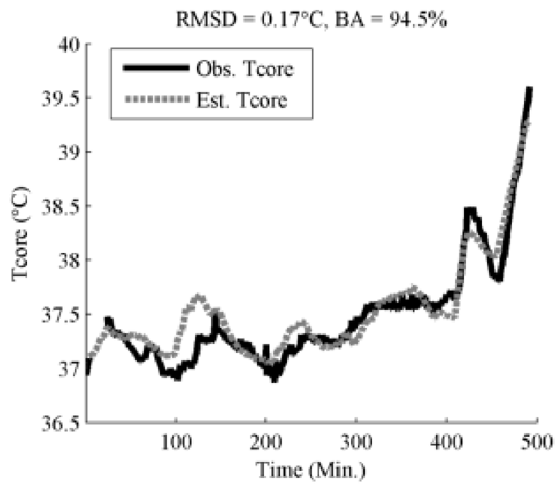

FIGURE 2.5. OBSERVED (OBS.) AND ESTIMATED (EST.) TCORE RESPONSES FOR AN INDIVIDUAL MILITARY CADET WHO BECAME A HEAT EXHAUSTION CASUALITY DURING TRAINING. RMSD = ROOT MEAN SQUARE DEVIATION, BA=NON-PARAMETRIC BLAND ALTMAN PERCENTAGE (FIGURE FROM BULLER ET AL., 2010).

RECOMMENDATIONS

1. Ensure adequate hydration before shifts by self-monitoring urine.
2. Remain aware of environmental conditions during strenuous work.
3. Remove PPE as soon as possible following firefighting work.
4. Use aggressive cooling techniques (submerge forearms, misting fans, slurry drinks) when ambient temperatures and relative humidity are high.
5. Drink a bottle of water every time you change your SCBA bottle.
6. Pay attention to recovery for 24 hours after firefighting.
7. PPE manufactures should continue to make improvements in PPE that lessens heat strain and improves mobility.

RESOURCES

REPORTS

- **Illinois Fire Service Institute Website** (https://bit.ly/2JGXsnp)
  - "Firefighter Fatalities and Injuries. The role of heat stress and PPE"
- **First Responder Health and Safety Laboratory Website** (https://bit.ly/2LhOCjd)
  - "Effect of Heat Stress and Dehydration on Cardiovascular Function"
- **American College of Sports Medicine Website** (https://bit.ly/2MldVSa)
  - "Exercise and Fluid Replacement" Position Stand
- **National Athletic Trainers' Association Website** (https://bit.ly/2NJTD62)
  - "Exertional heat illnesses" Position Statement
- **National Fire Protection Agency Website** (https://bit.ly/2JBCoP3)
  - "Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises"

ARTICLES

- **First Responder Health and Safety Laboratory Website—Fire Service Publications** (https://bit.ly/2LhOCjd)
  - "Implementing Effective On-Sudden cardiac eventne Rehabilitation"
  - "Incident Sudden cardiac eventne Rehabilitation: a Leadership Challenge"
- **First Responder Health and Safety Laboratory Website—Scientific Publications** (https://bit.ly/2xHaETF)
  - "Core temperature and heart rate responses to repeated bouts of firefighting activities"

VIDEOS

- **First Responder Health and Safety Laboratory Website** (https://bit.ly/2xHa6gm)
  - Research Study: The Effects of Heat Stress and Dehydration on Measures of Cardiac and Vascular Function


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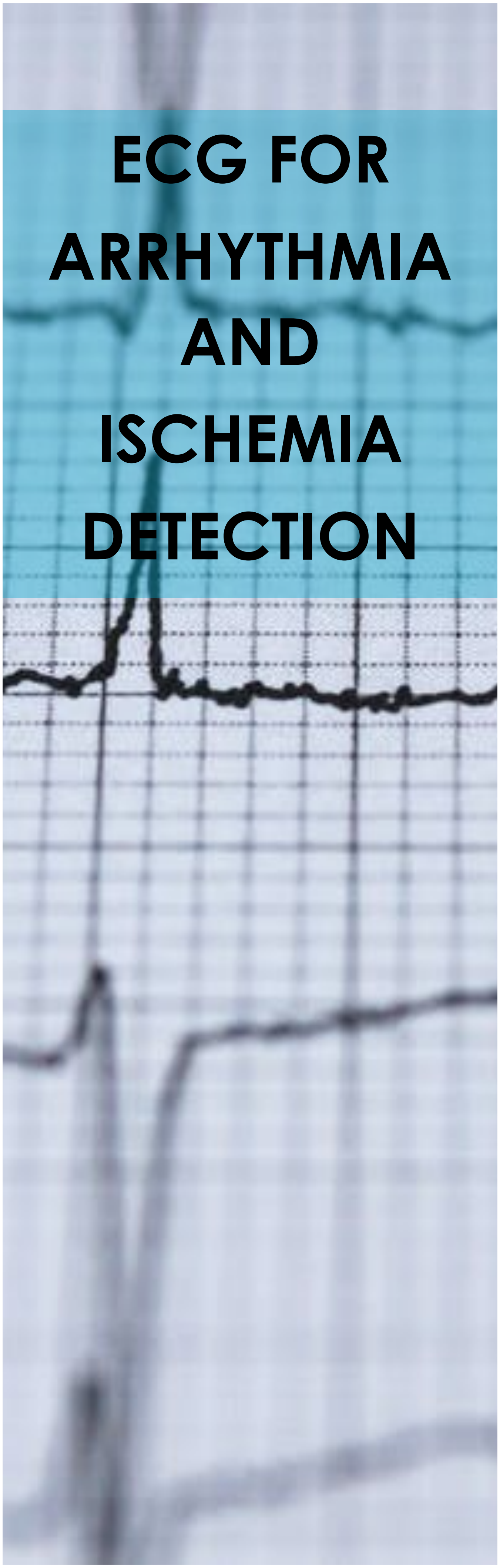
ECG FOR ARRHYTHMIA AND ISCHEMIA DETECTION



CARDIAC-RELATED LINE OF DUTY DEATHS

With sudden cardiac events accounting for the vast majority of line-of-duty deaths and overexertion or strain being the leading cause of injuries on the fireground (Fayhe, LeBlanc & Molis, 2018; Haynes & Molis, 2017), there is a clear need for interventions that address this threat to firefighter's life and health. As shown in Figure 3.1, the cardiovascular strain of firefighting can trigger a sudden cardiac event in individuals with underlying cardiovascular disease (Smith et al., 2013). Multiple factors contribute to cardiovascular strain of firefighting, including activation of the sympathetic nervous system, heavy muscular work, heat stress, dehydration, and exposure to particulate matter. Together, these factors increase cardiac work, alter vascular function, and enhance coagulatory potential. In the vast majority of firefighters this cardiac and thermal strain does not result in a sudden cardiac event. However, in individuals with underlying cardiac conditions like atherosclerosis and structural heart disease (cardiomegaly and LVH) firefighting work can serve as a trigger for **arrhythmias** and **ischemia** (Smith et al., 2018). An arrhythmia is deviation from normal electrical signal of the heart and can lead to a cardiac arrest. Ischemia is a decrease in blood flow as a result of an atherosclerotic plaque (Becker, 2006; Mayo Clinic Staff, 2018). Underlying cardiovascular disease may be present even in firefighters who have passed a standard annual physical exam.

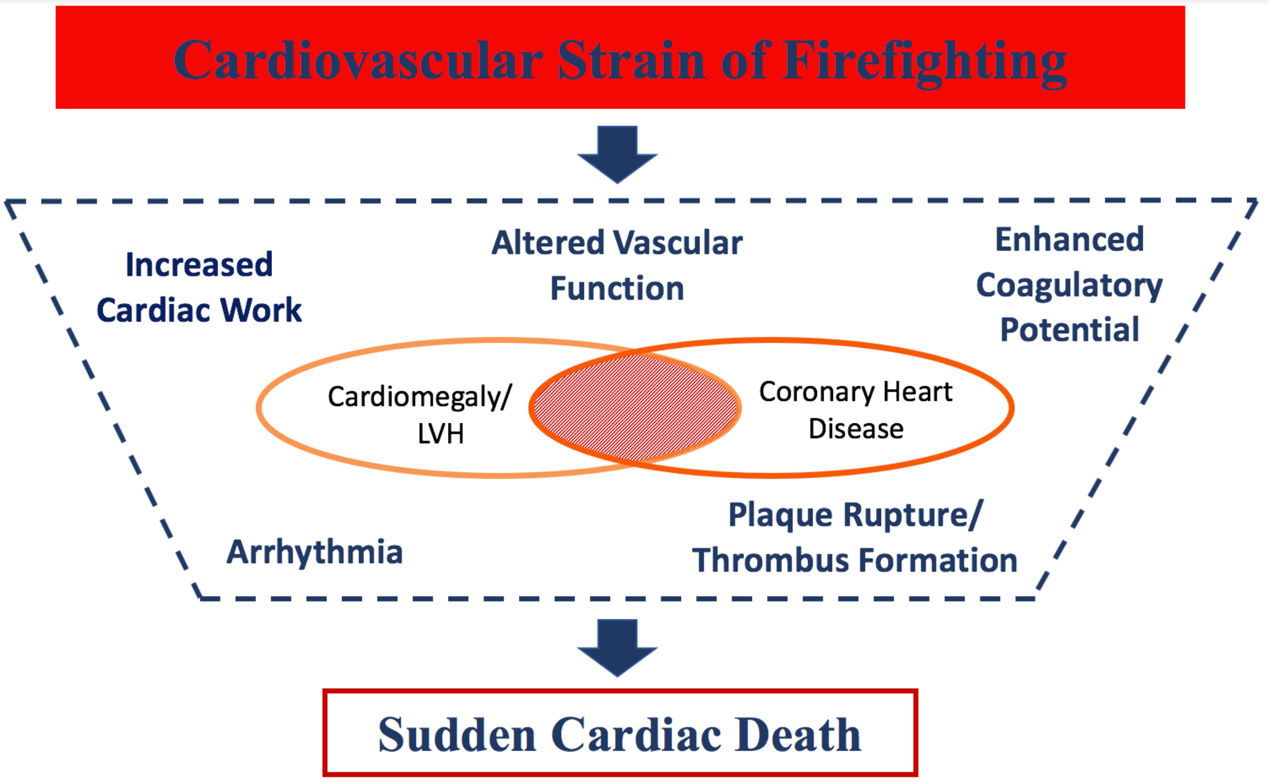


FIGURE 3.1. SUDDEN CARDIAC DEATH INFOGRAPHIC.

It would be a significant step forward to be able to monitor ECG changes during firefighting in order to get an early warning that a firefighter is reaching a danger zone, when a cardiac event is imminent. Until now, though, it has not been able to realistically consider outfitting a firefighter with a 12 lead ECG while they engage in firefighting.

However, ECG technology is rapidly advancing, and the SMART team was able to explore the adequacy and feasibility of a portable, single lead electrocardiogram monitoring system for detecting arrhythmias and ischemia during a 24-hour shift. While data indicates that firefighters are more likely to suffer a cardiac event or myocardial infraction during fire suppression activities (Smith et al., 2019; Kales et al., 2007), it would not be possible to capture ECG changes unless the electrodes were placed on the firefighter before they received the call.

ANATOMY AND PHYSIOLOGY OF THE HEART

To pump blood throughout the body, the upper chambers (atria) and lower chambers (ventricles) of the heart must rhythmically contract and relax. This rhythm is regulated by specialized heart cells that generate electrical signals (Becker, 2006). In a healthy heart, each cycle of contraction and relaxation begins when an electrical signal is fired at the sinoatrial (SA) node, a group of cells in the upper right chamber of

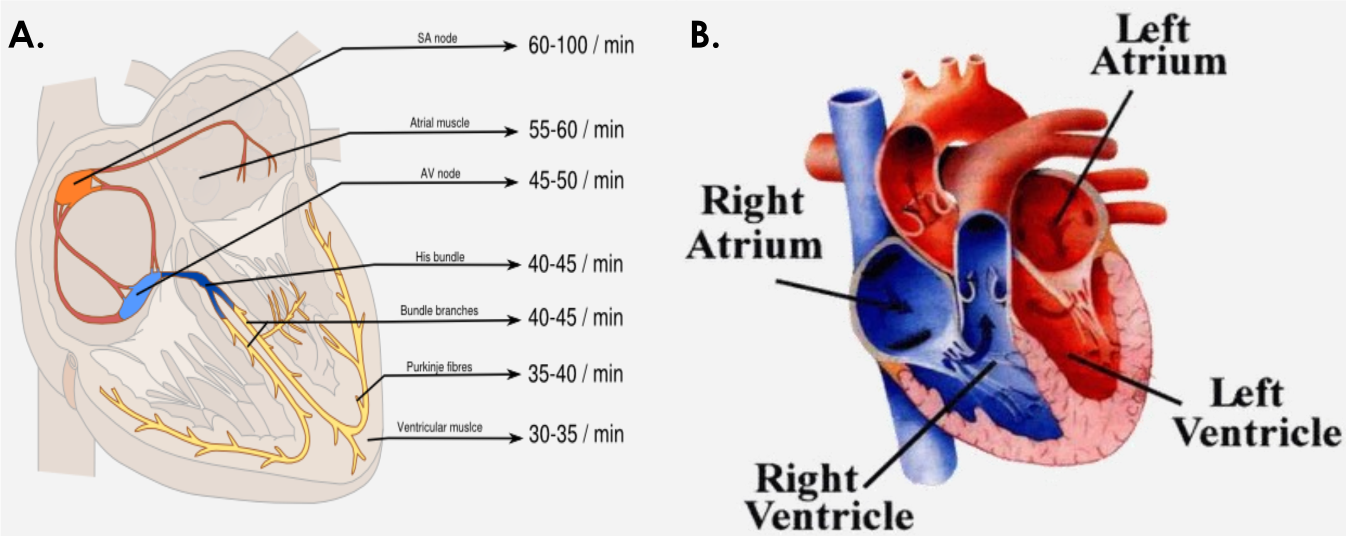


FIGURE 3.2. A. CONDUCTION PATHWAY OF THE HEART, **B.** CHAMBERS OF THE HEART.

heart (Figure 3.2). The electrical signal travels from the upper chambers to the atrioventricular (AV) node, a group of cells located between the upper and lower chambers. At the AV node, the signal is delayed, which provides time for blood to be pumped from the atria to the ventricles. After the ventricles fill with blood, the electric signal continues to travel through the heart. When the electrical signal reaches the Purkinje fibers, this causes the ventricles to contract and blood is pumped out of the heart (Van Weerd & Christoffels, 2016).

ELECTROCARDIOGRAPHY

The electrical signal in the heart can be monitored by placing electrodes on the body through a process known as electrocardiography. As the signal travels, tracings are recorded on an ECG monitor or printed out on ECG paper. A description of an ECG is displayed in Figure 3.3. The vertical axis denotes voltage or the charge in the heart cells; the horizontal axis denotes time. The specific ECG waves recorded vary depending on the direction from which the heart is looked at. The location electrodes placed on the body enable us to look at electrical activity from different angles known as leads. ECG instruments that record between one and twelve leads are currently available for use in a variety of settings. The number of leads does not necessarily match the number of electrodes. For example, in a 12 lead ECG, only ten electrodes are typically used. The ten electrodes are arranged on the body in a specific way that allow the heart to be looked at from twelve angles. Lead II typically records the largest waves, so it is often the only lead monitored to identify basic electrical abnormalities, or arrhythmias. Diagnosing heart attacks, structural problems in the heart, and complex electrical abnormalities often requires information available from a 12 lead ECG (Becker, 2006).

The electrical signal in a healthy heart produces a characteristic ECG tracing or wave pattern (see Figure 3.3). Therefore, a trained practitioner can identify abnormalities by

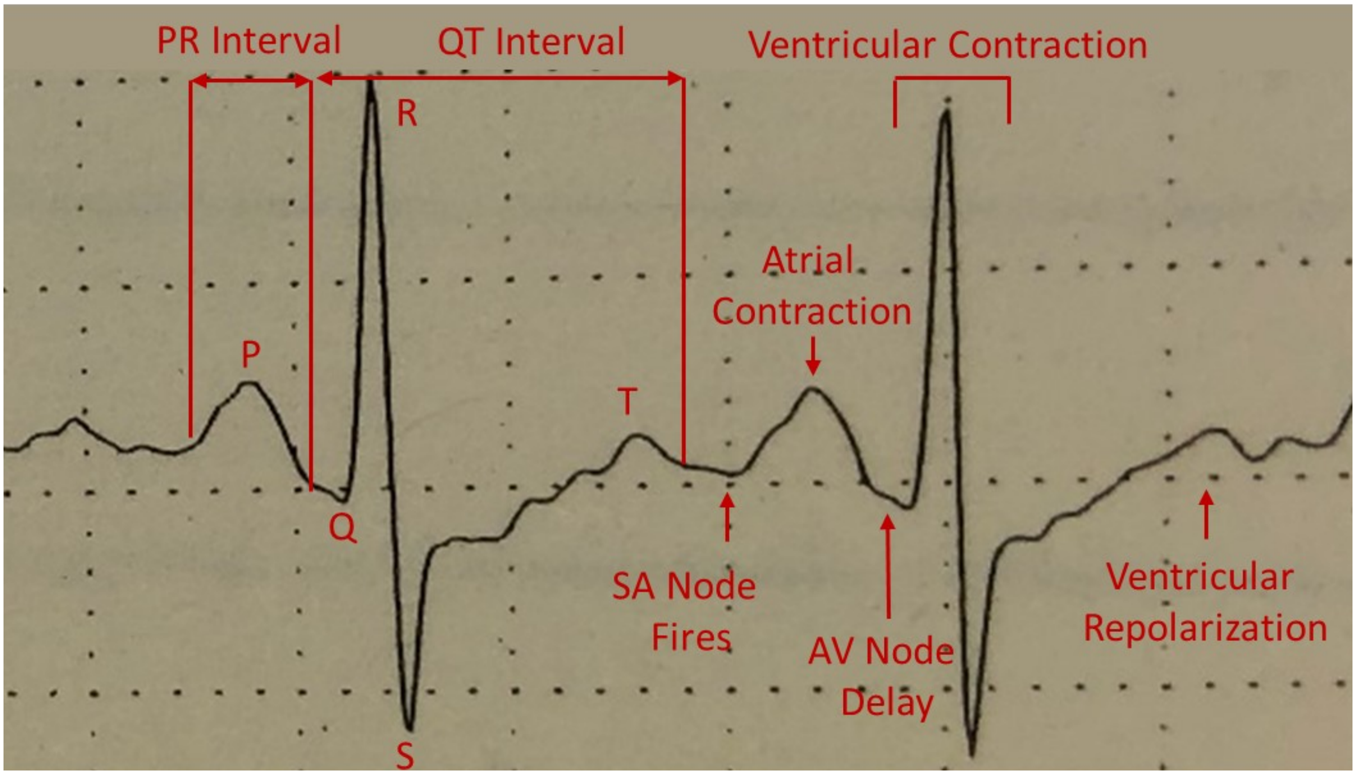


FIGURE 3.3. EXAMPLE EKG AND PQRST COMPLEX WITH PHYSIOLOGICAL PROCESS LABELS.

monitoring an ECG recording. The waves observed on an ECG tracing correspond to specific events in the cardiac cycle. The first wave is referred to as the P-wave, which represents depolarization of the atria. The second series of waves, known as the QRS complex, represent depolarization of the ventricles and the T wave represents ventricular repolarization. The presence, size, shape, and direction of each wave (and the segments between waves) depend on which angle of the heart, or lead, is being viewed and on whether a normal or abnormal rhythm is being observed.

ARRHYTHMIA

Arrhythmias often have tell-tale alterations in the waves that are characteristic of specific arrhythmia types (Becker, 2006). Table 3.1 lists basic arrhythmia types with descriptions, signs and symptoms, and risk factors.

Because sudden cardiac events account for such a large percentage of LODDs, firefighters should learn the signs and symptoms so they can recognize them and respond appropriately. In all incidences of a sudden cardiac event, the best response is a quick response. Cardiopulmonary resuscitation (CPR) and treatment with a defibrillator can improve chances of survival. Three-lead Holter ECG monitors enable monitoring for 24 hours or longer and have been routinely used for the diagnosis of arrhythmias that occur intermittently. When identifying basic arrhythmias, 3 lead ECG has been shown to be as effective as 12 lead ECG (Antonicelli et al., 2012; Kristensen et al., 2016). However, the vast majority of accuracy testing of ECG devices has taken place in clinical settings, where movement artifact is limited.

ISCHEMIA DETECTION

Myocardial ischemia is another condition that can be detected by an ECG. Signs and symptoms of ischemia include chest pressure or pain (especially on the left side of the body), neck or jaw pain, shoulder or arm pain, fast heartbeat, shortness of breath during physical activity, nausea and vomiting, sweating, and fatigue (Mayo Clinic Staff, 2018). Firefighters should be alert to these classical signs and symptoms, as well as more vague complaints of "not feeling right." Alterations in the ST-segment are indicative of myocardial ischemia (heart attack). Recent preliminary work has demonstrated that a smartphone app ECG may be useful in detecting (but not predicting) heart attacks and has good agreement with identification from a 12-lead ECG (Muhlestein et al., 2015).

NOVEL ECG TECHNOLOGIES

Recently, ECG recorders that are more compact than traditional 3 lead Holter monitors have been created for mobile monitoring. Examples include single lead iPhone monitors and the single lead Zio Patch (Walsh, Topol, & Steinhubl, 2014). The Zio Patch is a simple adhesive patch that is the placed on the patient's chest. The patch continuously monitors for up to 14 days, and patients can manually activate a trigger if they experience symptoms. After monitoring, data is assessed by the manufacturers arrhythmia detection algorithm. In a clinical study, the use of the Zio Patch resulted in the diagnosis of almost as many arrhythmias as a traditional Holter monitor within 24 hours (Barrett, 2014). The fact that the Zio Patch did not perform as well as traditional monitors may be because the patch relies on only one lead; looking at the heart from different angles, or leads, can provide more information about the electrical activity of the heart (Walsh et al., 2014). In fact, interpretations of single-lead portable devices have been shown to disagree with rhythm interpretations from 3 lead hospital monitors (Mehta et al., 2015). Though patch devices enable monitoring of the ambulatory patient, further studies are needed to determine if these devices can effectively remain on firefighters and record data during live fire situations. An important consideration for this application is that these devices do not transmit ECG data in real time; rather, data is acquired at the end of the monitoring period.

Even more recent technological advancements have resulted in ECG recorders, such as the SEEQ Mobile Cardiac Telemetry (MCT) System, that enable real-time transmission of ECG data. Like the Zio Patch, the SEEQ MCT is an adhesive patch that enables continuous monitoring (Fung et al., 2015). The ECG data is transmitted by a small wireless transmitter to a diagnostic testing facility where the data is reviewed by certified technicians and overseen by a physician. A computer algorithm alerts the technicians if an arrhythmia is detected. The device has not yet been studied extensively for its accuracy in detecting arrhythmias compared to traditional hospital monitors. The device also has not been shown to promote the rapid, time-sensitive treatment of individuals in acute danger from an arrhythmia.

TABLE 3.1. BASIC ARRHYTHMIA TYPES.			
Arrhythmia	**Description**	**Signs/Symptoms**	**Risk Factors**
Ventricular Tachycardia	SA node no longer controls the beating of ventricles leading to increased HR. Rapid heartbeat (greater than 100 beats per minute) originating in ventricles with at least 3 irregular beats in a row. V-tach can be fatal.	Sensation of “skipping beats”, SOB, dizziness, syncope. May be asymptomatic.	Acute coronary ischemia, myocardial scar tissue (from previous MI, heart disease heart surgery), congenital diseases, electrolyte imbalances, hypoxia, drug/alcohol use (Koplan & Stevenson, 2009).
Ventricular Fibrillation	Uncontrolled, irregular heartbeat. This arrhythmia is a medical emergency.	Pulseless, apneic, unconscious.	HX of heart disease, HX of MI, atrial fibrillation, family history of sudden death (Bardai et al., 2014; Glinge et al. 2016; Surawicz, 1985).
Supraventricular tachycardia/ paroxysmal supraventricular tachycardia	SVT refers to a range of conditions characterized by a rapid heartbeat that originates above the ventricles. Paroxysmal refers to episodes of SVT that occur from time to time . Can result in myocardial ischemia or cardiac failure for individuals with a preexisting condition.	Palpitations, pounding in the head/neck, chest discomfort, dyspnea, anxiety, lightheadedness, syncope.	Episodes can be triggered by caffeine/alcohol intake, stress, physical exertion, and fatigue (Hals & McCoy, 2015; Medi & Freedman, 2009).
Atrial Fibrillation	A quivering, irregular heartbeat that originates in the atria. Can increase risk of cardiac emboli, congestive heart failure, and ischemic stroke.	Dyspnea, chest pain, dizziness, fatigue, palpitations, may be asymptomatic.	Older age, male sex, smoking, obesity, hypertension, diabetes, myocardial infarction, heart failure, valvular heart disease, cardiac surgery, hyperthyroidism, heavy alcohol use, frequent vigorous exercise, familial A-Fib (Heidt et al., 2016; Magnani et al., 2011).

TESTING ECG TECHNOLOGIES

Over the course of the SMARTER project, two novel single-lead ECG technologies (Zephyr Bioharness and Omnisense Software, and AliveCor Kardiaband and App) were examined to determine if they would potentially be suitable for monitoring firefighters.

Zephyr Bioharness and Omnisense Software

Zephyr Technology Systems (owned by Medtronic) produces a patch and harness (Figure 3.4) that are capable of recording a range of vital signs and physiological data. The devices enable recordings of single lead ECGs, which can be downloaded for analysis. The ECGs cannot be monitored in real time and the system currently does not employ an arrhythmia detection algorithm; however, it is the only device that has been incorporated into a system made specifically for firefighters (the Wearable Advanced Sensor Platform [WASP] by Globe).

FIGURE 3.4. ZEPHYR BIOHARNESS.

ECG data from this device is not visible in the Zephyr Omnilivedata viewer. This device is not currently suitable for ECG monitoring in the fire service because it does not provide a real-time ECG, requires significant data processing, and does not include arrhythmia detection software.

FIGURE 3.5. ALIVECOR KARDIABAND & APP.

AliveCor Apple Watch Band and App

While this technology has utility during research, it is not currently suitable for real-time firefighting monitoring. However, newer ECG technologies now incorporate smartphone applications (apps) to provide live single-lead ECG monitoring. Researchers have shown that apps that enable recording of a single ECG lead in real time, such as AliveCor, can be effectively used to detect atrial fibrillation and heart attacks when compared to standard 12 lead ECGs (Muhlestein et al., 2015; Chung & Guise, 2015; Lau et al., 2013).

The Alivcor Kardiaband (shown in Figure 3.5) was the newest device the SMARTER team tested. This system was most developed among the devices we examined and included both real-time ECG and arrhythmia detection software. Before the device can be used regularly, a resting baseline must be recorded and sent to a cardiologist for review, a process that can take up to 24 hours. Currently, the application can detect atrial fibrillation with 94% accuracy (Lau et al., 2013). Although the product was not developed for the fire service and is not feasible for use during firefighting activity, it does suggest that technological advancement may someday make ECG monitoring during firefighting a reasonable and feasible option.

FUTURE STEPS

Given the power of ECG technology to detect potentially life threatening arrhythmias, it would be ideal to monitor ECGs on firefighters during live fire situations. To effectively use the technology in this capacity would require that: 1) ECG electrodes be worn during firefighting activities; 2) ECGs be recorded without artifact; 3) ECG readings be transmitted in real time to Incident Command/EMS/analysis centers; 4) arrhythmia be automatically detected; and 5) criteria established for the removing firefighters from the scene immediately upon arrhythmia detection, and provided with follow up medical care. It is important not only to be able to record ECGs, but also to immediately transmit the data to appropriate facilities for immediate analysis. It is also essential that arrhythmias or warnings be detected automatically; it is not feasible to have a trained health care professional constantly monitor the ECGs firefighters. This need for automatic arrhythmia detection presents the greatest challenge to live ECG monitoring on the fireground. Given the subtle differences between heart rhythms, computer algorithms often generate a high proportion of false alarms (Sanquist, 2015). This is problematic because the incident commander does not want to remove firefighters from a fire if they are not truly at risk of suffering a sudden cardiac event.

It should also be noted here that the severity of arrhythmias varies greatly. For example, while individuals with V-Fib are always in cardiac arrest, individuals can occasionally have PVCs while presenting no symptoms or being in immediate danger. Clinical evaluation and additional information (e.g. patient history), which may not be available during live firefighting activity, is typically required for effective ECG interpretation (Sanquist, 2015). Therefore, until the technology of analyzing ECGs on the fireground has improved, it would not be advisable to remove a firefighter from the scene based solely on the detection of an arrhythmia.

Lastly, without clear criteria for determining when to remove firefighters from a situation for medical care, identifying arrhythmias will have no value for preventing SCD.

Because of the advancements in technology needed to implement single-lead ECG monitoring on the fireground, responders should instead focus on prevention of sudden cardiac event. Steps firefighters can take to reduce their risk are shown in Figure 3.6.

FIGURE 3.6. PREVENTING SUDDEN CARDIAC EVENTS.

1. Get an appropriate annual medical exam (consistent with NFPA 1582 guidelines) from a physician who understand the demands of firefighting.
2. Know your numbers (cholesterol, blood pressure, and other health metrics) and follow up on findings.
3. Aggressively manage risk factors.
   - *Manage blood pressure (see Table 3.2).*
   - *Control cholesterol (HDL serum > 60 mg/dL).*
   - *Reduce blood sugar (healthy range: fasting blood glucose ≤ 100 mg/dL).*
   - *Maintain a healthy diet (eat a wide variety of vegetables and limit consumption of processed foods; shop on the perimeter of the grocery store).*
   - *Do not use any tobacco products of any kind .*
   - *Lose excess weight.*
   - *Get active (30 minutes or more daily).*
4. Ensure you are able to work at the firefighter readiness level of 12 METs by implementing a daily exercise regiment.
   - *Exercise throughout the week.*
   - *Remain physically active throughout the day by limiting sedentary time (time spent sitting or lying down).*

RECOMMENDATIONS

1. Never ignore symptoms.
2. Take steps toward preventing sudden cardiac events.
3. Know the signs and symptoms of a heart attack.
4. Look out for yourself and crew members following periods of exertion and high-stress.
5. Receive a full medical evaluation (including a 12 lead ECG/stress test/echocardiogram) before returning to duty if you have had a cardiac procedure.
6. ECG monitoring technology is improving; consider using it during firefighting when it is both feasible to implement, and able to provide meaningful and actionable information.

RESOURCES

REPORTS

- **National Institute of Occupational Safety and Health Website**
    - "Preventing Firefighter Fatalities Due to Heart Attacks and Other Sudden Cardiovascular Events" (https://bit.ly/2S7daMr)

ARTICLES

- **Mayoclinic Website**
    - "Myocardial Ischemia" (https://mayocl.in/2ECuPbp)
- **American Heart Association Website**
    - "About Arrhythmia" (https://bit.ly/2LPfPcy)
    - "High Blood Pressure or Hypertension" (https://bit.ly/1fFTYsN)

OTHER

- **IAFF Wellness Fitness Initiative Resource** (https://bit.ly/2xLoi84)
- **Heart Healthy Firefighter Website** (https://bit.ly/2BLMIOA)

PARTICULATE MONITORING

PARTICULATE MATTER

Particulate matter is made up of small particles found in the air that come from a variety of sources, including dirt, diesel engines, and fires (Baxter et al., 2014; United States Environmental Protection Agency, n.d.; Occupational Safety and Health Administration, 2013; Robinson et al., 2008). The composition of particulate matter on the fireground varies dramatically, depending on conditions such as fuel, temperature, ventilation, and extinguishing agents (Baxter et al., 2014; Queensland Fire and Rescue, 2011). Additional research is necessary to understand how the overwhelming amount of chemical compounds on the fireground affect those exposed to it.

Firefighters encounter particulate matter that is composed of hundreds of different chemicals. Typically particulates range from 2.5μm (micrometer – one millionth of a meter) to 0.1 μm in diameter and are grouped into broad categories including ionic, inorganic, or organic compounds (Baxter et al., 2014; Robinson et al., 2008). As shown in Figure 4.1, particulate matter is dangerous for multiple reasons: exposure increases risk for cancer, respiratory complications, and cardiovascular diseases and events (Baxter et al., 2010; Daniels et al., 2015; Demers et al., 1992; Dockery, 2001; Simkhovich, Kleinman, & Kloner, 2008).

This chapter outlines exposure to particulate matter in various fire settings, potential adverse health effects faced by firefighters, and work the SMARTER team has been doing to address this vulnerability.

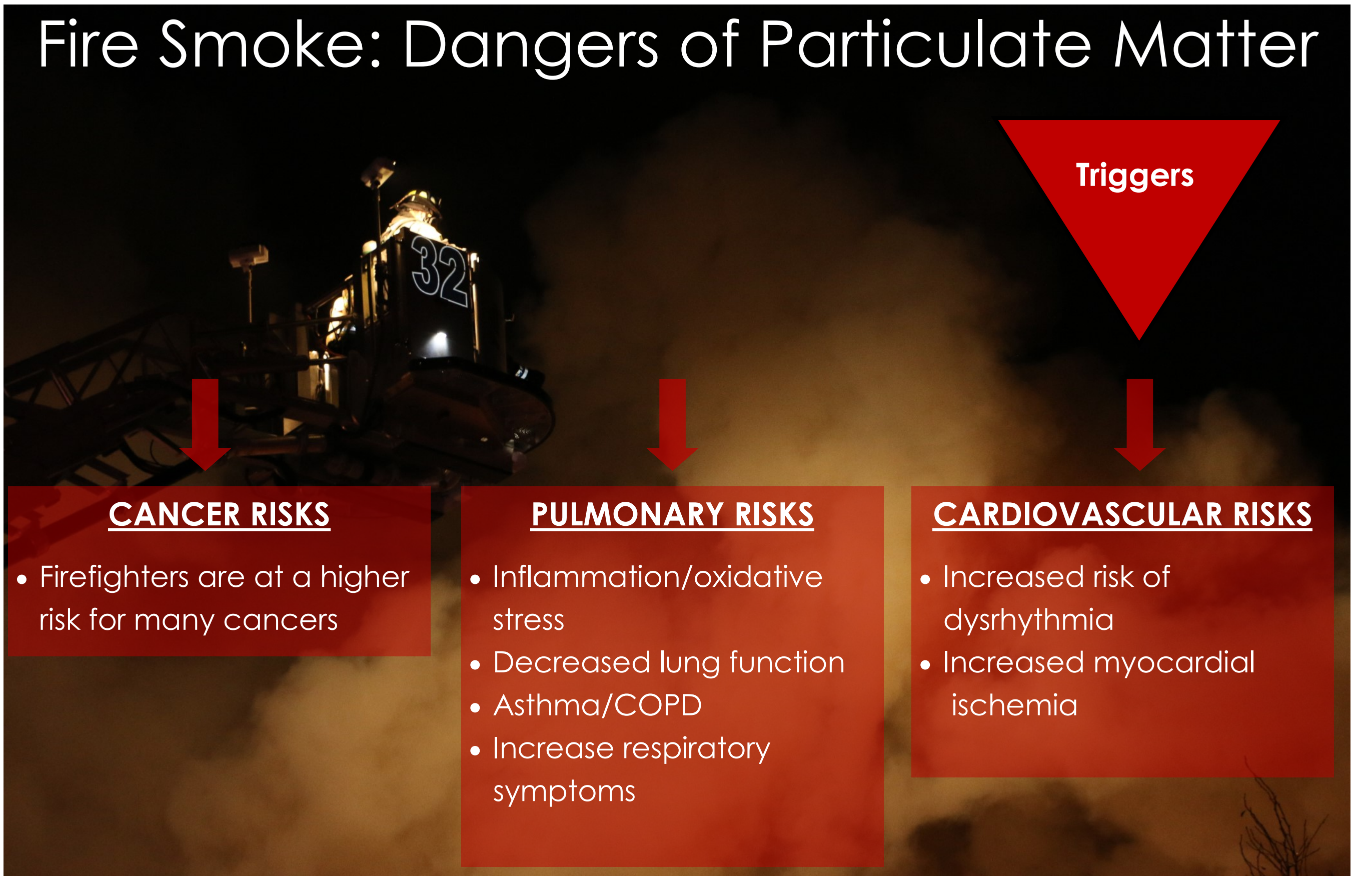


FIGURE 4.1. DANGERS OF PARTICULATE MATTER (BONANNO, 2008; TURNER ET AL., 2011).

EXPOSURE AND ADVERSE HEALTH EFFECTS

Researchers have investigated particulate matter, routes of exposure, and health consequences of exposure for firefighters (Evans and Fent, 2015; Forchhammer et al., 2012; Leonard et al., 2007; Lonnermark & Blomqvist, 2006; Queensland Fire and Rescue, 2011; Robinson et al., 2008; Turner et al., 2011). Chemical components of particulate matter occur in three general categories, byproducts of building/residential, wildland (trees/grass/brush), and vehicle fires.

Particulate matter is a umbrella term that encompasses both solid and liquid components that are either released from sources of pollution or formed in the atmosphere when chemicals in the air react with pollutants. Solid particles range from those that are visible only under a microscope to those that humans can see (Environmental Protection Agency, n.d.). While larger particles often receive attention because they are most visible, the smallest particulates are most dangerous; particles smaller than 10μm are easily inhaled and can get deep into lungs and bloodstream. Firefighting exposure to particulate matter and particles smaller than 2.5 μm also results in diminished visibility on-sudden cardiac events (Environmental Protection Agency, n.d.).

Exposure to particulate matter occurs by inhalation, ingestion, or dermal absorption.

Firefighters must be vigilant about avoiding these chemicals both when responding to fire calls and following incidents.

Specific risks of exposure to products of combustion from different fire sources are described in the following subsections. Chemical components of these fires are also listed in Table 4.1.

Building/Residential Fires

Firefighters may be exposed to arsenic, asbestos, benzene, carbon monoxide, hydrogen cyanide, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and other compounds when fighting structure fires (Demers et al., 1992; Underwriters Laboratories Inc., 2010; Queensland Fire and Rescue, 2011; Laitinen et al., 1992; University of Victoria, 2015). Limiting exposure to these compounds is important because arsenic, asbestos, benzene, formaldehyde, and PAHs are carcinogenic. Carbon monoxide and hydrogen cyanide are asphyxiants that cause respiratory complications by interfering with the availability of oxygen in the air (Centers for Disease Control and Prevention, 2013; Centers for Disease Control and Prevention, 2017; Demers et al., 1992; Underwriters Laboratories Inc., 2010). Firefighters

TABLE 4.1. COMMON CHEMICAL COMPONENTS OF FIRE.
Building/Residential Fires
Arsenic
Asbestos
Benzene
Carbon Monoxide
Hydrogen Cyanide
Formaldehyde
Polycyclic Aromatic Compounds (PAHs)
Wildland Fires
Benzene
Formaldehyde
PAHs
Acetaldehyde
Acrolein
Methyl Chloride
Toluene
Polycyclic Aromatic Compounds (PAHs)
Vehicle Fires
Hydrogen Chloride
Sulfur Dioxide
Benzene
Polycyclic Aromatic Compounds (PAHs)
Polychlorinated Dibenzo-p-dioxins (PCDDs)
Polychlorinated Dibenzofurans

should be especially mindful of periods following fire suppression; Baxter et al. (2014) found that firefighters may have the highest exposure to particulate matter during overhaul events. Wearing SCBA during this overhaul period is one of the most important ways to reduce exposure to toxic compounds and mitigate cardiovascular and pulmonary strain.

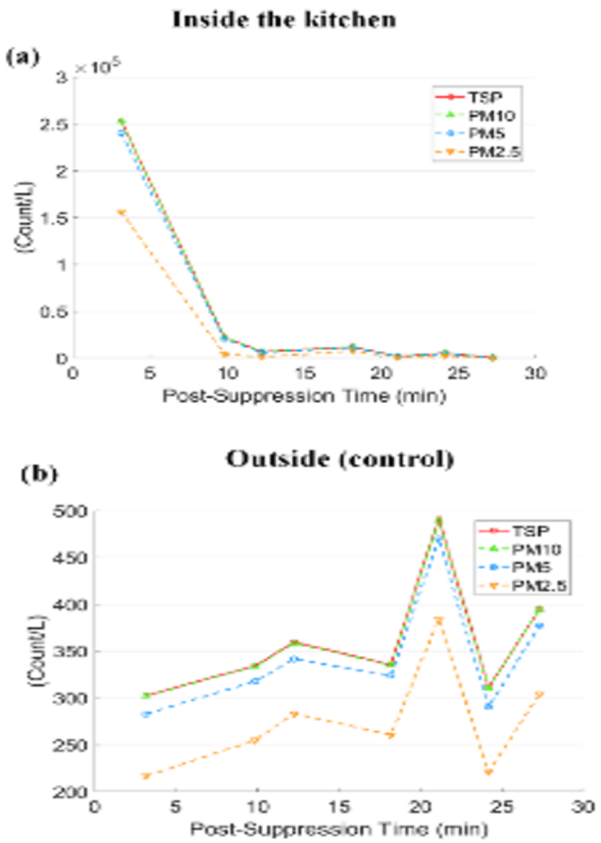


FIGURE 4.2 BURN BUILDING ON SITE AT THE NEW YORK FIRE TRAINING ACADEMY.

Residential Burn Experiments

In November 2018, we measured particulate matter (PM) using the c-Air in Dayton, Ohio at the planned structural burns being conducted by the UL Firefighter Safety Research Institute that included a burn of the kitchen, which featured basic appliances and typical kitchen furnishings. Two identical c-Air platforms were used. These were positioned at locations that were identified in consultation with firefighters in charge, ensuring safety of the equipment and participants.

Once the "kitchen fire" was put out, the firefighters took one of the c-Air devices and placed it inside of the building on the window frame, while the other c-Air unit was placed just outside of the building at a distance of approximately 20 meters. During the experiments, when saturated images were remotely detected, firefighters brought the c-Air unit positioned inside back to the researchers, so its cartridge could be expediently replaced and the unit repositioned inside of the building in its original monitoring place. Figure 4.2 shows a plot of particulate matter counts for the device inside of the kitchen (Fig. 4.2a) and the control device positioned outside (Fig. 4.2b). Figure 4.2a shows that the counts of particulate matter inside of the building return to the original levels after about 10-12 minutes post-suppression. At the same time, from about 12 minutes post-suppression the c-Air unit located outside begins to register increasing particle counts, reaching a maximum at approximately minute 21 post-suppression.

Wildland Fires

Like building fires, smoke from wildland fires contains benzene, formaldehyde, and PAHs (University of Victoria, 2015). Although less than 5% of wildland fire smoke is comprised of PAHs, this amount is still concerning because of its carcinogenic nature (Robinson et al., 2008). Wildland fires also contain acetaldehyde, acrolein, methyl chloride, toluene, and various other toxic compounds (University of Victoria, 2015). Furthermore, ultrafine particles in the wildland fire smoke contain carbon radicals and other precursors that lead to free radical production. Free radicals are associated with numerous health complications including general inflammation, cancers, and cardiovascular diseases such as atherosclerosis (Leonard et al., 2007). Firefighters are particularly susceptible to the negative health effects of particulate matter when fighting wildland fires because SCBA is typically not worn in these cases, and because heavy work (and heavy breathing) may occur over many hours.

Vehicle Fires

Because vehicle fires occur in open areas and are usually suppressed in minutes, firefighters may underestimate the risks of exposure to harmful chemicals during this type of fire. Unfortunately, many agencies do not require their firefighters to wear SCBA when

fighting vehicle fires, which exposes them to a number of harmful substances (Fent el al., 2012). While suppressing vehicle fires, firefighters' greatest risk for exposure to particulate matter occurs during overhaul and when crews position themselves downwind of a vehicle (Evans and Fent, 2015). These fires produce toxic compounds including hydrogen chloride, sulfur dioxide, benzene, PAHs, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) (Lonnermark & Blomqvist, 2006; University of Victoria, 2015).

Post-Incident

Contact with particulate matter during suppression activities is only one of many opportunities for exposure. While risk is high during fire calls, the hazards associated with particulate matter persist long after fire suppression. Turnout gear that has been exposed to a fire becomes contaminated with toxic byproducts of combustion, and if not decontaminated, can result in secondary exposure through absorption and ingestion.

In addition to particulate matter, firefighters should be aware of the dangers of gases that are released from fires. Even after PPE is removed from the fireground it continues to off-gas harmful chemicals. Following exposure to a controlled burn, Fent et al. (2012) found that in the majority of samples, firefighters' PPE released up to 14 types of volatile organic compounds. These researchers also collected firefighters' breath 4-14 minutes post-exposure and analyzed samples for several VOCs (benzene, toluene, ethylbenzene, xylene, and styrene); ultimately they observed a greater than two-fold increase in the concentrations of these compounds (Fent et al., 2012).

Off-gassing from bunker gear is a major concern when considering the frequency of periods that firefighters are exposed to contaminated PPE without air protection (during doffing, tool/hose clean-up, and when riding back to the station).

Fires are not the only source of exposure to particulate matter. Diesel particulate matter poses a threat to firefighters health any time there is contact with vehicle exhaust from fire apparatus.

AVOIDING EXPOSURE

Firefighters may limit exposure via inhalation by avoiding smoke whenever possible and wearing a Self-Contained Breathing Apparatus (SCBA). As mentioned in the previous section, it is especially important that those who respond to brush and vehicle fires are conscious about the dangers of particulate matter because SCBAs is typically not worn in these situations. Wearing undergloves (to prevent skin contamination) and showering as soon as possible (to avoid absorption of particulates through the skin) can also help prevent the adverse health effects associated with exposure (Queensland Fire and Rescue, 2011; Laitinen et al., 2010; University of Victoria, 2015). Post-incident, firefighters should also avoid eating before cleaning skin (to avoid ingestion of particulates) and limit time in enclosed areas with contaminated gear (to avoid inhalation of particulates).

DEVELOPING A LOW-COST, PORTABLE PARTICULATE MONITOR

As part of SMARTER, our partners at the lab of Dr. Aydogon Ozcan at UCLA (https://bit.ly/2NOKzwX) have been working to develop a low-cost, portable monitor called the c-Air (Figure 4.3) that will be able to measure particulate matter on the fireground and in overhaul situations. Though the monitor is still in development, a current prototype has been evaluated in field settings.

The C-Air Device

The c-Air device (shown in Figure 4.3) includes a lightweight sensor that integrates computational imaging and mobile-sensing techniques to reconstruct images of particles. The c-Air device also permits on-the-ground and drone-based 3D mapping of

FIGURE 4.3. THE C-AIR PROTOTYPE.

TABLE 4.2 PARTICULATE MONITOR TESTING: BURN TRIAL DESCRIPTIONS.

Trial	Fuel	Fuel Consumption	Duration (min)	Ventilation
1	2 Pallets, hay	Materials fully consumed	5	Natural horizontal low-vent condition via left side window
2	2 Pallets, hay	Materials fully consumed prior to ventilation	5	Natural horizontal medium-vent condition via right side window
3	3 Pallets, hay	A full pallet and all hay fully consumed and 2 pallets partially consumed prior to ventilation	5	Natural horizontal low-vent condition via left side window (covered with plywood)
4	3 Pallets, hay	A full pallet and all hay fully consumed and 2 pallets partially consumed prior to ventilation	5	Natural horizontal low-vent condition via left side window (covered with plywood)
5	Brown Chair	Partially consumed	5	Low-vent condition via back door
6	Chair & Ottoman	Fully consumed	4	Low-vent condition via back door
7	Sofa	Partially consumed	5	Low-vent condition via back door

emissions from pollution sources such forest fires. This device improves on previous technologies in portability, cost, and speed of measurement. The c-Air takes advantage of technological innovations in cameras (by incorporating a camera similar to that of common smart phones) to size and characterize particulates with results that are comparable to gold-standard devices. The device can size particles with 93% accuracy at a fraction of the size and cost of other devices. The Ozcan team estimates that the final monitor will cost less than $100.

Hopefully, the c-Air, in combination with gas meters, will provide useful information on air quality for firefighters. This device may be utilized for interior or exterior environments.

Testing at Wildland Fire Sites

The Sand Fire

In July of 2016, measurements were taken of the Sand Fire (burning in Angeles National Forest about 50 miles from UCLA) using the c-Air at both UCLA and at several sites closer to the fire location. Results indicated that small particles were able to travel long distances as they were found even in samples taken at the location farthest from the fire.

La Tuna Fire

In 2017, measurements were taken of the La Tuna Fire (burning in the Verdugo Mountains in Los Angeles) at three locations that varied in distance from the source. The team found a significantly higher amount of smaller par-

ticulates (< 2 microns) at .6 miles from the source. They also found that particles closer to the fire were elongated.

Overall, the c-Air showed promising results for detecting and tracking particulate matter across long distances during wildland fires. Given the unique shape, size, and concentration of particles at sites closest to the fires, there may be future uses for the c-Air as a tool to identify points of origin of the fire.

Testing at a Live Burn Facility

The SMARTER team conducted seven live burn trails at the Saratoga County Fire Training Center (shown in Figure 4.4). The c-Air was deployed in each case to assess air contamination levels on the fireground and determine the applicability of the device to structural fires and overhaul.

The on-site burn buildings were constructed of modular shipping containers (20 ft x 8 ft x 8 ft each). The containers were designed with steel plates to reduce damage from thermal stress and temperature changes as well as steel doors and windows. Four burns were conducted using 100 to 120 pounds of class A material (pallets and straw). Overstuffed materials containing plywood composite, polyurethane foam, and synthetic upholstery were used for the three remaining burns. Burns lasted about five minutes.

Table 4.2 lists burn times, material, and ventilation protocol.

Training personnel from New York State Office of Fire Prevention and Control ignited and suppressed all fires. Firefighters from Sa-

FIGURE 4.4. BURN BUILDING ON SITE AT THE SARATOGA COUNTY FIRE TRAINING CENTER.

ratoga Springs Fire Department, Malta Ridge Volunteer Fire Company, West Crescent Fire Department, and Rock City Falls Fire Department provided additional testing support.

The c-Air was deployed following fire suppression once temperature had fallen to 100°F because the current prototype could not be placed in the room at a higher temperature. A Seek Thermal Imaging Camera was used to obtain room and instrument temperatures throughout the trials (Figure 4.5). The live burn testing provided valuable insight into both air contamination on the fireground and future improvements that can be integrated into the c-Air. The device had trouble assessing contamination levels immediately post-suppression because of the high concentration of particulates, thus post-suppression measurements were considered out of range. Within the first three minutes post-suppression, samples consisted largely of elongated, smaller particles. The majority of particles captured were volatile and evaporated within the first half minute. Within 10 to 12 minutes post-suppression,

FIGURE 4.5. FIREFIGHTER USING THE SEEK THERMAL IMAGIING CAMERA (LEFT) IMAGE FROM SEEK CAMERA OF C-AIR AND COMMERCIAL PARTICULATE MONITOR IN BURN FACILITY (RIGHT).

concentrations of particulate matter in the ventilated burn room had returned to baseline levels.

NEXT STEPS

The research team is working to improve the current c-Air prototype by miniaturizing it, making it lighter, and refining its ability to sample on the fireground.

It is expected that the final device will be appropriate for use on the fire scene (interior and exterior operations, and near apparatus) and in fire stations. Though this device will help firefighters avoid major vulnerability, it is important to remember that particulate matter is only one of many dangerous compounds present in air on the fireground. Care should be taken in protecting firefighters from all potential contaminants in the air.

RECOMMENDATIONS

1. Protect against exposures.
   - Wear SCBA during all structural firefighting operations.
   - Wear SCBA during overhaul.
   - Consider donning SCBA in smoky conditions—even during exterior firefighting.
   - Wear SCBA when suppressing car fires.
2. Protect against dermal exposure.
   - Use on-scene decontamination.
   - Use wipes in the field.
   - Shower as soon as possible.
3. Avoid eating or using hands until they are clean to avoid accidental contamination.
4. Clean gear to avoid continuous exposure.
5. Do not transport contaminated gear in apparatus cabs or bring it into living quarters.
6. As technology advances, consider using air monitors to identify levels and types of particulate matter and gases.

RESOURCES

REPORTS

- **Illinois Fire Service Institute Website**
  - Cardiovascular & Chemical Exposure Risks in Modern Firefighting (Training Fires) (https://bit.ly/2JGXsnp)

ARTICLES

- **University of Victoria Online Resource**
  - "FIREFIGHTERS: Three reasons why using your SCBA makes sense" (https://bit.ly/2NVwKwq)
- **Centers for Disease Control and Prevention Website** (https://bit.ly/2G9LjpU)
  - "Contamination of firefighter personal protective equipment and skin and the effectiveness of decontamination procedures" (2017)
  - "Firefighter's perspective on flame retardants" (2015)
  - "Simulated smoke, real health effects" (2014)
  - "Assessing the risk to firefighters from chemical vapors and gases during vehicle fire suppression" (2011)
- **United States Environmental Protection Agency Website**
  - "Particulate matter (PM) basics" (https://bit.ly/2bcJrzB)

VIDEOS

- **First Responder Health and Safety Laboratory Website** (https://bit.ly/2xHa6gm)
  - "Research Study: Cardiovascular and Carcinogenic Risks in Modern Firefighting"

PHYSIOLOGICAL MONITORING

INTRODUCTION

Technology is becoming increasingly interwoven with daily life. As evidenced in the fire service, improvements to safety gear, SCBA, apparatus, and other equipment are reliant on automation and information technology. While many aspects of fire protection have embraced technological advancements, firefighter health initiatives have lagged behind. Wearable technology is one of the latest innovations that allows healthcare providers and users to collect information relatively easily and potentially within an actionable time period. As part of this project, the SMARTER team, deployed a physiological monitoring system (PSM) called the Wearable Advanced Sensor Platform (WASP) to determine the potential utility of these novel devices for the fire service.

ZEPHYR BIOHARNESS 3 SYSTEM WITH OMNISENSE SOFTWARE

The Wearable Advanced Sensor Platform (WASP) is a PSM comprised of a Globe® flame-resistant baselayer shirt and Zephyr™ Bioharness 3 technology (shown in Figure 5.1). The Zephyr Bioharness is a compact device that can capture real-time or recorded information for research and field or operational scenarios. Coupled with Omnisense software, the Bioharness allows users to track cardiac and thermal strain along with activity. It is important to note that technology advances rapidly and there are likely already differences in the technology that we are reporting on. This report describes what the SMARTER team did with the technology

FIGURE 5.1. GLOBE SHIRT AND ZEPHYR STRAP HARNESSES OF THE WASP SYSTEM.

that was available. Zephyr has already made significant improvements to their devices and programs; they now offer cloud-based storage, mobile applications, shorter download times, and enhanced possibilities for data viewing.

PARTICIPANTS: HANOVER PARK FIRE DEPARTMENT

To assess the applicability of the WASP system to emergency calls, training, and physical fitness routines, 54 firefighters of varying ranks from the Hanover Park (IL) Fire Department wore the system throughout their 24-work shift for a period of more than six months.

All ethical guidelines for human participant testing were followed. The study was approved by the Institutional Review Board of Skidmore College and funded by the Assistance to Firefighters Grant Program. Participants provided written informed consent along with medical histories (including physical activity and prescription or over-the-counter drug use) before data collection.

Department Description

The Village of Hanover Park Fire Department is a municipal organization located in the Chicago metro area. It is a Cook County community, but has about half of its landmass lying within DuPage County. Cook and DuPage are the two most populous counties in Illinois and serve as economic engines for the entire state. The village has an overall landmass of 7.5 square miles and a population of nearly 40,000 residents. It plays a major role in the area transportation system with roadways providing four-way directional access to the village and the expressway system surrounding and traversing the metropolitan area. Its location in the Chicagoland area places it at the terminal end of the I-390 expressway and in the flight path of O'Hare International Airport. Daily traffic levels exceed 200,000 vehicles moving through the village limits. In addition, Hanover Park is crossed by two rail lines, including the Metra passenger rail system transporting more than 1,500 passengers daily. Three industrial parks are tucked into the tight confines of the village and are home to several national manufacturing firms.

The department operates with a complement of 35 full-time and 19 part-time firefighters and officers. These personnel are supplemented by a full-time administrative assistant, two volunteer fire chaplains, and 15 Fire Corps volunteers. In addition, the department is also responsible for the village's Inspectional Services Division that manages the entire building permit process from project conception through issuance of a final certificate of occupancy. Structural, mechanical, and electrical plan reviews and inspections are performed by two staff architects, and several inspectors and permit coordinators.

Call responses range between 3,600 – 4,000

emergency calls annually; approximately 70% are EMS. Services are provided using a staffed paramedic equipped Rescue/ Engine (Squad), a staffed Paramedic Equipped Engine Company, two Mobile Intensive Care Ambulances, one of which is a jump company to a Tower Ladder and a Battalion Commander, along with myriad other ancillary response equipment.

All personnel are trained at a minimum to the level of Basic Operations Firefighter as recognized by the Illinois State Fire Marshal's Office and the International Fire Accreditation Council, as well as Illinois EMT-Basic. All full-time staff are required to hold current

certification as Advanced Operations Firefighters and possess an Illinois Paramedic license. The department actively participates and responds as part of MABAS (Mutual Aid Box Alarm System) Division 12 and staffs a Haz Mat Squad of15 technicians to serve as the rapid response squad to all departments/communities throughout the division. The squad/trailer combination provides "Level A" Haz Mat equipment as well as specialized monitors and decontamination systems. The population of the total area served by MABAS Division 12 exceeds 900,000.

The department's EMS Division has responsibility for management of the Fire Corps program. Fire Corps is a component of the Village's Citizen Corps Council and functions as an operational team within the Fire Department. Fire Corps members are volunteers tasked with the responsibility of providing on-scene emergency rehab for firefighters. The team serves Hanover Park Fire Department and is an active part of the MABAS response system. Additionally, Fire Corps assists with public fire and life safety education, community events, fireground/ emergency incident support, and emergency management activities.

Firefighters work a traditional 24/48-hour schedule with shifts beginning at 0700 each morning and ending at 0700 the following day.

WASP System Workflow

Steps	Supplies	Personnel	
Technology configuration & assignment	Computer, software, and WASP system with accessories	Research team and fire department leadership	Field Use
Data collection (firefighters wear technology)	Computer, soft-ware, WASP system, and if recording live, transmission device	Participants, research team, and fire service personnel	
Data extraction	Computer, software, WASP system, and accessories	Research team and fire service leadership	Research Use
Technology reconfiguration & call log processing	Computer, software, call logs, and WASP system with accessories	Research team and fire service leadership	
Data compilation, cleaning, & analyzing	Computer and software	Research team	
Dissemination of results	Computer, software, and printing materials	Research team	

FIGURE 5.2. WASP SYSTEM WORKFLOW.

WASP SYSTEM WORKFLOW

A variety of equipment and personnel are necessary to deploy the WASP system in both field work and research. There are six fundamental steps that occurred in our team's process between receiving the system and understanding the potential usability of this technology. These steps included:

1. Technology configuration & assignment
2. Data collection
3. Data extraction
4. Technology reconfiguration & processing
5. Data compilation, cleaning, & analysis
6. Dissemination of results

The WASP workflow (Figure 5.2) outlines the steps taken in using the WASP system for research and field work. The only processes required for field use are technology configuration and assignment and data collection. Use of the system for research is dependent on all steps.

Technology Configuration and Assignment

The Zephyr BioModule Device can be worn with either a Zephyr strap or a shirt (Figure 5.1). Users must be fitted to ensure a tight fit that will provide quality data. Individuals' heights, weights, ages, and gender were recorded, then entered into the database to ensure accuracy. Configuring the Biomodule devices takes approximately one minute per participant.

Data Collection

One of the aims of this research was to determine the potential of 24 hour monitoring of firefighters. The SMARTER team sought to describe physiological stress during the work shift. To accomplish this, we firefighters wore the devise while on duty so that when they received an emergency call data could be collected during events.

Data Extraction

Extracting data from the Zephyr Biomodule devices required placing the Biomodule in a data transmission cradle. Devices were attached to a computer with Omnisense software by either research teams or fire department leadership; extraction ranged from 5 to 30 minutes per participant, depending on the volume of data collected.

Technology Reconfiguration and Processing

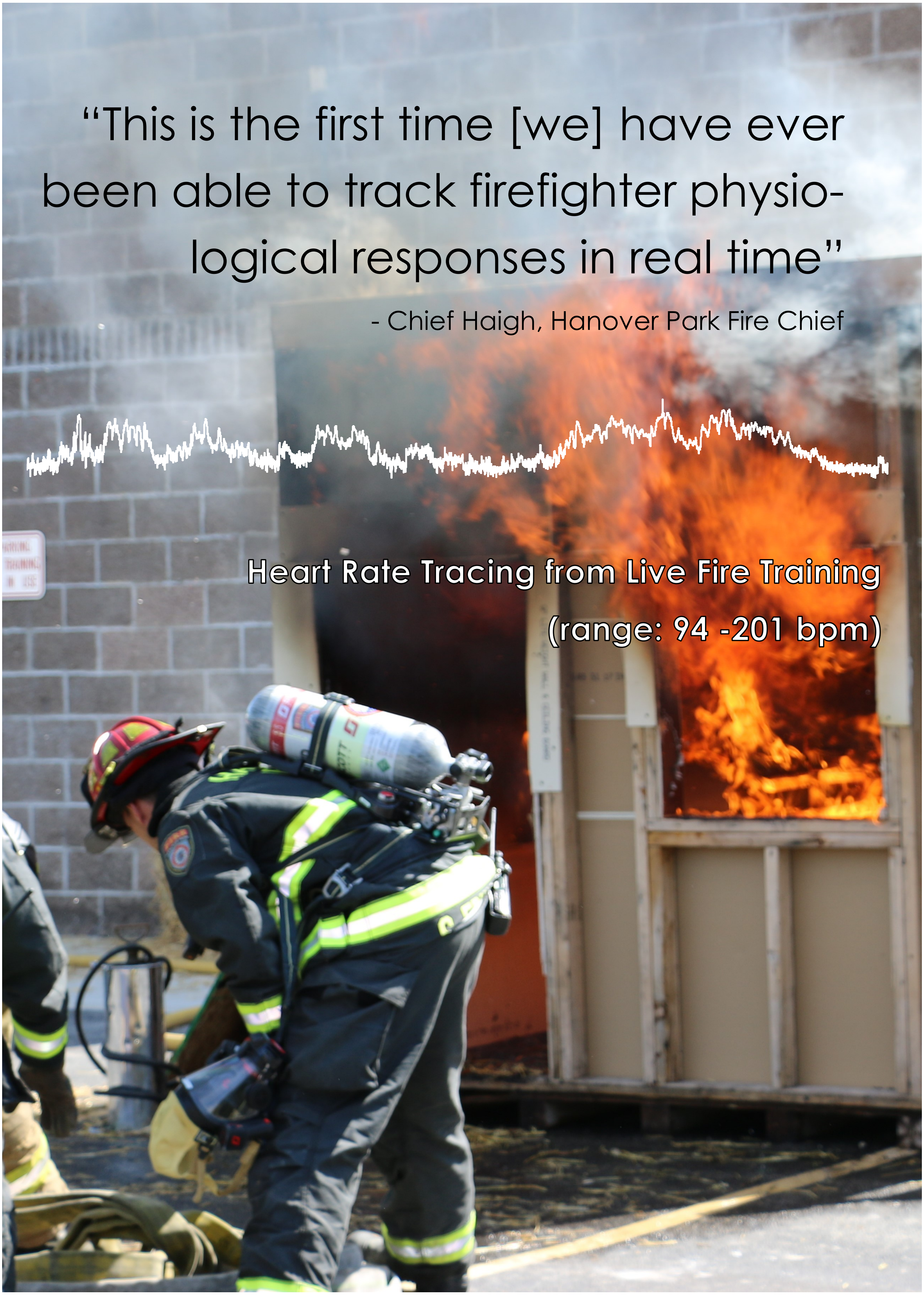
Once data was extracted from the Biomodule devices, researchers and/or fire department leaders reconfigured and recharged the devises for future use; this process took about 120 minutes. Call logs were also processed to match the physiological data with the activities that occurred during collection periods.

Data Compilation, Cleaning, and Analysis

Data processing and analysis was a time-consuming step in the WASP System workflow. Data was viewed, partitioned, and grouped using Omnisense software. While compiling and categorizing data for the SMARTER project, researchers used detailed descriptions of calls and training exercises to assess physiological strain of various activities. Data was exported from Omnisense to Microsoft Excel files and then to a statistical program for in-depth analysis.

“This is the first time [we] have ever been able to track firefighter physiological responses in real time”

- Chief Haigh, Hanover Park Fire Chief



RESEARCH

Live Fire Training

In May of 2016, the Hanover Park Fire Department conducted three days of live fire training using a four-story brick class A fire training facility operated by Addison Fire Protection District in Illinois. Zephyr Bioharness System was worn by all participating firefighters throughout the drills and the resulting data was transmitted to the research team. Only data from the first training was analyzed to a) assess the cardiovascular and thermal strain of training; b) compare physiological responses of firefighters to instructors; and c) determine the feasibility of the WASP for live fire training scenarios.

Participants

Overall, 29 firefighters and 6 instructors (35 total participants) took part in the first day of live fire drills. The average age, height, and weight of instructors were 36 years, 70 inches, and 211 pounds respectively, while firefighters averaged 35 years, 71 inches, and 201 pounds.

Structure and Environmental Conditions

The training structure was made entirely of concrete and had one stairwell in the middle of the building. It was also equipped with an alarm system that would activate when ceiling temperatures reached an excess of 500°F (260°C). An exterior roof prop was attached on a second-floor patio style area and the windows to the building were enclosed with plywood that slid to allow for ventilation. The training fire was relatively small, fueled with straw and wood pallets, and located in the corner of the first floor. The weather was clear throughout the day with a low of 49°F and a high of 76°F; relative humidity was 51%.

Drills

Three drills were carried out during training, including: 1) a transitional attack with ventilation and a multiple floor search; 2) a high-rise standpipe drill; and 3) a ventilation, enter, isolate, and search drill. Descriptions of each drill with team assignments can be found in Table 5.1, Live Fire Training Drill Descriptions. The duration of drills ranged from 30 to 50 minutes and the full training took six hours.

Data Collection and Management

Firefighters and instructors wore Zephyr bioharness shirts or straps for the entire training day. Once participants returned to the fire station, all data from the Zephyr Biomodules were downloaded and uploaded to the Skidmore College, First Responder Health and Safety Laboratory Dropbox site. A researcher from the First Responder Health and Safety Laboratory then reviewed each participant's data set and created subsets for each drill. Baseline physiological measurements (upon arrival and during the safety briefing) were taken from data captured during this process. Four periods of interest were analyzed, including: drill 1, clean-up following drill 1, drill 2, and drill 3. Instructors were also compared to firefighters to determine if cardiac or thermal strain differed between cohorts.

All data was reviewed to ensure values were within physiological limits and imported into the statistical software package.

TABLE 5.1. LIVE FIRE TRAINING DRILL DESCRIPTIONS.
Drill 1: Transitional Attack with Ventilation and a Multiple Floor Search
Engine 1 (3 firefighters) — carried out initial fire attack and advanced hose to second floor of burn building Truck (2 firefighters) — performed vertical roof ventilations on a prop (3/4 inch plywood) using chainsaws, circular saw, mauls, and axes Engine 3 (2 firefighters)— searched all floors inside burn tower Medic Company (3 EMTs/firefighters) — stand by as rapid intervention team (RIT), threw ladders to the second floor windows, and carried equipment to the front of the building Incident Commander — assumed command from initial companies
Drill 2: High Rise Stand Pipe Operation
Engine 1 — carried a 21/2 inch (100 foot) high rise bundle to the second floor standpipe connection and advanced hose to the third floor Truck — performed vertical roof ventilations on a prop (3/4 inch plywood) using chainsaws, circular saw, mauls, and axes Engine 3 — searched all floors inside burn tower Medic Company — served as RIT standby, threw ladders to the second floor windows, and carried equipment to the front of the building Incident Commander — assumed command from initial companies
Drill 3: Ventilation, Enter, Isolate, and Search
Engine 1 — advanced hose to the first floor burn Truck — performed complete ventilations and search techniques including climbing up a ladder to a second floor window, entering the window and completing a search of the room Engine 3 — climbed the main tower ladder (Day 1) or tower stairs (Days 2 & 3) to the fourth floor for entry where they conducted a search of the room Medic Company — served as RIT standby, threw ladders to the second floor windows, and carried equipment to the front of the building Incident Command — assumed command from initial companies

Results

Our results indicated that live fire training produces significant cardiovascular strain. As seen in Figure 5.2, HR increased with the various drills. Although it is useful to be able to visualize how all the individuals responded, it was necessary to perform statistical analyses to see how the average values differed by drill and between the students and instructors. The average peak HR attained during the training was 187 bpm. The overall average HR (for the entire day) was 116 bpm. These data indicate that there were periods of intense work associated with the drills and with clean-up, but when considered over the course of the entire training day, the cardiovascular strain was relatively moderate. When the team investigated the impact of individual drills, the peak HR ranged from 163-171 bpm (Figures 5.2, 5.3). There were no statistically significant differences among heart rate or estimated core temperature (Figure 5.4) changes among the drills. There were also no statistically significant differences between instructors and firefighters throughout training.

A major finding was that the highest peak HR attained during the live-fire training did not occur during the actual drills. In fact, the highest observed value was during the clean-up following drill 1. Although clean-up was performed with PPE jacket off, firefighters' estimated core temperatures rose after the activity of drill 1 and HRs were greater in this time period than during any drill. Additionally, there was a large difference in the firefighters work during this time period

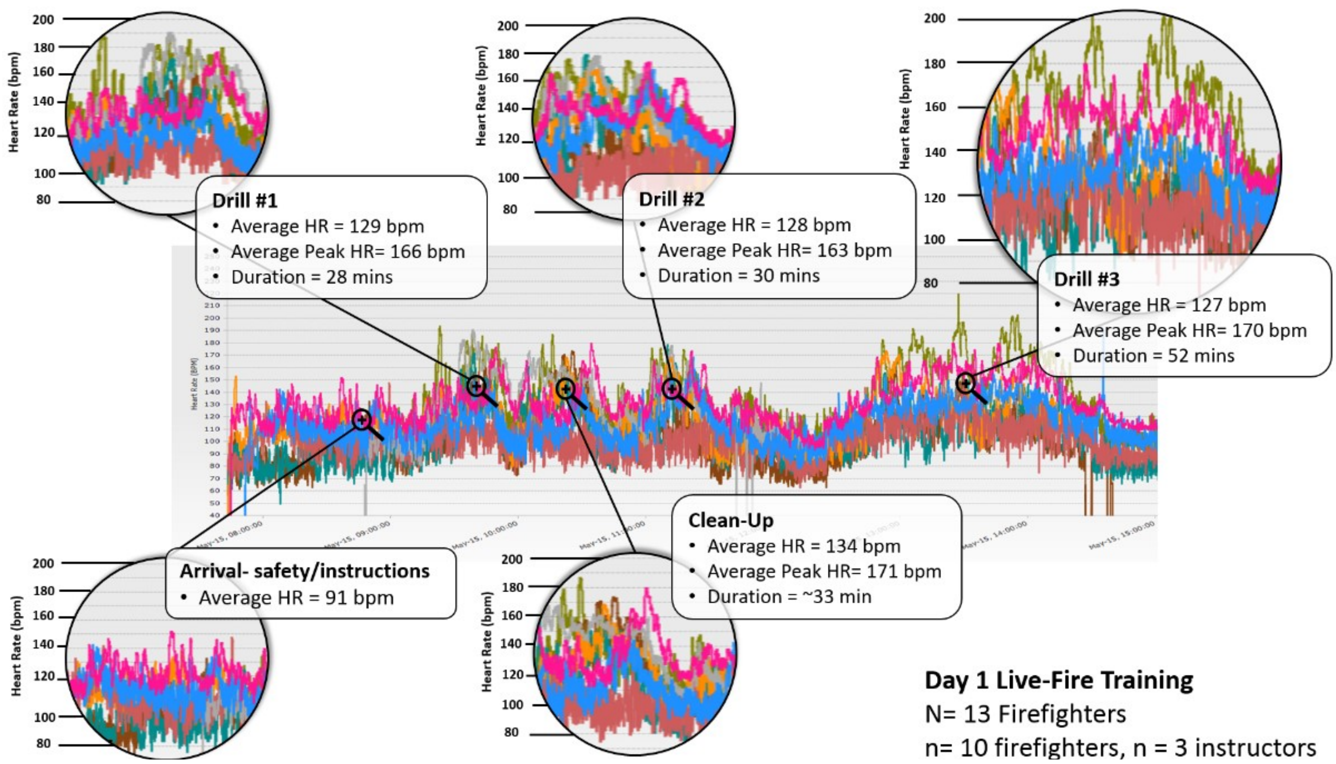


FIGURE 5.2. WASP SYSTEM HEART RATE DATA FROM LIVE-FIRE TRAINING WITH ANALYSIS.

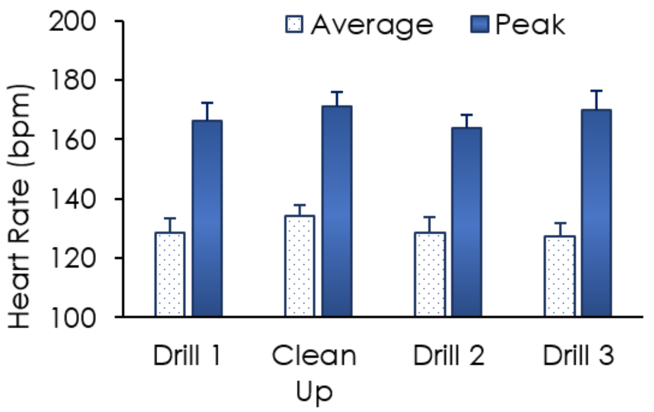


FIGURE 5.3. AVERAGE AND PEAK HEART RATE DURING LIVE FIRE TRAINING (N=13).

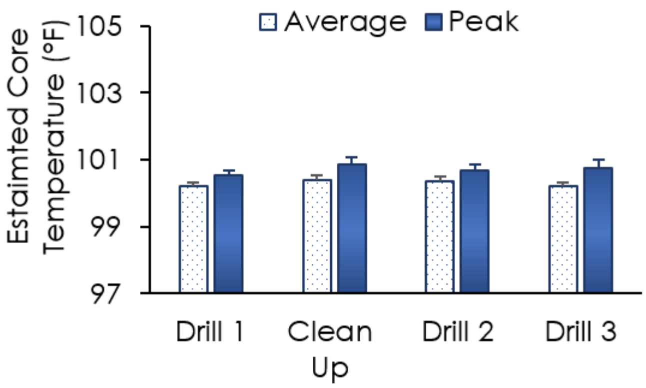


FIGURE 5.4. AVERAGE AND PEAK ESTIMATED CORE TEMPERATURE LIVE FIRE TRAINING

compared to that of the instructors, with firefighters performing greater work. This result is important for all fire service personnel to note—that the work performed outside of the official drills may have the greatest impact on the cardiovascular strain.

Because instructing officers do not perform as much work during this period they may easily underestimate the level of exertion of drills. Therefore, the effects of overhaul, performed both in training and on the fireground, needs to be accounted for by safety officers when evaluating the overall health and fitness of a fire crew.

Bailout Training

Hanover Park Fire Department conducted routine bailout training throughout September of 2017. Compared to other activities, bailout training is a short and low-intensity; nevertheless, the drill still presented the psychological challenges of high stress situations, such as those firefighters face on a regular basis. Our research team aggregated available WASP data during these targeted trainings, in order to determine the cardiovascular and thermal strain of this drill compared to live fire training and fire calls.

Bailout *Drill*

This drill consisted of firefighters using a window frame built above a drop, attaching a heat-resistant hook to the frame, and climbing sideways out of the window before dropping and letting the bailout device catch them (see Figure 5.5). From there, a lever on the device was used to create a controlled decent and lower the firefighter to the ground. Figure 5.6 shows a Hanover Park firefighter completing bailout training. An officer stayed at the window frame throughout training to instruct the participant and ensure the device was set up and used correctly. Firefighters were required to complete two cycles of the drill that lasted less than one minute each.

Participants

Though most Hanover Park firefighters participated in the bailout training as part of mandatory training, only a subset wore the monitors during this training. Thus, only data from 19 firefighters was analyzed.

FIGURE 5.5. BAILOUT TRAINING.

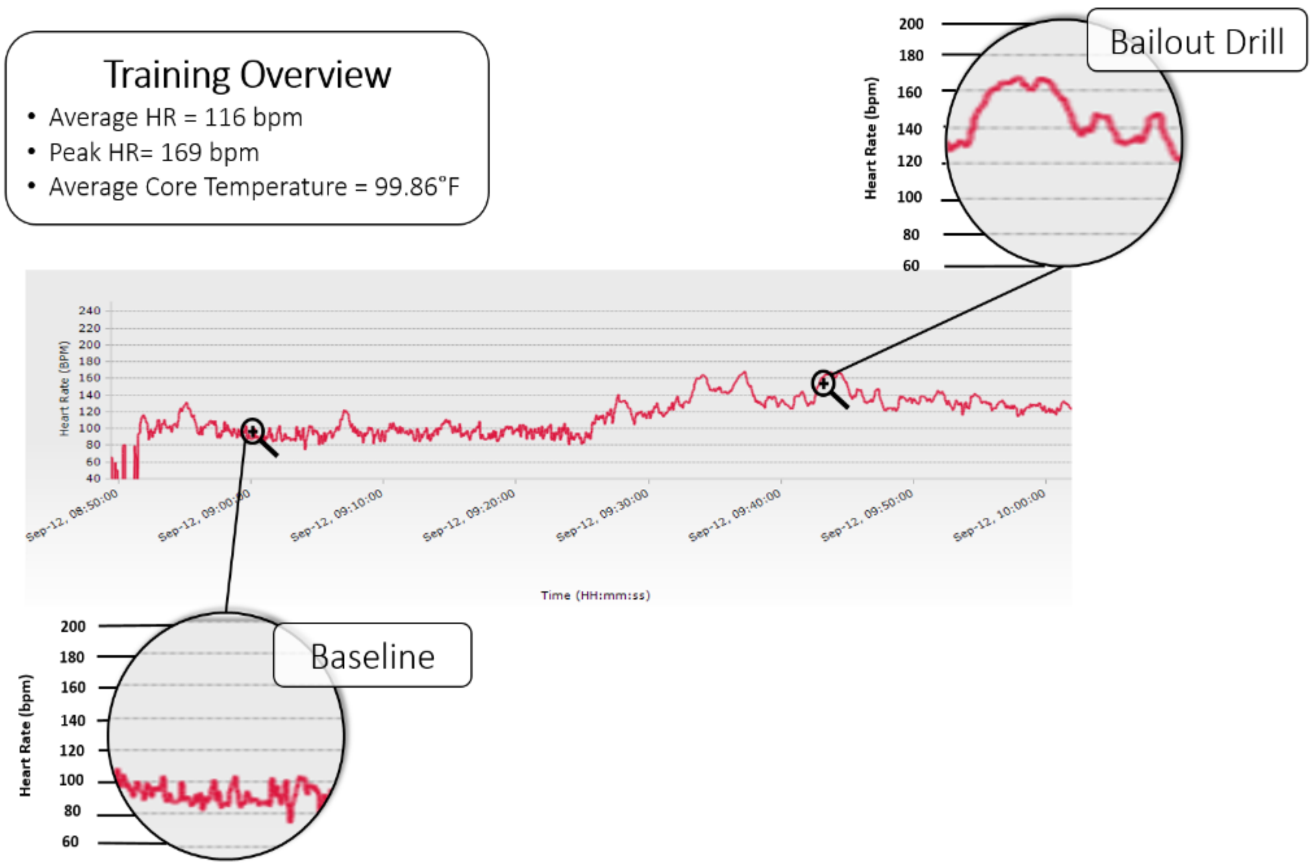


FIGURE 5.6. EXAMPLE HEART RATE TRACING FROM BAILOUT TRAINING (single participant).

Results

The results demonstrated the extent to which the sympathetic nervous system is activated had a bearing on cardiovascular strain. Though bailout training is considered a relatively "low-intensity" activity (taking less than one minute), the heart rate responses seen during this drill mirrored those of live fire training. As shown in Figure 5.6, heart rates reached near maximal levels at the time of bailout jump for participants, regardless of years of service. At their peaks, heart rates ranged from 74%-98% (~160-180 bpm; Figure 5.6) of age predicted maximum. Fire department leadership found that the heart rate responses observed during bailout training surprising, given the low intensity of the drill and number of experienced firefighters participating. Overall, these results highlight the need to consider how psychologically demanding tasks affect firefighter cardiovascular health.

Fire Calls

From January 16 - July 17, 2017, the team paid particular attention to WASP data from actual fire calls to assess feasibility of wearing PSM. Out of 51 fire incidents during the time period, 27 fire calls were selected for analysis, and comprised the final sample.

Methods

The research team obtained incident logs and rosters for every fire call that took place between January and July of 2017 and used logged information to determine the amount of Biomodule data captured during relevant time periods. Utilizing Zephyr's heart rate confidence metric (a measure of how accurate a heart rate reading is at any point in time) we were able to determine how much data was considered accurate. Average and peak heart rates and estimated core temperatures were then calculated for relevant time periods. ECG data was also explored, to determine if it was useable.

Results

As seen in Figure 5.7, though a portion of the data was removed after filtering for heart rate confidence, the amount of information that remained indicated that the device performs generally well when capturing heart rate data on the fireground. The ECG data was not useful for detecting arrhythmias or ischemic changes as it was not a measure that could be viewed live or in the Omnisense data viewer. ECG data was also 'noisy' because of movement artifact that occurred due to firefighters moving their upper body while wearing Biomodules.

Live Mode

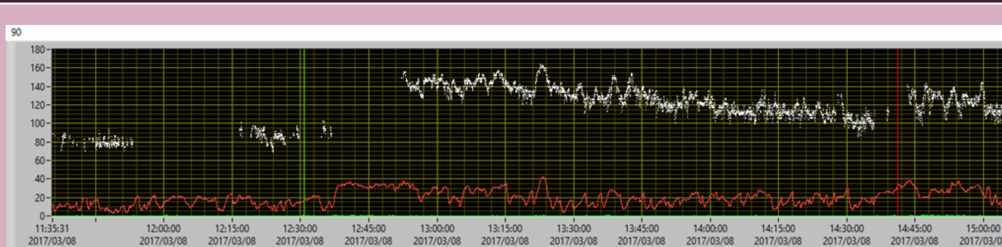
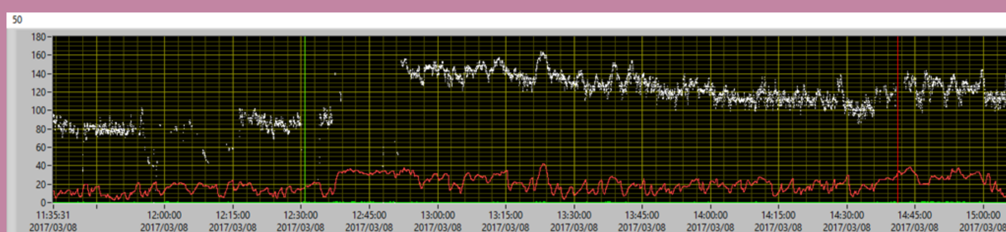
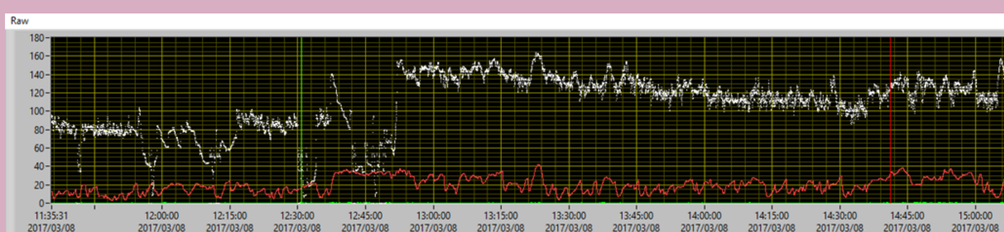
The WASP System also included a program that allowed us to view a "live" or real-time report of some physiological variables the Zephyr Biomodule. The Hanover Park Fire Department command car was outfitted with laptops that included the live software (OmniSense Live) and a database of Hanover Park Fire Department participants; this allowed battalion chiefs to view participants' heart rate, activity, estimated core temperature, and breathing rate in real time during emergency situations. Live mode was used for training, rehab, and emergency calls during the study. The chief of the department found the system to be helpful to a point, with strong possibilities for future applications.

In most instances, incident commanders would not be able to stop a "push" or a rescue effort due to physiological data readings seen at the command post. However, with data about the physiological stress of the operating crews, commanders may be able to assign additional staff or rotate crews in an attempt to reduce the overall load. The PSMs were also helpful in monitoring HR and temperature while firefighters underwent rehab, and this information may be useful in determining when to put crews back to work following rehab. They made medical assessments more efficient and eased the overall data collection with less errors or omissions.

Several issues require additional research. These include establishing the threshold limits of concern, and determining the 1) variance between individuals; 2) fluctuations from day to day; and 3) whether a base level of understanding of each firefighter's physiology is needed in order to interpret readings.

Incident commanders found that the command team needs to be very robust to evaluate all information available from both the incident and the PSMs. Unless supported by a fairly large staff, the incident commander quickly can easily become overloaded, and unable to process all the data needed to support critical decision making.

Figure 5.7. HEART RATE DATA BY QUALITY (CONFIDENCE).

Data Quality	Visual
90% Confidence	
50% Confidence	
Raw	

Case Study

The advantages of Zephyr's Live Mode were apparent during a grass fire. It was a cool day at 45°F and 56% humidity with 18 mph winds. Five firefighters responded along with battalion chief and the fire chief. Upon arrival to the scene, the battalion chief connected the laptop; he had real-time data on the firefighters in about three minutes.

Data collected indicated that firefighters had peak heart rates ranging from 159 to 205 bpm. High peak estimated core body temperatures for the initial attack firefighters were 103.1°F, 102.2°F, 101°F and 99.3°F.

A generally accepted standard for defining heat stroke is a core hyperthermia above 104°F (Mayo Clinic, 2017). It has been established by previous research that even when firefighters are removed from the hot environment and doff their PPE, core body temperatures can continue to rise. Taking this into account, it is easy to speculate that firefighters responding to this incident were, at least in one case, dangerously close to experiencing significant heat illness. It is important to note that the ambient temperature at this incident was only 45°F. As the ambient temperature increases, the risk of heat-related illness increases dramatically.

Based on the availability of this "real time" data, the incident commander made the decision to pull the firefighter with the highest estimated core body temperature and send him for immediate rest and hydration, which also included doffing of PPE.

This incident led the fire chief to question the logic of having firefighters operate at brush or wildland incidents wearing structural PPE. During these types of incidents, the overall thermal protection offered by bunker gear is not required and can actually be physiologically detrimental. Based on this, Hanover Park and Skidmore are currently evaluating a wildland pant and coat (i.e. non-structural PPE) configuration that provides flash/abrasion/blood borne pathogen protection. This study, separate from SMARTER, is approved by the Skidmore College Institutional Review Board (IRB) and funded by the Hanover Park Fire Department – Foreign Fire Tax Insurance Board. Findings from this additional study will provide a comparison of the physiological responses of firefighters working in structural PPE vs those wearing non-structural gear.

Summary

The Live Mode proved very useful when Hanover Park officers were able to manage operations while viewing physiological data. However, incident commanders generally did not have the time to do so. Unfortunately, without adequate resources and time, Live Mode is difficult to integrate into incident command operations. In order to effectively use the information during an emergency incident, it will likely require that a designated individual be assigned the sole task of reviewing data and communicating recommendations to command. Live mode is however suited for utilization during training and rehabilitation, and has been adopted by several fire departments for these specific uses.

RECOMMENDATIONS

1. Recognize overhaul and training as periods of significant cardiac and thermal strain.
2. Increase awareness about the effects that high psychological stress places on the cardiovascular system.
3. Consider modifications to gear to decrease cardiovascular strain in situations where bunker gear may not be necessary (such as extrication and brush fires).
4. Consider physiological monitoring during live fire training, physical training, and fire calls.
5. Be attentive to technological advances that may make monitoring more feasible in the future.

RESOURCES

RELEVANT WEBPAGES

- WASP™ Wearable Advanced Sensor Platform Webpage (https://bit.ly/32psed9)
- ZEPHYR™ PERFORMANCE SYSTEMS Webpage (https://bit.ly/2XGwT6T)
- Hanover Park Fire Department Webpage (https://bit.ly/2xJUHfm)

Reference List

CHAPTER 1

Daniels, R., Bertke, S., Dahm, M., Yiin, J., Kubale, T., Hales, T., Baris, Zahm, S., Beaumont, J., Waters, K., and Pinkerton, L. (2015). Exposure-response relationships for select cancer and non-cancer health outcomes in a cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950-2009). *Occupational & Environmental Medicine*, 72(10), 699-706.

Evarts, B., Molis, J.L. (2018). Data, publications, & library. Retrieved from https://bit.ly/2XHYy7v

Fahy, R. F., LeBlanc, P. R., & Molis, J. L. (2018). Firefighter fatalities in the united states - 2017. Quincy, MA: NFPA Research, Data and Analytics Division. Retrieved from https://bit.ly/30uTx3D

Fahy, R. F., LeBlanc, P. R. & Molis, J. L. (n.d.) Fatalities and injuries. Retrieved from https://bit.ly/2xkwVqK

Fehling, P. C., Haller, J. M., Lefferts, W. K., Hultquist, E. M., Wharton, M., Rowland, T. W., & Smith, D. L. (2015). Effect of exercise, heat stress and dehydration on myocardial performance. *Occupational Medicine (Oxford, England), 65*(4), 317-323. 10.1093/occmed/kqv015

Firefighter Life Safety Research Center, Illinois Fire Service Institute. (2008). *Firefighter fatalities and injuries: The role of heat stress and PPE*. Urbana-Champaign, Illinois: University of Illinois at Urbana-Champaign.

Horn, G. P., Blevins, S., Fernhall, B., & Smith, D. L. (2013). Core temperature and heart rate response to repeated bouts of firefighting activities. *Ergonomics, 56*(9), 1465-1473. 10.1080/00140139.2013.818719 Retrieved from https://bit.ly/2XE3dav

Horn, G.P., Kesler, R.M., Kerber, S., Fent, K.W., Schroeder, T.J., Scott, Williams, S.,… Smith, D.L. (2017). Thermal response to firefighting activities in residential structure fires: impact of job assignment and suppression tactic. *Ergonomics, 61(3),* 404-409.

Smith, D.L., Barr, D.A., & Kales, S.N. (2013). Extreme sacrifice: Sudden cardiac death in the US fire service. *Extreme Physiology & Medicine*, *2(6)*,1-9.

Soteriades, E. S., Smith, D. L., Tsismenakis, A. J., Baur, D. M., & Kales, S. N. (2011). Cardiovascular disease in US firefighters: A systematic review. *Cardiology in Review, 19(4)*, 202-215.

CHAPTER 2

American College of Sports Medicine, Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J., & Stachenfeld, N. S. (2007). American college of sports medicine position stand: exercise and fluid replacement. *Medicine and Science in Sports and Exercise, 39*(2), 377-390. 10.1249/mss.0b013e31802ca597 [doi]

Barr, D. A., Haigh, C. A., Haller, J. M., & Smith, D. L. (2016). Medical monitoring during firefighter incident sudden cardiac eventne rehabilitation. *Prehospital Emergency Care : Official Journal of the National Association of EMS Physicians and the National Association of State EMS Directors, 20*(4), 467-476. 10.3109/10903127.2016.1139215 [doi]

Binkley, H. M., Beckett, J., Casa, D. J., Kleiner, D. M., & Plummer, P. E. (2002). National athletic trainers' association position statement: Exertional heat illnesses. *Journal of Athletic Training, 37*(3), 329-343. Retrieved from https://bit.ly/2xEMqt8

Reference List

Buller, M. J., Tharion, W. J., Cheuvront, S. N., Montain, S. J., Kenefick, R. W., Castellani, J., & Hoyt, R. W. (2013). Estimation of human core temperature from sequential heart rate observations. *Physiological Measurement, 34*(7), 781-798. 10.1088/0967-3334/34/7/781 [doi]

Buller, M. J., Tharion, W. J., Hoyt, R. W., & Jenkins, O. C. (2010). Estimation of human internal temperature from wearable physiological sensors. Paper presented at the *Twenty-Second Conference on Innovative Applications of Artificial Intelligence*.

Espinoza, N. & Contreras, M. (2007). *Safety and performance implications of hydration, core body temperature, and post-incident rehabilitation*. Irvine, CA: Orange County Fire Authority, Wellness and Fitness Program.

Garzon-Villalba, X., Mbah, A., Wu, Y., Hiles, M., Moore, H., Schwartz, S. W., & Bernard, T. E. (2016). Exertional heat illness and acute injury related to ambient wet bulb globe temperature. *American Journal of Industrial Medicine, 59*(12), 1169-1176. 10.1002/ajim.22650 Retrieved from https://bit.ly/2Lm2qcD

Horn, G.P., Kesler, R.M., Kerber, S., Fent, K.W., Schroeder, T.J., Scott, Williams, S.,… Smith, D.L. (2017). Thermal response to firefighting activities in residential structure fires: impact of job assignment and suppression tactic. *Ergonomics, 61(3),* 404-409.

Horn, G. P., Blevins, S., Fernhall, B., & Smith, D. L. (2013). Core temperature and heart rate response to repeated bouts of firefighting activities. *Ergonomics, 56*(9), 1465-1473. 10.1080/00140139.2013.818719 [doi]

Horn, G. P., DeBlois, J., Shalmyeva, I., & Smith, D. L. (2012). Quantifying dehydration in the fire service using field methods and novel devices. *Prehospital Emergency Care : Official Journal of the National Association of EMS Physicians and the National Association of State EMS Directors, 16*(3), 347-355. 10.3109/10903127.2012.664243 [doi]

Wallace, R. F., Kriebel, D., Punnett, L., Wegman, D. H., Wenger, C. B., Gardner, J. W., & Gonzalez, R. R. (2005). The effects of continuous hot weather training on risk of exertional heat illness.*Medicine and Science in Sports and Exercise, 37*(1), 84-90. 10.1249/01.mss.0000150018.90213.aa Retrieved from https://bit.ly/2JRprkv

CHAPTER 3

Antonicelli, R., Ripa, C., Abbatecola, A.M., & Capparuccia, C.A., Ferrara, L., & Spazzafumo, L. (2012). Validation of the 3-lead tele-ECG versus the 12-lead tele-ECG and the conventional 12-lead ECG method in older people. *Journal of Telemedicine and Telecare,18(2)*,104-108.

American Heart Association. Understanding blood pressure readings. (2017). Retrieved from https://bit.ly/2Ih3zxs

Reference List

Bardai, A., Blom, M.T., van Hoeijen, D.A., van Deutekom, H.W., Brouwer ,H.J., & Tan, H.L. (2014). Atrial Fibrillation Is an Independent Risk Factor for Ventricular Fibrillation: A Large-Scale Population-Based Case-Control Study. *Circulation: Arrhythmia and Electrophysiology, 7(6)*,1033-1039.

Barrett, P.M., Komatireddy, R., Haaser, S., Topol, S., Sheard, J., Encinas, J.,…Topol, E.J.(2014). Comparison of 24-hour Holter Monitoring with 14-day Novel Adhesive Patch Electrocardiographic Monitoring. *The American journal of medicine*,*127(1)*,10.

Becker, D.E. (2006). Fundamentals of Electrocardiography Interpretation. *Anesthesia Progress*, *53(2)*, 53-64.

Chung, E.H. & Guise, K.D. (2015). QTC intervals can be assessed with the AliveCor heart monitor in patients on dofetilide for atrial fibrillation. *Journal of Electrocardiology, 48(1)*, 8-9.

Drew, B.J., Pelter, M.M., Adams, M.G., Wung, S.F., Chou, T.M., & Wolfe, C.L. (1998).12-lead ST-segment monitoring vs single-lead maximum ST-segment monitoring for detecting ongoing ischemia in patients with unstable coronary syndromes. *American Journal of Critical Care.* 7(5): 355-363.

Fahy, R. F., LeBlanc, P. R., & Molis, J. L. (2018). *Firefighter fatalities in the united states - 2017.* Quincy, MA: NFPA Research, Data and Analytics Division. Retrieved from https://bit.ly/30uTx3D

Foy S. & Levis J.T. (2014). ECG Diagnosis: Type I Atrial Flutter. *The Permanente Journal*, *18(2)*, 128.

Fung, E., Järvelin, M.R., Doshi, R.N., Shinbane, J.S., Carlson, S. K., Grazette, L.P.,…Peters, N.S. (2015). Electrocardiographic patch devices and contemporary wireless cardiac monitoring. *Frontiers in Physiology*, 6, 149.

Glinge, C., Sattler, S., Jabbari, R., & Tfelt-Hansen, J. (2016). Epidemiology and genetics of ventricular fibrillation during acute myocardial infarction. *Journal of Geriatric Cardiology*,*13(9)*, 789-797.

Hals, G. & McCoy, C. (2015). Supraventricular Tachycardia: A Review for the Practicing Emergency Physician. *Emergency Medicine Reports, 36(13).*

Haynes, H. J., & Molis, J. L. (2017). U.S. firefighter injuries in 2016. Retrieved from https://bit.ly/2LNvyZC

Heidt, S.T., Kratz, A., Najarian, K., Hasset, A.L., Oral, H., Gonzalez, R.,…Ghanbari, H. (2016). Symptoms In Atrial Fibrillation: A Contemporary Review And Future Directions . *Journal of Atrial Fibrillation*, *9(1),* 1422.

Kales, S.N., Soteraides, E.S., Christophi, C.A., & Christiani, C. Emergency duties and death from heart diseases among firefighters in the United States. (2007). *New England Journal of Medicine. 356:1207-1215.*

Koplan, B.A. & Stevenson, W.G. (2009). Ventricular Tachycardia and Sudden Cardiac Death. *Mayo Clinic Proceedings*, *84(3),* 289-297.

Kristensen, A.N., Jeyam, B., Riahi, S., & Jensen, M.B. (2016). The use of a portable three-lead ECG monitor to detect atrial fibrillation in general practice. *Scandinavian Journal of Primary Health Care*, *34 (3),* 304-308.

Lau, J.K., Lowres, N., Neubeck, L., Brieger, D.B., Sy, R.W., Galloway, C.D.,… Freedman, S.B. (2013). iPhone ECG application for community screening to detect silent atrial fibrillation: a novel technology to prevent stroke. *International Journal of Cardiology,165(1),* 193-194.

Magnani, J.W., Rienstra, M., Lin, H., Sinner, M.F., Lubitz, S.A., McManus, D.D.,…Benjamin, E.J. (2011).

Reference List

Atrial fibrillation: Current knowledge and future directions in epidemiology and genomics. *Circulation*. *124(18)*,1982-1993.

Mayo Clinic Staff. (2018). Myocardial ischemia. Retrieved from https://mayocl.in/2ECuPbp

Mehta, D.D., Nazir, N., Trohman, R.G., & Volgman, A.S. (2015). Single-lead portable ECG devices: Perceptions and clinical accuracy compared to conventional cardiac monitoring. *Journal of Electrocardiology*. *48(4)*, 710-716.

Medi, C., Kalman, J.M., & Freedman, S.B. (2009). Supraventricular Tachycardia. *The Medical Journal of Australia, 190(5),* 255-260.

Muhlestein, J.B., Le, V., Albert, D., Moreno, F.L., Anderson, J.L., Yanowitz, F.,…Muhlestein, J.B. (2015). Smartphone ECG for evaluation of STEMI: Results of the ST LEUIS Pilot Study. *Journal of Electrocardiology*. *48(2)*, 249-259.

Sanquist, T.F. (2015). Remote Physiological Health and Status Monitoring of First Responders: Promises, Practicalities, and Prospects. Pacific Northwest National Laboratory.

Smith, D.L., Haller,J.M., Korre, M., Sampani, K., Porto, L.G.G., Fehling, P.C., Christophi, C.A., Kales, S.N., (2019). *The relation of emergency duties to cardiac death among US firefighters.* American Journal of Cardiology. *123:736-741*.

Smith, D.L., Haller,J.M., Korre, M., Fehling, P.C., Sampani, K., Porto, L.G.G., Christophi, C.A., Kales, S.N., (2018). *Pathoanatomic Findings Associated With Duty-Related Cardiac Death in US Firefighters: A Case-Control Study. Journal of the American Heart Association*. 7:e009446. DOI" 10.1161

Smith, D.L., Barr, D.A., & Kales, S.N. (2013). Extreme sacrifice: Sudden cardiac death in the US fire service. *Extreme Physiology & Medicine*, *2(6)*,1-9.

Surawicz, B. (1985). Ventricular Fibrillation. *Journal of the American College of Cardiology*, *5* (6),43B-54B.

Van Weerd, J.H. & Christoffels, V.M. (2016). The formation and function of the cardiac conduction system. *Development*, *143,* 197-210.

Waldo, A. (2000). Treatment of atrial flutter. *Heart*. *84(2),* 227-232.

Walsh, J.A., Topol, E.J., & Steinhubl, S.R. (2014). Novel Wireless Devices for Cardiac Monitoring. *Circulation*, *130(7),* 573-581.

Wellens, H.J. (2001). Ventricular tachycardia: diagnosis of broad QRS complex tachycardia. *Heart, 86,* 579-585.

Reference List

CHAPTER 4

Baxter, C.S., Hoffman, J.D., Knipp, M.J., Reponen, T., & Haynes, E.N. (2014). Exposure of Firefighters to Particulates and Polycyclic Aromatic Hydrocarbons. *Journal of Occupational Environmental Hygiene*, 11(7), D85-91.

Baxter, C.S., Ross, C.S., Fabian, T., Borgerson, J.L., Shawon, J., Gandhi, P.D.,… Lockey, J.E. (2010). Ultrafine particle exposure during fire suppression-is it an important contributory factor for coronary heart disease in firefighters? *Journal of Occupational Environmental Medicine*, *52(8),* 791-6.

Bonanno, L. (2008). *Particulate Matter Characteristics, Health Effects and Exposure. PowerPoint presented at* NESCAUM Health Effects Workshop, Bordentown, New Jersey.

Centers for Disease Control and Prevention. (2017). HYDROGEN CYANIDE (AC): Systemic Agent. Retrieved from https://bit.ly/21f2r1n

Centers for Disease Control and Prevention: Environmental Health. (2013). *What You should Know about Formaldehyde*, Retrieved from https://bit.ly/2Plk0vr

Daniels, R.D., Kubale, T.L., Yiin, J.H., Dahmn, M.M., Hales, T.R., Zahm, S.H.,...Pinkerton, L.E.(2015). Mortality and cancer incidence in a pooled cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950–2009). *Occupational and Environmental Medicine*, 71(6), 388-97.

Demers, P.A., Heyer, N.J., & Rosenstock, L. (1992). Mortality among firefighters from three northwestern United States cities. *British Journal of Industrial Medicine*, *49(9),* 664-70.

Dockery, D.W. (2001). Epidemiologic evidence of cardiovascular effects of particulate air pollution. *Environmental Health Perspectives*, *109(Supplement 4),* 483-6.

Evans, D.E. & Fent, K.W. (2015). Ultra fine and respirable particle exposure during vehicle fire suppression. *Environmental Science: Processes & Impacts*, *17(10),*1749-59.

Forchhammer, L., Møller, P., Riddervold, I.S., Bonlokke, J., Massling, A., Sigsgaard, T., & Loft, S.(2012). Controlled human wood smoke exposure: oxidative stress, inflammation and microvascular function. *Particle and Fire Toxicology*, 9(7),1-11.

Fent, K. W., Evans, D. E., Booher, D., Pleil, J. D., Stiegel, M. A., Horn, G. P., & Dalton, J. (2012a). Volatile organic compounds off-gassing from firefighters' personal protective equipment ensembles after use. *Journal of Occupational and Environmental Hygiene, 12*(6), 404-414. 10.1080/15459624.2015.1025135 [doi]

Fent, K. W., Evans, D. E., Couch, J. & Niemeier, M. T. (2012b). Evaluating vehicle fire training inhalation hazards. Retrieved from https://bit.ly/2Lfx47s

Reference List

Laitinen, J., Makela, M., Mikkola, J., & Huttu, I. (2010). Fire fighting trainers' exposure to carcinogenic agents in smoke diving simulators. *Toxicology Letters,192(1),* 61-5.

Leonard, S.S., Castranova, V., Chen, B.T., Schwegler-Berry, D., Hoover, M., Piacitelli, C., & Guaghan, D.M. (2007). Particle size-dependent radical generation from wildland fire smoke. *Toxicology, 236(1–2),*103-13.

Lönnermark,A. & Blomqvist, P. (2006). Emissions from an automobile fire. *Chemosphere*, *62(7),*1043-56.

Occupational Safety and Health Administration. (2013). Diesel Exhaust/Diesel Particulate Matter [Internet] Occupational Safety and Health Administration. Retrieved from https://bit.ly/2XXcazF

Queensland Fire and Rescue. (2011). *Firefighter Exposures to Airborne Contaminants during Extinguishment of Simulated Residential Room Fires*: Kirk KM, Ridgway M, Logan M.

Robinson, M.S., Anthony, T.R., Littau, S.R, Herckes, P., Nelson, X., Poplin, G.S., & Burgess, J.L. (2008). Occupational PAH Exposures during Prescribed Pile Burns. *Annuals of Occupational Hygiene*, *52 (6),* 497-508.

Simkhovich, B.Z., Kleinman, M.T., & Kloner, R.A. (2008). Air Pollution and Cardiovascular Injury: Epidemiology, Toxicology, and Mechanisms. *Journal of American College of Cardiology*, *52(9),* 719-26.

Turner, M. C., Krewski, D., Pope, C. A., Chen, Y., Gapstur, S. M., & Thun, M. J. (2011). Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. *American Journal of Respiratory Critical Care and Medicine, 184*(12), 1374-1381. 10.1164/rccm.201106-1011OC Retrieved from https://bit.ly/2SgW92x

Underwriters Laboratories Inc. (2010). *Firefighter Exposure to Smoke Particulates*. Northbrook, IL: Fabian T, Borgerson JL, Kerber SI, et al.

United States Environmental Protection Agency. (n.d.). Particulate matter (PM) Pollution. Retrieved from https://bit.ly/2I4WL9x

University of Victoria. (n.d.). FIREFIGHTERS: Three reasons why using your SCBA makes sense. 2015. Retrieved from https://bit.ly/2NVwKwq

CHAPTER 5

Mayo Clinic Staff. (2017). Heat stroke. Retrieved from https://mayocl.in/2HzUKO4