Aerobic Capacity and Injury Risk: Determining Associative Factor of Injury Among Emergency Service Employees

AEROBIC CAPACITY AND INJURY RISK: DETERMINING ASSOCIATIVE FACTORS OF INJURY AMONG EMERGENCY SERVICE EMPLOYEES

by

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ABSTRACT

Background: The high frequency of emergency responses and the variety of response environments for firefighting and emergency medical services dictate a potential for high work demands and an increasing need for maintaining above average physical fitness. This study makes use of a retrospective occupational cohort study design to explore the relationships between measures of fitness and injury outcomes.

Methods: Data were collected from annual medical exams and injury surveillance records recorded for the years 2004-2009 among commissioned employees of the Tucson Fire Department. Fitness was assessed and contrasted via a submaximal estimate of aerobic capacity and a developed metric and score for comprehensive "fire fitness" encompassing seven separate measures for strength, endurance, flexibility, body composition and aerobic fitness. Individual fitness scores were classified as 'high fit', 'fit', and 'less fit'. The association between the fitness measures and injuries was evaluated using two approaches: log-binomial and time-to-event analyses.

Results: The annual injury incidence rate averaged 17.7 per 100 employees. One-third of all injuries (32.9%) resulted from physical exercise activities, while patient transport, training drills, and fireground operations resulted in 16.9%, 11.1% and 10.2% of injuries, respectively. For all job operations, sprains and strains were the most prevalent type of injury, followed by contusions and lacerations. The reliability of fitness and clinical measures showed mean flexibility, grip strength, percent body fat, and resting heart rate each had intraclass correlations (ICC) values above 0.5, suggesting fair to good reliability. In contrast, mean VO_2max was an unreliable measure with an ICC of 0.27.

Hazard ratios from time-to-event analyses indicated that increases in cardiorespiratory fitness were significantly associated with decreased risk against injury. Similarly, decreases in comprehensive “fire fitness” were associated with an increased risk of injury.

Conclusions: These findings add support that improving one’s fitness reduces the likelihood of injury. Future research should focus on the relationship between fitness, performance and health outcomes. Individual level fitness improvements should be objectively measured and designed within the functional limitations of that individual, and without subjecting the person to injury in that process.

INTRODUCTION

I. Explanation of the problem and its context

Globally, the burden of occupational injury is significant and largely preventable.(Concha-Barrientos et al, 2005; Nelson et al, 2005) In the United States (U.S.), 4,340 fatal work-related injuries were reported in 2009.(BLS, 2010a) The incidence rate of non-fatal injuries among private industry workers was 3.4 per 100 workers, while public sector workers showed a significantly higher rate of 5.8 per 100 workers.(BLS, 2010b) Using year 2000 data, it was estimated that the economic burden of medical treatment and lost productivity due to injury totaled more than $406 billion, with most of the costs attributed to lost productivity.(Finkelstein et al, 2006)

Combined, firefighting and emergency medical services (EMS) have been shown to have among the highest occupational incidence rates for injury and fatalities. (Studnek et al, 2007; Fabio et al, 2002; Fosbroke et al, 1997) Of the 1.1 million career and volunteer firefighters in the U.S. in 2009, 78,150 injuries were reported, a rate of 6.8 injuries per 100 firefighters.(Karter, 2010a and b) Since the late 1970s, the number of structural fires has steadily decreased,(Aherns, 2007) most notably due to the advent of improved fire suppression and protection systems. However, firefighters have taken on additional responsibilities and are considered first responders for all emergencies (e.g., fire, hazardous materials, medical responses, natural disasters, and terrorist acts). In one jurisdiction, the City of Tucson, Arizona, 84.4% of the 79,380 fire department emergency dispatches recorded in 2009 were medical emergencies.(City of Tucson, 2010) This high proportion of calls due to medical emergencies is consistent with many fire departments today, where medical responses constitute the predominant type of response activity. With these additional roles and responsibilities comes a host of dynamic occupational hazards and risk-laden environments that must be identified and managed.

An injury is the result from an overloading of force (or load) in relation to a tissue's load-bearing capacity.(Wilson, 2002) Factors that contribute to the occurrence and severity of an injury can typically be placed into one of the following categories in relation to their time-sequence of events: (1) agent (i.e., energy or energy-carrying source); (2) environmental (physical & social); and (3) human factors.

II. Injuries and Response Environments in the Tucson Fire Department

The Tucson Fire Department (TFD) is comprised of approximately 650 career firefighters and paramedics, operating 21 fire stations that service the approximate 520,000 permanent residents of the City of Tucson, Arizona. Despite continued efforts to improve workplace health and safety, the incidence of all injuries among Tucson emergency service employees (ESEs) is high. As shown in Table 1, 902 injuries were recorded among ESEs between the years 2004-2009, with annual incidence rates ranging between 13.6 and 21.5 injuries per 200,000 hours (equivalent to 100 full-time employees). These rates indicate the need for enhanced prevention strategies and overall safety promotion in this population.

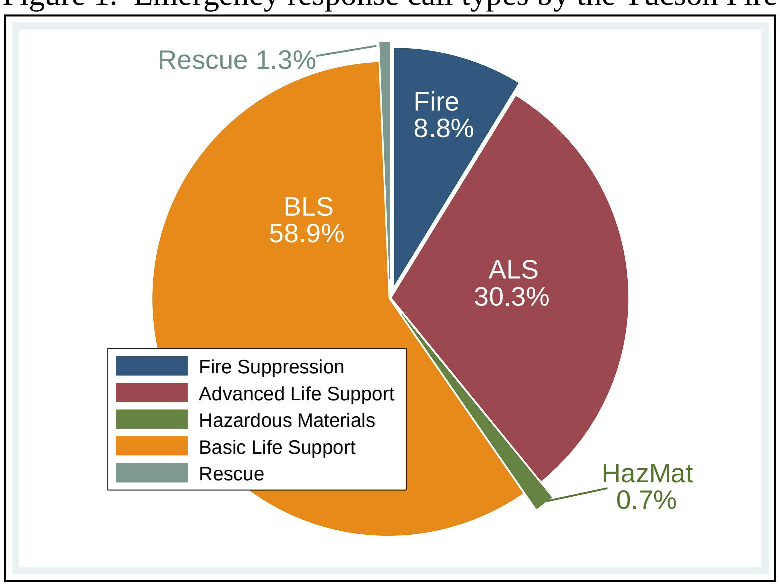
Table 1. Annual injury frequency and incidence rate, 2004-2009

Year	Injury Frequency	Number Employed	24-hour Employees	8-hour Employees	Total hours worked*	Incidence Rate (per 200,000 hrs)
2004	129	530	477	53	1441600	17.9
2005	128	577	490	87	1546000	16.6
2006	148	625	518	107	1664400	17.8
2007	174	659	566	93	1770800	19.6
2008	199	694	580	114	1852000	21.5
2009	124	667	613	54	1824400	13.6

*Based on an average of 2,800 and 2,000 hours worked by 24- and 8-hour employees, respectively

More recently, TFD responded to 82,089 emergency incidents, including fire suppression activities (7,217, 8.8%), EMS and advance life support (73,263, 89.2%), control of hazardous materials (578, 0.7%), and rescues involving trench, structural collapse, confined spaces, vehicle extrication, swift water and technical rescues (1,031, 1.3%) (Figure 1).(City of Tucson, 2012)

Figure 1. Emergency response call types by the Tucson Fire Department, 2011



III. Occupational athletes and functional fitness

The job duties related to firefighting and paramedicine require an active lifestyle with high physical demand. ESEs are often considered “occupational athletes” that have an increased risk for injuries due in part to the need to perform strenuous activities in dynamic environments.(Peate et al, 1997) Few studies exist that evaluate the underlying causes of injury among emergency service employees, and there is a lack of epidemiologic studies focused on developing relevant injury prevention strategies. Rarely in occupational settings is one able to comprehensively evaluate the differences that may exist between healthy employees and those that suffer illness or injury, as only the documentation of those ill and injured cases are required. Most municipal fire departments are different in that annual fitness and medical evaluations are required of the employee to assess one’s health status and determine any potential physiologic limitations that may prohibit the employee performing job-related tasks.

IV. Goals and Specific Aims

Focused research regarding the contribution of physical fitness to the occurrence and severity of injury in the emergency services has been limited .(Bos et al, 2004; Matticks et al, 1992; Lemon, 1977; Davis et al, 1987; Duncan et al, 1979; Williford et al, 1999; Davis et al, 1982; Rhea, 2004) The primary aim of this dissertation research is to understand the effect(s) aerobic capacity (an accepted measure of one’s overall fitness) has on the susceptibility of injury in a cohort of emergency service employees. A more global goal is to identify and measure key physiologic determinants of injury in an effort to better understand the relationship between measures of fitness and likelihood for injury. If there are measureable associations between aerobic capacity (or other fitness measures) and injury occurrence, then prevention strategies aimed at improving one's physiologic status and reducing the likelihood of injury can be developed (or advanced).

This research involves an analytical approach for studying risk factors associated with the occurrence and outcome of injuries in a population of commissioned employees in the TFD. This study makes use of administrative, secondary data to build a retrospective occupational cohort that allows the relationship between measures of fitness obtained during annual physical exams to be compared with injuries reported to an injury surveillance system. No direct intervention was introduced during the study period and the described risk factors were assessed annually at the person-level, over the span of five years. Aerobic capacity (VO_2max) is the primary exposure of interest, estimated using a submaximal treadmill test. This measure is commonly utilized in fire service physicals. Outcomes consist of all reported injuries sustained by the individual employee during the study period. Information on these attributes and other potential confounding factors were obtained using data collected from annual medical exams and injury surveillance records. The underlying questions governing this research include: are variations in fitness (via aerobic capacity) associated with the occurrence of injury in a population of emergency service employees?

There are three specific aims that are associated with three separate manuscripts. The aims of this dissertation research are:

Aim I. To describe the current injury trends in a metropolitan fire department and to identify potential risks & hazards for occupational injury (Manuscript 1)

Injury surveillance data were obtained from the TFD and analyzed for the years 2004-2009. Epidemiologic factors associated with injury and which could influence the outcome (i.e., severity) of the event were described. Information pertaining to the event included the agent, mechanism, nature of injury, body location, environment (both physical and social), and severity using the Abbreviated Injury Scale (AIS). Descriptive analytic methods and conceptual models derived from the Haddon's Matrix and risk assessment strategies were used to identify hazards, describe, analyze and characterize the nature of injuries.

Aim II. Describe measures of aerobic and musculoskeletal fitness, and their individual-level variability, and define a comprehensive measure for assessing fitness status (Manuscript 2)

Defining fitness is a difficult challenge and may largely be dictated by the manner or setting in which it is applied. The work demands for these emergency service employees are well documented as being diverse and requiring increased physical abilities. Aerobic capacity has often been used as a proxy measure for overall fitness.(ACSM, 2010) Recent studies suggest that the ability to perform all tasks associated with firefighting encompasses muscular strength, muscular endurance, and flexibility, as well as cardiovascular fitness.(Davis et al, 2002; Smith, 2011) It is generally recommended that firefighters maintain an aerobic capacity (VO_2max) of approximately 42.0 $mL \cdot kg^{-1} \cdot min^{-1}$ in order to safely complete the average workload of job demands.(Sothmann et al., 1992) This second aim was addressed utilizing annual clinic data from the required physical examinations of TFD employees. These data are used to assess the reliability of specific fitness measurements (e.g., VO_2max, percent body fat, strength, flexibility, etc.) over a five year time period. In addition, a comprehensive fitness score was developed that may more readily and reliably represent an individual's overall fitness status.

Aim III. To measure the effect of aerobic capacity and other components of fitness on injury occurrence (Manuscript 3)

Over the last decade, the job duties for emergency service employees have expanded, resulting in their general recognition as first responders to all emergencies. As such, both physical and mental fatigue that can result in a standard 24-hour shift may increase the likelihood of injury. Individuals with higher aerobic capacities by definition should be more efficient in circulating oxygen to all systems of the body and in energy production. Hence, those with higher VO_2max may have a lower potential for injury.

The final aim of this dissertation research focused on measuring the relationship between VO_2max and injury. It was hypothesized that ESEs with a lower estimated VO_2max will have an increased likelihood of injury compared to ESEs with normal-to-high levels of aerobic capacity. Quantitative methods, notably log-binomial and time-to-event (i.e., injury) regressions, were used to address this aim.

V. Significance

Injuries are a burden to any work environment and result in lost time and lost productivity to the organization and to the individual. Most injuries are multifaceted and can result from the time-sequence in which hazardous exposures are experienced. By identifying predictive factors of injury, proper strategies for injury mitigation and prevention can be developed, thus, improving the general health and wellness of emergency service employees. Given the limited resources that most fire services face, improving workforce conditions and employee health will decrease direct and indirect costs to departments. In addition, by developing a practical injury model, fire services will be more effective at evaluating and utilizing the health surveillance information they routinely collect.

This dissertation research stems from the investigators' previous work in occupational health and injury research. Occupational settings rarely collect regular health and exposure information that are of sufficient quality to allow valid comparisons between the ill and well, and the injured and uninjured. It is especially uncommon for injury studies to include a range of potential predictive measures of injury within a focused population. Prevention models developed from injury epidemiology and risk management approaches should act synergistically to identify appropriate injury prevention strategies.

The combination of incorporating available scientific data with conditional or situation-specific inputs increases the ability of researchers (and the organization) to recognize hazards and the potential consequences of risky and inadequately planned decisions.

VI. Explanation of the dissertation format

This dissertation research utilizes secondary data obtained by the candidate from the Tucson Fire Department. The format fits the elements of the “three paper approach” , with the three specific aims of the research associated with three separate manuscripts. Prior to the description of results, this dissertation includes an in-depth background and literature review that has a specific focus on the history and concepts of injury epidemiology, risk factors and the prevalence of injury in the fire service, measurements of fitness and aerobic capacity. Overall methodologies are detailed in the *Present Study* section, along with an expanded executive summary of the methods, results, and discussions unique to each of the primary aims and manuscripts. The *Conclusion* section presents potential biases and limitations of the overall design and a discussion of the implications of the overall work. Each of the three primary papers can be found within the appendices of this dissertation.

With oversight from committee members, the candidate was responsible for coordinating and conducting all data acquisitions, management and analyses related to this dissertation research. In addition, the candidate managed the administrative duties and coordination with the Tucson Fire Department.

BACKGROUND

I. Injury Defined

Injury can be defined as the damage sustained resulting from an imposed load that exceeds the tolerance (load-carrying ability) of a tissue.(Whiting and Zernicke, 1998) Factors that may contribute to the occurrence or severity of an injury include (but are not limited to) age, gender, genetics, physiological condition, nutrition, psychological status, fatigue, environment, equipment, previous injury, co-morbidities, drug use, human interactions, ergonomics, inadequate rehabilitation, skill level, experience, pain, and anthropometric variability (height, weight, body composition, etc.).

Relatively speaking, epidemiological methodologies focused on injury outcomes have not been the issues leading public health matters. Nevertheless, focused research to understand the etiology and survivability of injuries has been around for close to a century.

II. Evolution of Injury Science

While many researchers have added significant contributions to injury literature, the following five individuals (William Haddon, Jr., Hugh De Have, John Stapp, John Gordon, and James Gibson) best exhibit the progression of injury science since the early 1930s. Whether intentional or not, these researchers expanded each others' work to frame the fundamental understandings and methods used in today's injury prevention research. The following section provides an overview of the history of injury epidemiology.

William Haddon, Jr.

Many of the concepts and methodologies used in injury science today have a fundamental origin rooted in studies focused on the physics and biomechanics involved in automobile crashes. As the first Administrator of the U.S. Federal Highway Safety Agency (present day National Highway Traffic Safety Administration, NHTSA), William Haddon, Jr. is considered the father of modern injury epidemiology. Haddon is most noted for the development of "Haddon's Matrix", a theory-based model to conceptualize etiologic factors for injury and to identify potential preventive strategies.(Haddon, 1968; Runyan, 2003) The matrix is used to place the events leading to injury in sequential order, allowing for various epidemiological concerns to be identified: (1) human factors, (2) the agent or vehicle, (3) physical environment, and (4) sociocultural environment (Figure 2). Ten countermeasure strategies for injury control, also developed by Haddon, have demonstrated value in addressing most health problems (Table 2). These countermeasures, in conjunction with Haddon's Matrix, provide a fundamental basis for the development and implementation of prevention strategies.

Figure 2. The Haddon's Matrix, annotated with primary questions

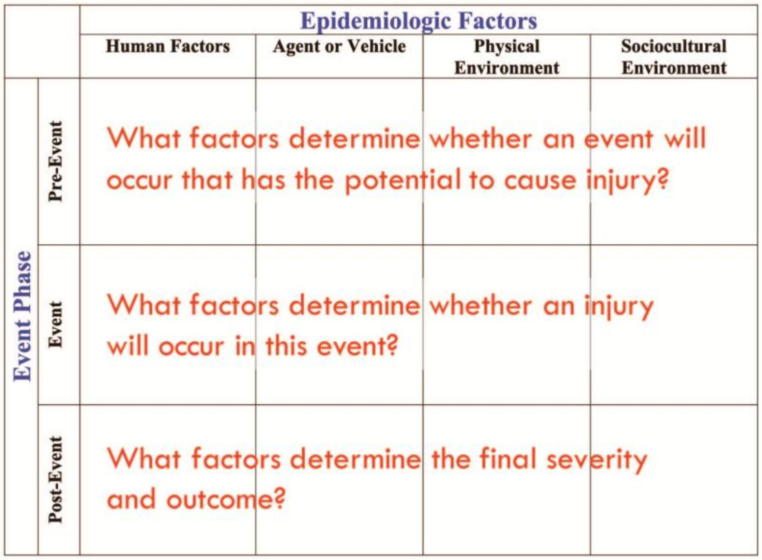


Table 2. Haddon's countermeasures for injury control

1	Prevent the creation of the hazard
2	Reduce the amount of hazard brought into being
3	Prevent the release of the hazard
4	Modify the rate of release of the hazard from its source
5	Separate the hazard from that which is to be protected by time and space
6	Separate the hazard from that which is to be protected by a physical barrier
7	Modify relevant basic qualities of the hazard
8	Make what is to be protected more resistant to damage from the hazard
9	Begin to counter damage done by the hazard
10	Stabilize, repair, and rehabilitate the object of damage

While Haddon, Jr. certainly deserves recognition for developing a simplified approach to examine the dynamic interactions of factors that contribute to the risk of injury and its outcome, his work came about as a natural progression of research conducted up to his time.

Hugh De Haven

Hugh De Haven was best known for his 1942 War Medicine publication, "Mechanical analysis of survival in falls from heights of fifty to one hundred and fifty feet," (De Haven, 1942) which first began to evaluate the limitations of the human body's ability to withstand mechanical injuries (most notably impacts from structures and objects). His intent to study "force survival" – the impact and deceleration forces distributed over time and surface of the body – demonstrated how even moderate changes to structural engineering of automobiles and aircrafts could produce significant benefits to safety. This began his research in the area of crashworthiness and engineering safety, from which his engineering approach and design for aviation safety were directly applied to automobile safety.

John Stapp

Colonel John Stapp, of the U.S. Air Force, expanded De Haven's research on human tolerance, conducting research from the 1940s through the 1970s. He was credited with designing the three-point restraint system (today's seatbelt), as well as being the "fastest man alive" and coining the phrase "Murphy's Law" (i.e., *"that which can go wrong, will go wrong; and at the most inappropriate time*") through various unexpected research testing failures. Stapp primarily studied the effects of high altitude flight, as well as human deceleration – the ability of the body to withstand gravitational forces (i.e. "G-forces").(Stapp, 1957) Prior to his research and testing methods, aircraft cockpits were designed to withstand forces up 18 Gs. Results from his research showed the human body could withstand forces upwards of 46 Gs, resulting in the redesign of aircraft seats and restraint harnesses to withstand 32 Gs. These concepts helped influence automobile safety and design, particularly seatbelt installations in vehicles, soft dashboards, collapsing steering wheels and shock absorbing bumpers.

John Gordon

John Gordon, MD, was Chief of Preventive Medicine for U.S. forces during WWII, head of Harvard's department of epidemiology and member of the World Health Organization. Gordon became the first to place injury control within the public health framework with his 1949 paper in the American Journal of Public Health entitled "The Epidemiology of Accidents." In this manuscript, Gordon related injury events to the common epidemiologic triad (host, agent and environment) and used both single source outbreaks and seasonal cyclical distributions to demonstrate the relationship between infectious disease epidemiology and injury, and how the concepts and methodologies are applicable. Specifically, an outbreak of typhoid fever at a circus in 1934 was compared to the large number of fatalities from the 1942 Cocoanut Grove night club fire in Boston (Figure 3). In addition, Gordon demonstrated the seasonal variation of Scarlet fever in relation to motor vehicle crashes during the same timeframe in Massachusetts (1943-1947, Figure 4).

Figure 3. Comparison of the 1934 typhoid fever outbreak to fatalities from the 1942 Cocoanut Grove night club. *From Gordon, 1949*

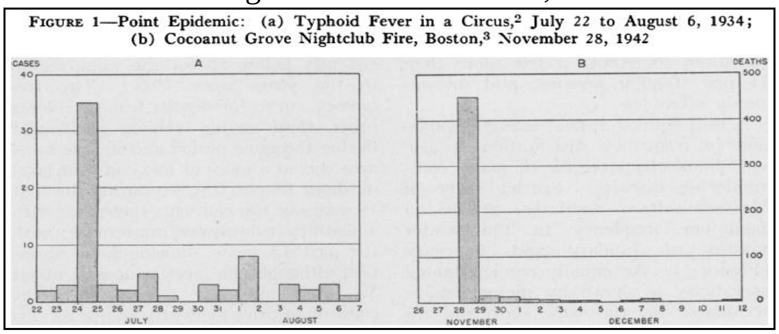
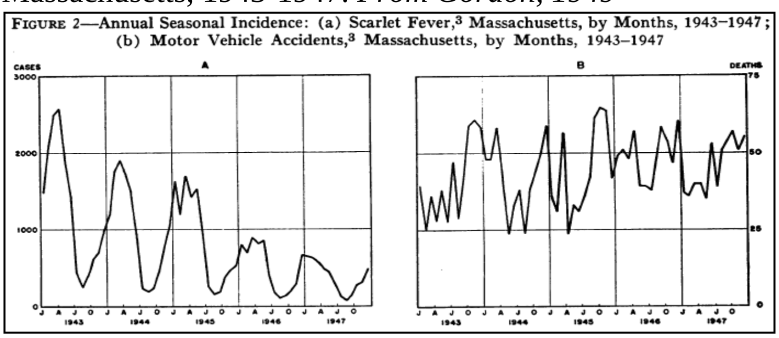


Figure 4. The seasonal variation of scarlet fever in relation to motor vehicle crashes in Massachusetts, 1943-1947. *From Gordon, 1949*



James Gibson

James Gibson was an experimental psychologist, whose research diverted from the more conventional focus of behaviorism at the time and developed theories around visual perception, most prominently detailed in his 1950 American Journal of Psychology article, “The perception of visual surfaces”. While this manuscript expressed fundamental construct for his future work, his most significant contribution to the epidemiology of injury came in a 1961 paper entitled, “The contributions of experimental psychology to the formulation of the problem of safety” in *Behavioral Approaches to Accident Research.*

In this work, Gibson began to detail the relationship between individuals' perceptions to that of 'dangers,' defined as "an external source of potential injury." The details and approach to his theories were dubbed "stimulus ecology," attempting to evaluate how and what information is presented to the individual and further developed into perception (of danger). How these perceptions of danger promoted behavior or action/inaction on a continuum was what Gibson referred to as "practical space-perception," which contributed to the margin of safety – the momentary cutoff in which the conditions of a situation change enough to reclassify a previously safe situation to dangerous (or vice versa).

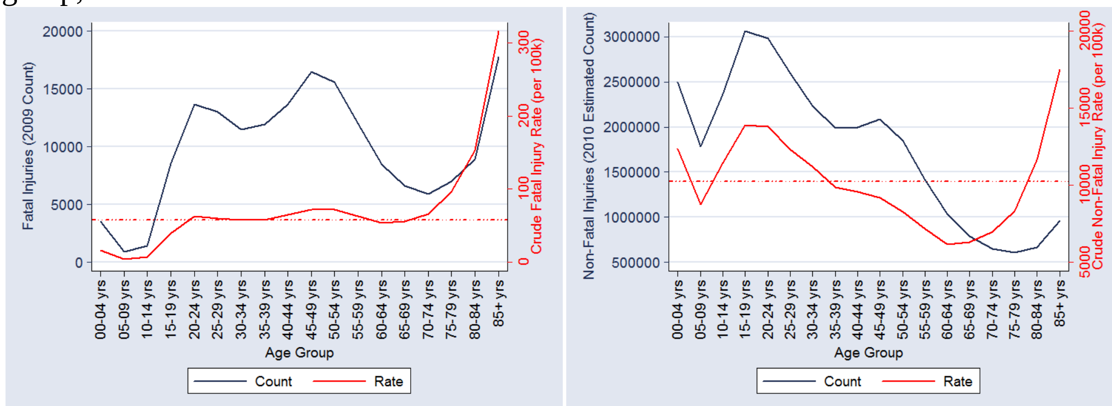
Arguably the most significant contribution of this research was Gibson's contention that, "*Injuries to a living organism can be produced only by some energy interchange*."(Gibson, 1961) This simple portrayal of injury quickly resulted in a coherent and well-defined classification scheme of the factors that could potentially contribute to injurious events, and thus be controlled to prevent or minimize one's exposure to these energies. It is at this time that Haddon conceptualized his Injury Matrix for breaking-down how injuries may evolve and where targeted intervention strategies should be applied.

III. Framing Today's Injury Problem

The Centers for Disease Control and Prevention (CDC) and the National Center for Injury Prevention and Control (NCPIC) maintain the Web-based Injury Statistics Query and Reporting System (WISQARS). This system is an interactive database accessible to the public and can be used to generate customized reports for injury related data. Fatal injury reports utilize death certificate data collected from the National Vital Statistics Programs. Non-fatal injury data are national estimates based on injuries treated from strategically selected emergency departments of the National Electronic Injury Surveillance System - All Injury Program (NEISS-AIP).(CDC/WISQARS, 2012)

Figure 5 illustrates the relationship between the frequency and rate of injuries for both fatal and non-fatal outcomes with respect to one's age for the year 2009. While the incidence rate of fatal injuries remains fairly constant for ages 15-70, it is around ages 70-75 that the rate of fatal injuries drastically increases with age. The non-fatal injury incidence rate appears to follow more of a elongated sinusoidal curve, with an elevated rate in the first 30 years of life, decreasing until the age of 60, followed by an exponential increase in incidence rate through the remaining age brackets. While risk of injury exists throughout an individual's life, the factors related to this risk will vary with stage of life, thus the distribution of injury types and frequency vary greatly with age. In 2009, unintentional injury was the leading cause of death in the United States (U.S.) for ages 1-44 years and the fifth leading cause of death for all ages.(NCIPC/CDC, 2012)

Figure 5. Count and rate (per 100,000) of Fatal* and Non-fatal[†] Injuries, by 5-year age group, 2009



*Fatal injury values taken from National Vital Statistics Program (via WISQARS)
[†] Non-fatal injuries are 2010 estimates from NEISS-AIP (via WISQARS)

Note: Horizontal reference line corresponds to the overall crude rate for all ages

Causes (according to the CDC) for fatal injuries were most often motor vehicle crash, poisonings, falls, suicides, homicides, suffocation and drowning. Among non-fatal injury events, the leading causes included falls, overexertion, being struck by or against an object, motor vehicle collisions, lacerations and piercings, physical assaults, and animal bites or stings, although these causes varied by age.(CDC, 2012)

IV. Risk factors for injury

Risk factors for injury are typically labeled as either intrinsic (factors related to the physical person) or extrinsic (factors related to the environment around the person), and can be further categorized as related to personal, ergonomic, or psychosocial (e.g., stress, boredom, fatigue, support) attributes.(Taimela et al, 1990; van Mechaelen, 1992; Wilson 2002) The interplay between intrinsic and extrinsic risk factors often creates conditions suitable for injury to occur.

Factors that may contribute to the occurrence and/or severity of an injury include (but are not limited to) age, gender, genetics, physiologic condition, nutrition, psychological status, fatigue, environment, equipment, previous injury, disease, drug use, human interactions, ergonomics, inadequate rehabilitation, skill level, experience, pain, and anthropometric variability (e.g., height, weight, body composition, etc.).

Extrinsic factors of Injury

Adverse environmental conditions suggest some of the more obvious factors that could contribute to injury. Conditions such as air quality, extreme temperatures, high humidity, altitude, wind, and visibility may lead to increased exposure and physical stress, delaying recovery and increasing risk of overtraining.(Raglin 1999, Renstrom and Kannus, 2000) Uneven or slippery surfaces and visibility of hazards (e.g., due to darkness) add additional risks toward promotion of injury.(Layne, 2004, Verma, 2010; Johansson, 2009) Exposure to excessive loads (i.e., energy) may be dictated by the type, speed and intensity of movement, as well as the number of repetitions. Personal protective equipment (e.g., properly fitting shoes, helmets, pads, etc.) help reduce energy loads experienced by the individual.(Daneshvar, 2011; Pasquier, 2011; Hirschmuller, 2011; Dick, 2007; O’Neil et al, 2011; Giuliani et al, 2011) The quality of equipment (e.g., during structured exercises or normal work operations) has also been shown to influence equipment failures. Furthermore, training errors, in terms of poor program planning (e.g., overtraining syndrome), improper biomechanical technique, or inadequate warming-up of the musculoskeletal system, can all influence the likelihood of injury.(Raglin, 1999; Renstrom, 2000)

Intrinsic Factors of Injury

Intrinsic risk factors are related to personal characteristics or factors such as age, gender, body composition, local anatomy, and fitness levels. Willems et al (2005 a & b) suggest that the true causal relationships between risk factors and injury is largely unexplained, mostly due to minimal prospective study designs and lack of consensus in influential intrinsic risk factors with regard to specific injury types (inversion ankle sprains). (Beynnon et al 2002)

The type of injury may be influenced by age.(Chau et al, 2009; Croisier, 2004; Hollander and Bell, 2010; King et al, 2009; Kaufman et al, 2000; Kenny et al, 2008) Younger individuals may have musculoskeletal systems that are not fully "developed", and therefore have more flexibility and laxity, while older populations tend to have reduced flexibility, laxity and possible degenerative conditions. Gender differences involved in injury include muscle strength, aerobic capacity, body fat and hormonal activity.(Chaudry et al, 2010; Croisier, 2004; Feuerstein et al, 1997; Hollander and Bell, 2010) Central motor control (i.e., balance), skeletal abnormalities, alignment of joints, ligamentous laxity, etc. each influence local anatomy and biomechanical limitations.(Lavender et al 2007a, b; Conrad 2008; Clemes, 2010; Chaffin, 2009; Crill and Hostler, 2005; Croisier, 2004; Fields et al, 2010; Kaufman et al, 2000; Mehta and Agnew, 2010; O'Niel et al, 2011; Hamonko et al, 2011; Hewett and Myer, 2011)

Fitness levels, as measured by muscular strength, muscular endurance, aerobic capacity, flexibility and body composition help predict one's ability to do work. Those individuals that are more "fit" might not be as susceptible to the microtraumas and can tolerate and recover a little better than their less fit counterparts.(Crill and Hostler, 2005; Croisier, 2004; Anderson, 2010; Giovannetti et al, 2012; Henning et al, 2011; Hollander and Bell, 2010; Kaufman et al, 2000) Conversely, a high fitness level may also be an indicator for increased injury risk as these individuals may have greater exposure to hazards and may be prone to increased loads. In addition, individuals (of similar fitness levels) will respond to stressors differently.(Raglin 1999) Observation and tracking of training performance, rest, and nutrition and hydration are essential in avoiding overreaching and overtraining. Other intrinsic factors that may predispose one to injury include psychological and psychosocial factors, previous injury, predisposing musculoskeletal disease or preexisting illness.(Fields et al, 2011; Marras et al, 2009; Caruso et al, 2004)

V. Occupational Injuries

Improvements in workplace practices, advancements in safety awareness, environmental control and the establishment of government agencies to promote and enforce safety policies led to significant gains in occupational health and safety in the twentieth century.(Hemenway, 2009) Still, however, occupational injuries comprise the greater part of reported workplace morbidity today. A review of the National Health Interview Survey (NHIS) estimated higher workplace injuries rates than what the Bureau of Labor Statistics reported, with approximately 11.7 injuries occurring to every 100 employed persons, 29% of which occurred at the workplace.(Smith et al., 2005) It was also estimated that in the year 2000 the economic burden of medical treatment and lost productivity due to injury totaled more than $406 billion, with most of these costs attributed to lost productivity.(Finkelstein et al. 2006)

Reducing injury rates is always a difficult challenge, and this challenge is increased for workers in a high risk industry. The need to evaluate health and safety measures used to protect firefighters and other emergency medicine personnel (e.g., emergency medical technicians, paramedics) has increased over the last decade, especially since the devastating events of September 11th.(Fabio, et al. 2002) However, few studies have evaluated the underlying causes of injury among the fire service, and there is also a lack of epidemiologic studies focused on implementing injury prevention strategies.

VI. Injuries in the Fire Service

According to the National Fire Protection Association (NFPA), there are an estimated 1.1 million firefighters in the U.S., approximately 30% of which are career firefighters, while the remaining 70% serve in a volunteer capacity.(NFPA, 2011) Firefighters and emergency medical services personnel have a high incidence of occupational injuries and fatalities. Through the U.S. Fire Administration (USFA) and National Fire Incident

Reporting System (NFIRS), the NFPA estimated that 71,875 firefighter injuries were reported in the workplace during 2010, in addition to 72 line-of-duty deaths.(Karter, 2011a; Fahy, 2011) Forty-five percent of injuries and 29% of fatalities occurred on the fireground. The USFA also reports that there were approximately 1,331,500 fires in the U.S. in 2010, resulting in 3,120 civilian deaths, 17,720 civilian injuries, and direct property damage totaling $11.6 billion.(Karter, 2011b)

It is worth noting that there is no standardized injury reporting system at the national level for fire departments. The NFPA and USFA each reported 72 and 87 line-of-duty deaths, respectively, for 2010.(Fahy, 2011; USFA, 2011) For an outcome that can be considered a reasonably clear outcome to classify, the differences in number of line-of-duty deaths for a given year highlights the inconsistencies in defining what qualifies as a job-related fatality. Given the lack of standardization or national model for injury reporting in the fire service, the number of individuals injured (non-fatally) while performing job-related duties must also vary.

In general, the mission of most fire departments is to protect life and property, while promoting public safety through comprehensive education and conservation programs. Since the late 1970s, the number of structural fires has steadily decreased (Figure 6, Karter, 2011) most notably due to the advent of improved fire suppression systems and construction.(Aherns, 2011; Huang, 2009) Over the last decade, fire service employees have taken on additional responsibilities and are considered first responders for all emergencies (e.g., fire, public emergencies, individual medical emergencies, natural disasters, and terrorist acts). With these additional roles and responsibilities, firefighters must manage a host of dynamic occupational hazards and risk-laden environments. It is unlikely that any other occupation is responsible for responding to such a myriad of events that present a potentially high risk range of hazards. Table 3 lists just a few of the various activities and hazards potentially faced during a firefighter's shift.

Figure 6. U.S. fire incident trends (in thousands): 1977- 2010. From Karter, 2011

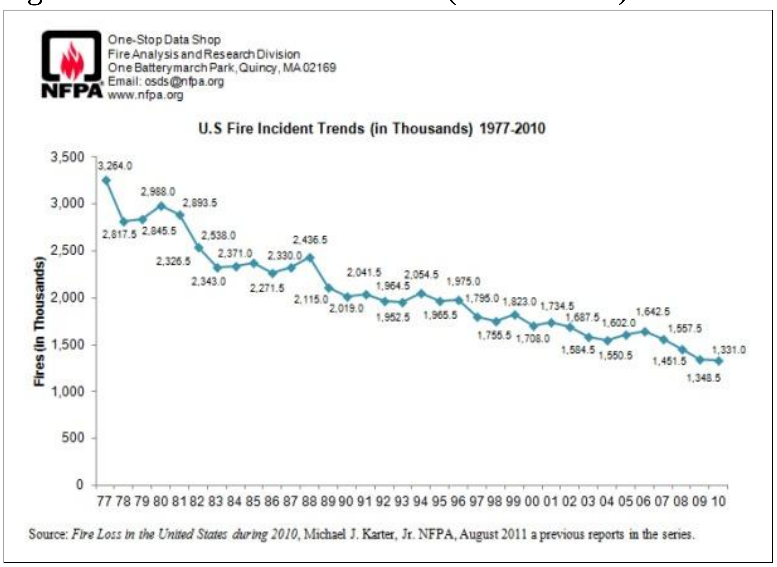


Table 3. Sample of common firefighting responses, job duties and hazards

Response scenes	**Job duties**		**Hazards**	
Structure fires	Patient search & rescue	Vehicle extrications	Extreme temperatures	Low visibility
Wildland, brush fires	Advance life support	Forcible entry	Confined spaces	Animals, wildlife
Motor vehicle crashes	Hose lift and carry		Electrical hazards	Heavy equipment
Medical emergencies	Stair and ladder climb		Violence	Unstable grounds
Technical rescue	Charged hose advancing		Hazardous Materials	

Within each of these response categories, the environments, potential hazards and risks are extremely dynamic. Given the extreme climactic and environmental conditions within the U.S. Southwest, potential risk dynamics are compounded and require equally as dynamic mitigation solutions. In addition, the risks from any of these hazards can be modified by the sense of immediacy (time), sensory deprivation (e.g. low visibility, high noise environments), the weight of the protective gear (e.g., turnouts and self-contained breathing apparatus, SCBA) and equipment used during response activities, and the potential for fatigue from high number of response calls and lack of adequate rest.

While firefighting and emergency medical services (EMS) have been shown to have among the highest occupational incident rates for injury and fatalities (Studnek et al, 2007; Fabio et al, 2002; Fosbroke et al, 1997), few studies have demonstrated significant evidence as to the root cause(s) of injury in the fire service. Those studies that have investigated injuries within a fire service generally focus on aspects or condition of the fireground.(Heineman et al, 1989; Hall and Harwood, 1989; Guidotti and Clough, 1992; Fabio et al, 2002; Rabbitts et al, 2005) Firefighters have a high risk of injuries due in part to the need to perform strenuous activities in a dynamic environment. Most training and response activities require awkward positioning and significant exertion, increasing the likelihood of injury, as well as the need for above-average functional movement.

VII. Work demands of firefighting

A metabolic equivalent of task (or MET) is an estimate of intensity based on the ratio of working metabolic rate to resting metabolic rate.(Heyward, 2010) It is used to describe the amount of work needed to complete a given task, in relation to the amount of energy expended during one minute of seated rest (MET = 1). Adopted from Matheson (1985), Table 4 lists common activities and the related MET required to complete the task. A MET of 1 is considered equivalent to an aerobic capacity (VO_2max) of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$, thus one measure can be estimated from the other.

Table 4. Physical Demand Characteristics of Work (from Matheson, 1985)

PHYSICAL DEMAND LEVEL	OCCASIONAL (0-33% of the workday)	FREQUENT (34-66% of the workday)	CONSTANT (67-100% of the workday)	TYPICAL ENERGY REQUIRED
SEDENTARY	10 lbs	Negligible	Negligible	1.5 – 2.1 METS
LIGHT	20 lbs.	10 lbs. and/or Walk/Stand/ Push/Pull of Arm/Leg controls	Negligible and/or Push/Pull of Arm/Leg controls while seated	2.2 – 3.5 METS
MEDIUM	20 to 50 lbs.	10 to 25 lbs.	10 lbs.	3.6 – 6.3 METS
HEAVY	50 to 100 lbs.	25 to 50 lbs.	10 to 20 lbs.	6.4 – 7.5 METS
VERY HEAVY	Over 100 lbs	Over 50 lbs.	Over 20 lbs.	Over 7.5 METS

For context, the National Institute for Occupational Safety and Health (NIOSH) has recommended that the energy expenditure for an 8-hour work shift should not exceed approximately 21% of aerobic capacity, when work is primarily performed with the arms and 30% otherwise.(Anderson, 2010; Waters et al., 1993; NIOSH, 1981) Maximal acceptable workloads have been shown to be significantly affected by the frequency of performing the task (e.g., lifting, lowering, carrying, pushing, pulling, etc.).(Garg and Saxena, 1979)

The job duties related to firefighting and paramedicine require an active lifestyle and high physical demand.(Barnard and Duncan, 1975; Bos et al, 2004; Davis et al, 1982; Davis and Dobson, 1987; Duncan et al, 1979; Gledhill and Jamnik, 1992; Holmer and Gavhed, 2007; Kilbom, 1980; Lemon, 1977; Matticks et al, 1992; Rhea, 2004; Sharkey and Gaskill, 2009; Smith et al, 2001; Williford et al, 1999; von Heimburg et al, 2006) Most studies evaluating the physiologic responses to firefighting have focused on simulated fire suppression activities, as these scenes require a wide variety of heavy work and stress. Measured responses to the typical fireground activities most often pertain to heart rate and oxygen consumption, which are then extrapolated to the required capacity to perform work. Barnard and Duncan (1975) were one of the first to document how strenuous firefighting activities led to near maximal heart rates, which can remain elevated for extended periods. This has been supported by many other researchers; more recently, Smith (2011) detailed how firefighting requires high level of aerobic fitness, anaerobic capacity, muscular strength and muscular endurance. The majority of simulated experiments testing the aerobic capacity needed to perform the activities regularly encountered on the fireground suggest that a minimum aerobic capacity between 33.6 – 49 $mL\cdot kg^{-1}\cdot min^{-1}$ is needed.(Gledhill, 1992; Lemon, 1977; Malley, 1999; Sothmann, 1990)

The Candidate Physical Ability Test (CPAT) was developed by select fire departments through the Wellness Fitness Initiative (WFI), established between the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC).(IAFF, 2008) CPAT is a widely utilized physical ability test that all candidates must pass (along with other civil service and oral exams) in order to be accepted into fire academy training. The CPAT involves a continuous circuit of 8 fire simulations tasks (Table 5) while wearing a weighted vest, safety gloves and helmet.(IAFF, 2000) For wildland firefighters, the Pack Test is a standard test for assessing fitness and ability to complete expected required job functions and involves a 3-mile hike to be completed in 45 minutes or less, while carrying a 45-pound pack. Completion of the test within the allotted time equates to an aerobic capacity of approximately 45 ml/kg/min.(Sharkey and Gaskill, 2009)

Table 5. Standard CPAT simulated drills from IAFF/IAFC Wellness Fitness Initiative (IAFF, 2000)

Stair climb	Forcible entry
Hose drag	Search
Equipment carry	Rescue drag
Ladder raise and extension	Ceiling breach and pull

Williams-Bell (2009) found that 65% of the variability in time to complete the CPAT was predicted by VO_2max, body mass index (BMI) and hand-grip. Average VO_2max for men and women that passed the test was 38.5 and 36.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively, with heart rates reaching 90% and 91% of the predicted maximum. Similarly, Michaelides et al (2011) identified abdominal strength, relative power (via step test), upper-body strength and upper-body endurance to be associated with time to completion of a fire simulation ability test. High resting heart rate, BMI and percent body fat were associated with poor performance in the ability test.

A more extensive assessment of the physiologic stresses associated with structural firefighting was conducted by Brown et al. (2009). They observed that the four most physically demanding job tasks on the fireground were – fire attack, search and rescue, exterior ventilation, and overhaul operations. Findings indicated that a person must be working within a range of 60-95% of one's maximal capacity for regularly performing these job tasks.

Fit individuals will be more efficient in their job tasks. That is, they will accomplish more with less fatigue; they will cope and recover faster from long shifts, hot environments, reduced rest; and they will miss fewer days from work due to illness or injury. Physical ability or capacity to do work (and thus fitness) will dictate one's performance.

VIII. Aerobic capacity

Most municipal fire departments require periodic individual fitness testing and medical clearance by means of a medical and physical exam. There are various metrics used to measure and define one's fitness, which are often debated between disciplines. Exercise physiologists (and similar researchers) often use the maximal oxygen uptake (VO_2max) as a measure of cardiorespiratory fitness (aerobic capacity) and a proxy measurement for overall fitness.(ACSM, 2010) Aerobic capacity can be defined as the highest rate at which oxygen can be taken up and utilized by the body during rigorous exercise.(Bassett, 2000)

The respiratory and cardiovascular systems play vital roles in energy production (adenosine triphosphate, ATP), delivery of oxygen and nutrients, and in the removal of waste products. Muscles transfer chemical energy into mechanical energy. The efficiency by which muscles conduct this transfer are related to (1) aerobic capacity, (2) blood flow, (3) muscle capillarity, (4) mitochondrial content of muscles cells, and (5) muscle hypertrophy (Wilson, 2002). Because oxygen consumption is linearly related to heart rate and energy expenditure, when oxygen consumption is measured, there is an indirect measuring of an individual's maximal capacity to do work aerobically.(ACSM, 2010) Aerobic capacity (VO_2max) is expressed as a rate, referenced in either absolute terms (L/min) or by relative measures (ml/kg/min) to account for individual size variations.

There are inter-individual differences in VO_2max. The four basic limiting factors of VO_2max are (1) pulmonary diffusing capacity; (2) maximal cardiac output; (3) oxygen carrying capacity of the blood; and (4) skeletal muscle characteristics. Aerobic capacity is primarily limited by the rate of oxygen delivery (i.e., heart, lungs, and blood), not the ability of the muscles to take up oxygen from the blood. It is estimated that 70-85% of the limitation in VO_2max is linked to maximal cardiac output.(Cerretelli, 1987)

Aerobic fitness can be measured by a number of tests, each of which is more or less appropriate for the population to which it is applied. The *Bruce Protocol Stress Test* was established in the early 1960s for the evaluation of known or potential cardiac care patients, and since has been adapted and used by many medical and occupational disciplines.(Heyward, 2010) In general, the treadmill test consists of approximately ten stages during which the incline and speed are increased every three minutes until the patient reaches complete exhaustion (hence, a maximal test). Data on blood pressure, heart rate, and sometimes perceived physical exertion are collected during the test. This protocol indirectly calculates VO_2max, as it uses a formula to estimate VO_2max (one for men and women). Those formulas are

Male: $VO_2max = 14.8 - (1.379 \times T) + (0.451 \times T^2) - (0.012 \times T^3)$

Female: $VO_2max = 4.38 \times T - 3.9$

where T is the amount of time (minutes) spent on the treadmill.

Another measure used in fire departments (including Tucson Fire Department) is *Gerkin Treadmill Protocol* (an adaptation of the *Bruce Protocol Stress Test*). The Gerkin Protocol is a submaximal test used to estimate maximal aerobic capacity via an incremental treadmill test, using guidelines suggested by the National Fire Protection Association (NFPA).(Gerkin, 1997) Direct measurement of VO_2max can be completed in a laboratory setting with oxygen and carbon dioxide analyzers, in addition to monitoring of electrocardiogram (EKG) output; however, it is typically too expensive (and uncomfortable) for most fire departments to employ.

The cardiorespiratory work required to perform firefighting duties has been a contentious debate, and was well described in two articles by Mark Sothmann.(Sothmann et al, 1992 a and b) The theory is that a more "fit" person will have a greater reserve to do work than an "unfit" person. By having a lower capacity to do work, the "unfit" person is more susceptible to risk of injury, in addition to a host of other morbidities. For emergency service workers, an "unfit" person would also risk the ability to perform life-saving procedures and community protection that they selflessly undertake on a daily basis. In a review of heart rate response and oxygen consumption (VO_2max) during actual fire suppression activities and maximal treadmill testing of ten male firefighters, Sothmann found an average predicted VO_2maxof 40.0 $mL \cdot kg^{-1} \cdot min^{-1}$ during emergency events (Sothmann et al, 1992b). He further recommended that active firefighters maintain a VO_2max range of 33.5 – 42.0 $mL \cdot kg^{-1} \cdot min^{-1}$ in order to adequately perform duties associated with fire suppression.

IX. Aerobic Capacity and Injury

As exhibited above, there are extensive studies that assess the relationship between various measures of fitness (e.g., cardiorespiratory fitness, body composition, flexibility, muscular strength, muscular endurance) and the performance of a given task (occupational, sport, recreational or other). However, the number of studies focused on assessing the association between fitness and injury potential are few and inconsistent in terms of methodologies and in findings.

Citing work completed by Battiee et al (1989), McSweeney et al, described inconclusive evidence for minimizing injury risk in the general working population through increased cardiovascular conditioning. Their study on manual material handlers indicated no difference in likelihood to report an injury between exercisers and non-exercisers.(McSweeney, 1999) The relationship between VO_2max and injury was not directly measured; however, those that exercised had a significantly higher absolute VO_2max. The authors also emphasized that increased or habitual exercise was likely to reduce absenteeism occurrence and duration.

After instituting a new fitness program among United States Air Force (USAF) service members to increase fitness and participation in fitness related activities, mean VO_2max increased significantly (6.04 and 3.24 $mL \cdot kg^{-1} \cdot min^{-1}$ among men and women, respectively) over three years of the program.(Giovannetti et al, 2012) Interestingly, the number of injuries also increased during that time, which was noted as a likely result of increased participation in exercise activities (i.e., increases in exposure time) with no injury prevention strategies embedded within the program.

Hootman et al (2001) studied the relationship between cardiorespiratory fitness and musculoskeletal injuries among participants of the Aerobic Center Longitudinal Study. Following a baseline treadmill test for VO_2max, participants were assessed for physical activity over a 12-month period. Physical activity was categorized into sedentary, walkers, runners, and sport participants, based on the amount of time spent each week in various activities. An increase in injury risk was associated with increases in cardiorespiratory fitness (via treadmill test), and increases in the amount of physical activity per week. Stratified analyses by physical activity type suggested that the association with cardiorespiratory fitness was potentially driven by unmeasured intensity levels of exercise.

During an 8-week basic military training regimen, musculoskeletal injuries were assessed in relation to baseline body composition (BMI), aerobic fitness (3000 meter run), health assessment measures and age.(Heir and Eide, 1996) Univariate analyses showed significant associations between injury and age over 23 years, increased BMI, slow run times, and dysfunction of back or lower limbs. Factors shown to be predictive measures in a mutlivariate logistic regression model included increased BMI, minor back and lower limb dysfunctions, as well as mental dysfunctions.

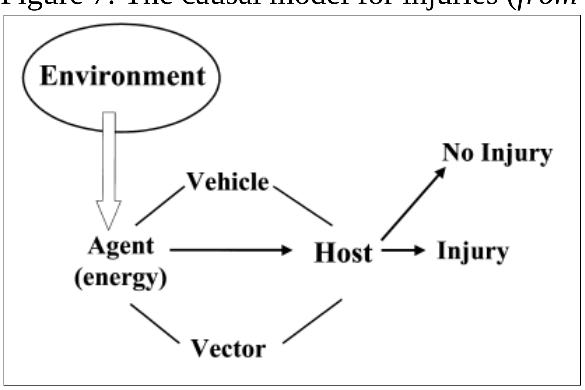
The relationship between injury occurrence, aerobic capacity (both absolute and relative), and body composition was studied among male material handler employees at three separate regional facilities.(Craig et al, 1998) No association was observed between injury occurrence and absolute aerobic capacity; however, injury and body composition were significantly related to the relative measure of VO_2max, suggesting that the methods used for measuring fitness are essential for understanding any potential relationships with injury (or other health outcomes).

Studies evaluating fitness within occupational or athletic settings tend to focus on performance-based outcomes (e.g., time to finish task, etc.) rather than injury. Of the studies that have assessed fitness and injury, few utilize measures other than aerobic power or endurance. Noreau and Shephard (1992) reported a positive relationship between muscular strength, endurance and body composition with return to work among paraplegics. Occupational health and fitness evaluations are also making more use of functional movement screening (FMS) tools. Improved body composition and FMS scores were related to decreased lost time and improved readiness for return to work.(Gross et al, 2004; Lee et al, 1997) In a study of Marine officer candidates, individuals with low FMS scores (≤14) had an increased risk of injury within two cohorts of short- and long-cycle training regimens.(O’Connor et al, 2011) While the current firefighter study assesses the relationship between cardiorespiratory fitness and injury, it will also explore the use of a comprehensive fitness score to potentially better reflect the functional fitness requirements associated with the job demands.

X. Summary of Background

Most injuries are multi-causal and evolve from a sequence of events. Rarely does the event result in injury from just one cause. Whether it is related to a decision made (or not made), an environmental factor, or an engineering failure, the causal pathway that leads to injury is complex, as exhibited by Peek-Asa's "causal model for injuries."(Figure 7, 2003) Epidemiologic strategies attempt to align with other disciplines (e.g., engineering, risk assessment, etc.) by combining available scientific data with subjective condition and situation-specific inputs. The framework laid out by Haddon (i.e., Haddon's Matrix) is used to analyze injury based on the host, agent, and the physical/social environment. These aspects are explored over time: actions leading up to the event, the event itself, and directly after the event with intent on identifying causal factors and potential injury preventive strategies.(Runyan 2003)

Figure 7. The causal model for injuries (*from Peek-Asa, 2003*)



The etiologic understanding of injuries among emergency service personnel is no less complex. The job responsibilities and work demands for firefighting lead to a need for increased physical fitness, influencing job performance (e.g., the ability to withstand loads, time to diminished capacity, and time to recover) and thus the likelihood for injury. A fit individual is able to complete tasks with less fatigue; cope and recover faster from long shifts, hot environments, and reduced rest; and miss fewer days from work due to illness or injury. The potential for injury increases once physical overexertion places one in a state of fatigue, as the ability to withstand external forces and continue job tasks in a controlled, safe manner is diminished.

This study assesses one's level of fitness, inferring job performance, in an effort to predict the potential for injury in a cohort of fire service employees. The hypothesis driving this research is that fit individuals will be overall more efficient in their ability to perform all job tasks, and thus be less susceptible to injury.

PRESENT STUDY

An explanation of the overarching methods and data sources are first presented in this section. More specific methodologies and results unique to each of the three primary aims and not included in the manuscripts are then presented in the form of an expanded executive summary. The prepared manuscripts are located in the appendices.

I. Study Design Overview

The research question governing this research is: are variations in fitness (via aerobic capacity or comprehensive measure for fire fitness) associated with the occurrence and/or severity of injury in a population of emergency service employees?

By making use of a retrospective occupational cohort study design, this research involves both descriptive and analytic approaches for studying risk factors associated with the occurrence and outcome of injuries in a population of commissioned service members of the Tucson Fire Department. No direct intervention was introduced during the study period. The described risk factors were assessed annually at the individual-level, over the span of six years (2004-2009) during annual physical examinations required by the department. Aerobic capacity (measured in terms of relative VO_2max) is the primary exposure of interest, estimated using a submaximal treadmill test commonly utilized in the fire service. Outcomes consist of any reportable injury sustained by the individual firefighter or paramedic during the study period. Information on these attributes and other potential confounding factors were obtained using data collected from both injury surveillance reports, and annual medical physical exams.

I.A. Conceptual Framework

Occupational settings rarely collect regular health and exposure information on healthy workers that would have the potential to make valid comparisons between the ill and well; the injured and uninjured. It is especially uncommon for injury studies to complete a census analysis of potential predictive measures of injury for a focused population. In large part, this research is data-driven. However, the combination of available scientific data with subjective conditional or situation-specific inputs increases the ability to recognize hazards and the potential to identify relevant control strategies of known or measured risks.

Preventing events means to actively cause something to not happen and, in order to do so, one must understand the circumstances in which an event occurs. The first aim of this study provides a more complete description of injuries in this population, over the years 2004-2009. The nature of injuries and factors related to their occurrence are classified according to standardized measures widely utilized in injury science.

The second aim describes trends among the physiologic and anthropomorphic characteristics of the complete occupational population (i.e., injured and non-injured) for the years 2005-2009 (note: clinic level data are unavailable for the year 2004) with emphasis on the reliability of measures over time. A more global (or comprehensive) measure of fitness is also developed to account for strength, endurance, flexibility, and body composition, in addition to aerobic capacity. The intent of this new measure of comprehensive fitness is to be used as a possible improved predictive tool for estimating the likelihood of injury.

The final (third) aim combines data from the first two aims to enable a direct comparison of physiologic characteristics between those who were and were not injured. The primary focus is to evaluate the relationship between VO_2max and injury. Quantitative research methods, notably log-binomial and time-to-event (i.e., Cox proportional hazards) analyses are used to evaluate the incidence of injuries sustained by employees in relation to their overall levels in VO_2max and comprehensive fire fitness, prior to injury. Models are used for the interpretation of exponentiated slopes, indicating the expected change or difference in the incidence rate ratio of injury based on changes in one or more of the explanatory predictors.

I.B. Setting & Population

The Tucson Fire Department (TFD; Tucson, Arizona) is an ideal population for this research because of strong leadership across all levels of the Fire Department as well as their history of collaboration on various health and safety projects with The University of Arizona Mel and Enid Zuckerman College of Public Health. The TFD is a medium-sized metropolitan fire department in the Southwest United States (U.S.). Fire service personnel include firefighters, paramedics, engineers, captains, inspectors, battalion chiefs, etc., referred to in this report as emergency service employees (ESEs). The TFD is comprised of approximately 650 career fire service employees, operating 21 fire stations that service nearly 520,000 permanent residents of the City of Tucson (increasing during Winter and Spring months). TFD employees averaged 41 years of age, were 5% female, and race/ethnicity was reported as 76.4% non-Hispanic whites, followed by Hispanics (19.6%), with all other groups each comprising less than 3% of the total.

Inclusion criteria consisted of active duty fire service personnel (e.g., firefighter, paramedic, inspector, safety chief, etc.) and a minimum 18 years of age. Volunteer and civilian fire service personnel were excluded from study analyses. While cardiac events (e.g., stroke, heart attack, etc.) are the most frequent cause of line of duty deaths in the fire service (Fahy, 2011), these events (along with heat exhaustion, stress and other medical issues) were excluded since these conditions are neither musculoskeletal nor integumentary, which are the foci of our analysis.

I.C. Data Collection & Management

I.C.1. Sources of Data

Data for this study were compiled using two databases utilized by the TFD. Outcome data were from the injury and illness surveillance databases maintained by TFD, which contained information related only to injured or ill firefighters. Results from required annual medical exams and performance testing were gathered for all active fire service employees utilizing the separate database maintained by the department's subcontracted occupational physician.

I.C.2. Injury Database

Injury data were obtained from injury/illness surveillance databases. The Tucson Fire Department is required to follow regulations denoted by Part 1904.12 of the Occupational Safety and Health Act of 1970 which defines recordable injuries to be any occupational injuries resulting in: (1) fatalities, regardless of the time between the injury and death; (2) lost workday cases, other than fatalities, that result in lost workdays; or (3) nonfatal cases without lost workdays which result in transfer to another job or termination of employment, or that require medical treatment (other than first aid), or involve loss of consciousness or restriction of work and/or motion. The surveillance database also included internally documented injuries (i.e., those deemed non- OSHA reportable) which were not associated with any immediate loss of job function or capabilities, but were documented in case the injury later progressed to a point requiring a report and or treatment (e.g., due to cumulative or repeated trauma). In addition, any injury that occurred to specific body regions: eye, neck, back, knee, ankle and shoulder were emphasized by TFD for employees to report. Variables included in the obtained injury data base included injury type, body part, location (scene) of injury, date and time, age, job rank, shift and station assignment, and a brief narrative.

No standard definition exists that is consistent across industries either nationally or abroad for the classification of injury. To help characterize injury incidents, the Occupational Injury and Illness Classification System (OIICS), developed by the Bureau of Labor Statistics was employed.(BLS, 2007) The general characteristics of injury events evaluated and classified in this study included: (1) nature of injury, describing the physical characteristics of the injury (e.g., fracture, sprain, laceration); (2) part of the body directly affected; (3) energy source (or agent) that directly inflicted the injury or illness; (4) mechanism of injury, which describes the manner in which the injury was inflicted by the source; and (5) secondary sources that contributed to the event or exposure. When available, a review of the narrative section of the injury report was used to better classify the risk factors (i.e., actions, agents and environmental characteristics) involved in the injury event. The mechanism of injury (MOI) was classified according to classification schemes from CDC's Web-based Injury Statistics Query and reporting System (WISQARS) (CDC, 2003), the World Health Organization's (WHO) External Cause of Injury Mortality Matrix for ICD-10 (WHO, 2001), and the Nordic Medico-Statistical Committee's External Causes of Injury (NOMESCO, 2007).

Injury Severity

In addition to the occurrence of injury, there was potential for an association between aerobic capacity and injury severity. Severity of the injury was scored two ways: (1) by number of days lost, if classified as a lost time injury and, (2) utilizing the Abbreviated Injury Scale (AIS). AIS is commonly used in trauma settings as a standard for measuring anatomical severity and is the basis for assessing the Injury Severity Score (ISS) for multiple injuries.(AAAM, 2008; Baker et al, 1974) Included in the most recent AIS coding structure is a prediction score for functional impairment (i.e., the Functional Capacity Index, FCI), which could be used to rank the anticipated level of functional ability one year post injury event. AIS and FCI were evaluated to add a standardized measure of severity and expand on the more common occupational use of indicating lost time. AIS is one of the most widely accepted tools to determine injury severity. The level to which AIS can be utilized will depend on the original data source and how well information on the injury is detailed.

Each injury observation was individually reviewed by the author and coded for mechanism of injury, energy type and potential agents when the information was provided. Given the limited details specific to injury, some coding for AIS and FCI could be considered subjective; however, the scoring of injuries was also completed by the author (a trained and certified AIS coder). The more important aspect of injury research is that methods accounting for the degree of severity use a standardized method to judge, score, and rank injury severity.

I.C.3. Clinical Exam Database

As part of their employment, commissioned employees are required to have annual physical exams to monitor for any potential deleterious effects or conditions (e.g., hearing loss, vision impairment, cancer risk), in addition to assessing for cardiovascular disease (the leading cause of line-of-duty-deaths among firefighting populations). The goal of the exam is to have an assessment of fitness status to ensure that the employee can maintain the ability to perform the myriad of job functions they are responsible for completing on a daily basis with little-to-no limitations. These assessments are not completed for any punitive purpose, but rather so that the individual may be provided the necessary level of guidance and resources (as determined by the department physician) to maintain a healthy career and retire with full function.

Data from annual physical exams were only available electronically for the years 2005-2009. Information collected from annual exams includes, but is not limited to, anthropomorphic measures (height, weight, body fat percentage), aerobic function (FEV_1/FVC) and capacity (VO_2max), muscular strength, muscular endurance, flexibility, blood analytics (cholesterol, blood pressure, triglycerides, C-reactive protein, etc.), and other medical indicators (smoking status/history, prostrate-specific antigen, etc.).

I.C.4. Clinic Data Quality Control and Assurance

The clinic data contained results from annual physical exams for members of the Tucson Fire Department (TFD) over the years 2005-2009. During that time 799 individuals from TFD were seen for annual physicals, resulting in 2,820 clinic observations (approximately 3.5 clinic visits per employee). Data for the year 2004 were not electronically available.

When the clinic data were first received, there were 2,949 clinical observations in the database. Inconsistencies were noticed in the identification of the same individual from year to year. These discrepancies were primarily due to errors made during the manual entry of personal identifying information at each visit into the clinic database (i.e., there was no auto-populating of patient information upon visit). In all, there were 438 (14.9%) person-year observations requiring additional review of paper records and correction prior to generating and verifying unique identifiers and completing the remaining data quality checks. In addition, since clinic visit dates were kept in a separate spreadsheet within the clinic and there was no means of easily merging this variable with the primary clinical database, these dates were manually entered (using double data entry methods) into the clinical database. Clinic visit dates were needed to accurately define age, time between evaluations and for time-to-event analyses.

In addition to the data checks for unique identifiers and creation of the clinic visit variables, a quality assurance check was performed on a 5% random sample of individuals in the dataset (n = 40 subjects). A medical chart review was completed for each year the individual was in the clinical database, resulting in 126 person-year observations. The review was focused on 33 variables of interest, therefore 4,158 data points.

Each record was examined by two reviewers. Six individual medical charts were unable to be located and reviewed due to the person's retirement and relocation of the medical record. Findings identified that 162 of the 4,158 data points were inaccurate (3.8%). Most errors were small in magnitude, with variations measured in tenths of a unit value (e.g. VO_2max of 43.6 instead of 43). Larger differences were often the result of a typographical error that should be identified and corrected by a simple descriptive analysis of value ranges. Two variables (left and right hand strength) were recorded as kilograms instead of pounds for the years 2005 and 2006 and were corrected prior to analysis. The two lung function variables (forced vital capacity, FVC, and forced expiratory volume in one second, FEV_1) were often found to be entered in reverse order; however, these measures were not of primary interest for this research. Still, no errors were found in the ratio of FVC to FEV_1, so the documented ratio may be used with greater confidence if lung function is explored. Overall, the variables of interest were within normal ranges to what was documented in the medical charts.

After completion of quality control of each data base, the dataset was merged with the injury data using a unique identifier generated for each employee identification number. All personal identifying information (e.g. name, social security numbers) were then removed prior to analysis.

I.D. Statistical Analyses

The first aim focuses on the description and distribution of injuries as it pertains to this population for the years 2004-2009, expanding the scope of description beyond the fireground and includes all job-related operations and activities. Injury rates were estimated using known staffing levels and the distribution of 8- and 24-hour employees. Injuries were classified as contusions, lacerations, sprains/strains, fracture, dislocation, etc., and further described (when possible) in terms of mechanism of injury (MOI), job operation, energy types and sources (agents) of energy.

Aim #2 describes selected individual health and fitness measures for the entire workforce population that were observed from the annual physical exams. The variation and reliability of these measures over the study period were evaluated using Rosner's intraclass correlation criteria.(Rosner, 2000) This analysis enables an indication of how individual fitness status (measured by distinct values as well as a combined metric) may fluctuate, change or remain over the five year period, and thus which may be the more consistent indicator for total functional fitness. Creation of a comprehensive fire fitness score was developed and assessed, and is described in the *Executive Summary* for Aim II below.

Aim #3 assessed the association between VO_2max and incidence of injury. That association was then contrasted against two other models that utilized other measures of fitness: (1) one that included seven variables or measures of fitness as independent explanatory variables, and (2) a model that included a summary fitness variable (fire fitness) which categorized individuals into one of three fitness levels, based on the summary scores of the seven fitness measures. The outcomes of interest included (1) any injury, (2) injury associated with physical exercise, and (3) any sprain or strain.

The clinical data analyzed for specific aims 2 and 3 involved repeated measures of individual employees over the years 2005-2009. Observations correspond to the employee's annual medical exam, which occurred approximately every 12 months and during which time the outcome (reported injury occurrence) was accumulated. The actual calendar dates vary for each individual; however, exposure variables were assumed constant throughout each time interval, during which injury may or may not occur. Not every employee has an observation for each year of the study period. Some individuals may be introduced later in the study period (e.g., new employees, etc.), while others may drop out (e.g., retirement, transfer).

Statistical Power

The incidence of injury in TFD during the study period was approximately 21 injuries per 100 employees. A power analysis for logistic regression with a single continuous predictor variable was performed. Assuming the probability of injury at the mean VO_2max is $p_1 = 0.2$ (approximate to the prevalence), and estimating the probability of injury at the mean VO_2max plus one standard deviation is $p_2 = 0.25$, a sample size of 532 individuals is needed to detected an odds ratio (OR) of 1.33 with 80% statistical power, assuming a significance level of 0.05. Adjusting the probability of injury for the mean plus one standard deviation (p_2), Table 6 demonstrates the necessary population sizes for various estimates of statistical power. Given the use of repeated measures on the same individuals, actual statistical power is likely to be greater. The added strength of being able to capture time-series (or longitudinal) data for the population should increase the ability to control for confounding effects both within and across individuals, and to evaluate for secular trends.

Table 6. Power and sample size estimates

	Power							
	0.60	0.65	0.70	0.75	0.80	0.85	0.90	
p2	**n**	**n**	**n**	**n**	**n**	**n**	**n**	**OR**
0.15	216	247	281	320	367	425	505	0.71
0.25	313	357	407	464	532	618	734	1.33
0.30	97	110	125	141	161	186	220	1.71
0.35	57	64	72	81	92	106	124	2.15

Analyses were conducted using Stata software, version 11.2 (StataCorp, College Station, TX). Human subjects' approval and monitoring was provided by the University of Arizona Institutional Review Board. This research falls under the guidance of a 4-year CDC/NIOSH-funded project focused on characterizing the risks of injury throughout the processes of patient transport, fireground operations and physical exercise. The identification, implementation and evaluation of prevention control strategies are being led by a partnership between the TFD workforce and project researchers.

II. Executive Summary of Primary Aims Methods and Findings – Aim I

[Beyond the Fireground: Injuries in the Fire Service]

II.A. Specific Aim I: To describe the current injury trends in a metropolitan fire department and to identify potential risks & hazards for occupational injury

The following is a summary of the methods, results and conclusions for this first aim. The completed paper, published in *Injury Prevention*, can be found in Appendix A.

Methods:

The descriptive approach for this aim was fairly straightforward. The most important (and unique) aspects of the methodological approach were to (1) expand the scope of injuries and hazard identification to all operations and jobs task, not just fireground operations; and (2) attempt to include and evaluate the utility of an anatomically-based severity scale (Abbreviated Injury Scale, AIS) that would aid in standardizing injury severity, rather than relying on the more common occupational method of evaluating the frequency and length of injuries resulting in time away from work (i.e., lost time injuries). Another important inclusion was the use of the Functional Capacity Index (FCI), which is a relatively new measure in injury assessments and could add relevance to this population, given their reliance on physical ability and any impact or limitation(s) from which an injury may result.

Results:

From 2004-2009, there were 902 injuries recorded in the surveillance data system. The annual injury incidence rate averaged 17.7 per 100 employees. One-third of all injuries (32.9%) resulted from physical exercise activities, while patient transport, training drills, and fireground operations resulted in 16.9%, 11.1% and 10.2% of injuries, respectively. For all job operations, sprains and strains were the most prevalent type of injury, ranging between 40.2-85.2%. Contusions and lacerations were the second leading injury type for all operations (7.7-26.1%). The third most common injury was related to the conventional hazards of the individual job operation: fractures and dislocations accounted for 4.7% of exercise injuries, 3.3% of patient transport injuries were punctures, while 15.2% and 7.0% of injuries during of fireground operations and simulated training drills, respectively, were burns.

The highest frequency of injuries occurred during the first six hours of the 24-hour shift (approximately 56.0% percent between the hours of 7AM – 1PM) and is likely related to the propensity for conducting daily exercise routines during this time. Most injuries (n = 862, 95.6%) were minor in severity according to AIS, while 4.3% of injuries were classified as having some impedance of normal function (FCI = 3). Moderate injuries (AIS = 2) were infrequent, but comprised a greater proportion of fireground injuries (8.7%) than the other activities (1.0-4.1%); however, lost time injuries were more frequent for patient transport injuries (46.1%) than the other operations (22.0-29.1%).

The five most prevalent mechanisms of injury (MOI) were acute overexertion (53.1%), cutting and piercings (9.8%), being struck by or caught between objects (8.3%), falls (4.8%), and thermal effects (2.6%). The data did not provide enough standardized detail to accurately describe or determine the most common agents or energy-carrying sources involved in injury events.

Discussion and take-home messages:

Injury rates at the individual fire department level may vary greatly compared to that of nationally reported averages. Variations may stem from a combination of practices, but is most likely driven by the lack of national reporting policies and limited standardization for reporting constructs. In addition, given the wide variety of known and unknown job activities that can occur within a 24-hour work shift, common practices of recording all adverse events, regardless of functional loss appears to be appropriate. This is especially true in instances of injury progression to a point of reduced capacity, requiring lost time from work and an insurance claim. Standardized data reporting systems are needed for more accurate tracking of department-level progress, as well as to enable comparisons to cities or municipalities of similar size and structure.

Lost time was limited in its ability to determine injury severity and was found to be more of an indicator of cost, as only injuries that did not result in reassignment (e.g., light-duty cases) or use of accrued time off (e.g., vacation, sick leave, etc.) were documented as "lost time" cases. Despite using a standardized metric for assessing injury severity, the

AIS did not represent the type of injuries most often suffered in this occupational setting. While acute in nature, the majority of these injuries often do not result in the need for trauma care that may be better suited for an AIS-type assessment. A potential ideal metric – possibly for most occupational settings – might involved a combination of the AIS and FCI scales, in which the acute (short term) loss of function related to the anatomical injury could be established, and perhaps could be of more utility to assessing occupational health.

Finally, injuries were not retricted to the fireground, despite those environments involving the most dynamic hazards. Physical exercise (PE), patient transport, and training activities were responsible for a greater percentage of injuries than fireground operations. Referred to as the "PE Paradox," it is ironic that exercise would result in the most number of injuries, as PE's inherent purpose is to prepare the individual employee with the utmost amount of physical readiness so that all other job-related demands may be met with the most skill and efficiency.

It is also worth noting that fireground operations resulted in relatively few injuries, despite involving the most dynamic environmental hazards and physical stresses. A logical deduction is that the simulated training and drilling, along with fire operation protocols translates well into real emergency events. It may be that the structured approaches used for preparing for and engaging safe practices on the fireground (or derivations thereof) should be applied to other operations and job activities, most notably daily exercise routines and patient transport responses.

Executive Summary of Primary Aims Methods and Findings – Aim II

[Fire Fit: Assessing Comprehensive Fitness in the Fire Service]

II. B. Specific Aim II: Describe measures of aerobic and musculoskeletal fitness, and their individual-level variability, and define a comprehensive measure for assessing fitness status

The following is an abstracted summary of the methods, results and conclusions for the second aim. The prepared manuscript for peer review can be found in Appendix B.

Methods:

Five components of fitness were the focus of this research and assessed through seven separate variables collected during annual physical exams: cardiovascular fitness (aerobic capacity, resting heart rate), muscular strength (handgrip strength), muscular endurance (push-up and sit-up repetitions), flexibility (sit-and-reach distance), and body composition (percent body fat). Aerobic capacity (VO_2max) was estimated using the Gerkin submaximal treadmill protocol.(Gerkin et al, 1997)

Using a combination of normative standards and the normal distributions within this population, three levels (or categories) of fitness were established for each of the seven variables mentioned above (Appendix B, Table 1). In each case, Level I represented high performance or fitness, whereas values that were categorized in Level III put into question the ability of the individual to safely perform all emergency job tasks. Subsequently, Level II indicated a mid-level of performance during the assessment. In effort to simplify the estimation of one's comprehensive fitness, an equally-weighted fitness score was calculated for each person-year observation by tallying the respective fitness levels for each of the seven measures. Three categories – "high fit," "fit," and "less fit" – were established for comprehensive fitness and related to scores of 7-8, 9-10, and ≥ 11, respectively.

Statistical analyses were focused on the descriptive and distributional characteristics of individual and comprehensive fitness measures and their relationship to each other, as well as over time. Reliability of the measures were assessed through person-level mean summary statistics, as well as intraclass correlations (ICC). In addition, factor analyses were conducted to explore the potential for more simplified and meaningful combinations of the fitness variables.

Results:

With the exception of push-ups, sit-ups and flexibility among women, the distributions of variables were relatively normal. Figures 8 to 15 display the person-mean distribution fitness measures collected during years 2005-2009, in addition to the individual fitness level cutoff points presented in Appendix B, Table 1.

Figure 8. Person-mean VO_2max distribution

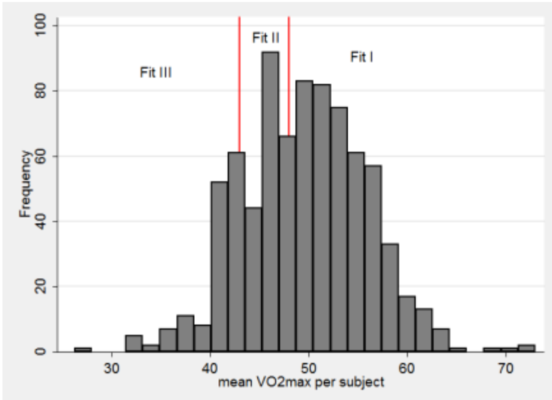


Figure 9. Person-mean resting heart rate distribution

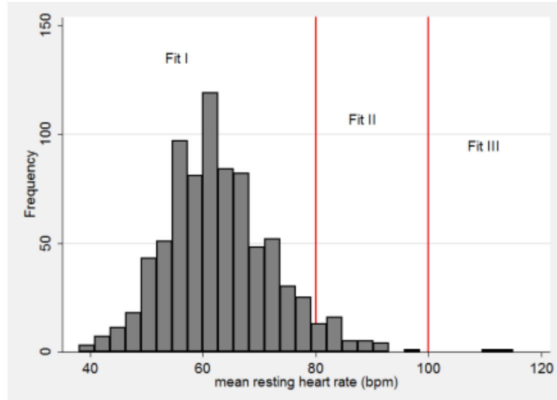


Figure 10. Male person-mean flexibility distribution

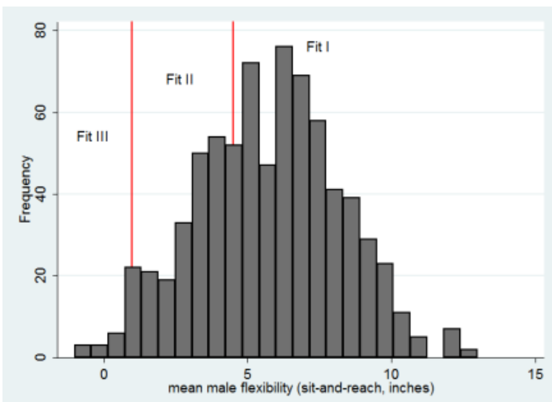


Figure 11. Female person-mean flexibility distribution

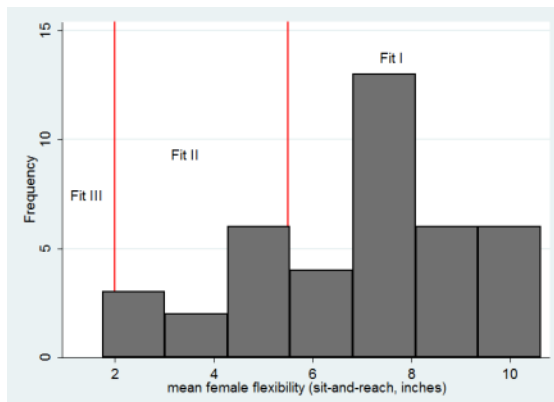


Figure 12. Male person-mean grip strength distribution

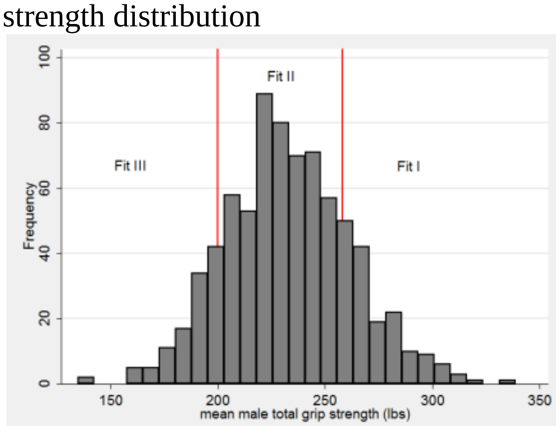


Figure 13. Female person-mean grip strength distribution

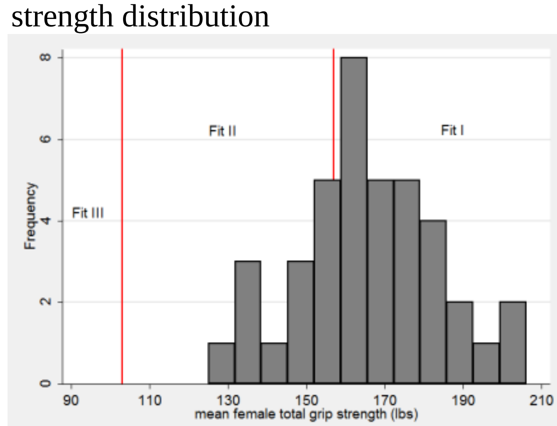


Figure 14. Male person-mean percent body fat distribution

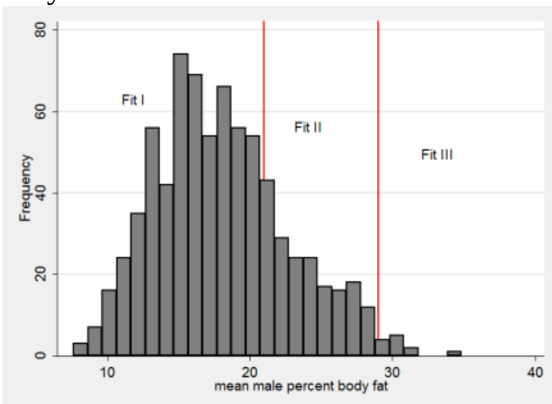
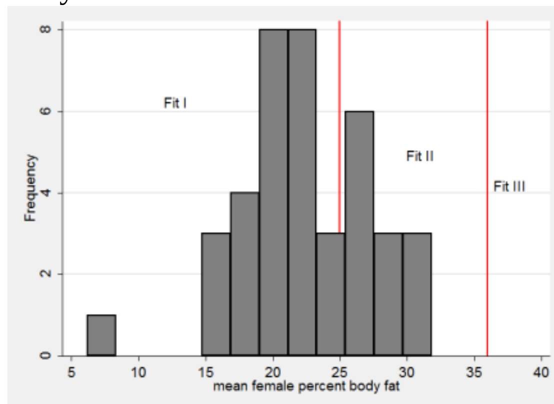


Figure 15. Female person-mean percent body fat distribution



It was common practice to stop testing for sit-up and push-ups after 30 repetitions were completed, as it represents the top level of fitness. Meeting the top level mark of 30 repetitions was achieved by at least 99% and 94% of the population for push-ups and sit-ups, respectfully.

To some extent, broad ranges were observed between the population mean minimum and maximum values for five of the seven measures (Appendix B, Table 3). The overall population mean for VO_2max across time was 49.2 mL/kg/min, with a 12.2 unit difference between the mean minimum and maximum values. Interestingly however, a person's last observation was, on average, greater than their first. The averaged minimum and maximum values for resting heart rate ranged by 12 bpm; total grip strength, 36.1 lbs; flexibility, 2.5 inches; and percent body fat by 5.5.

Factor analyses indicated that the variables assessed did not “load” well together, suggesting no natural combination of related variables. The reliability of variable measures was assessed using Rosner’s scale for ICC, in which poor, fair to good, and excellent reliability are indicated by ICC values of < 0.4, ≥ 0.4 to < 0.75, and ≥ 0.75, respectively.(Rosner, 2000) Appendix B, Table 4 indicates that mean flexibility, grip strength, percent body fat, and resting heart rate each have ICC values above 0.5, suggesting fair to good reliability. The mean VO_2max was shown to be an unreliable measure with an ICC of 0.2695.

The proportional distributions for each individual fitness measure varied over the study period. In general, the proportion of individuals in the top fitness level for percent body fat and grip strength declined, while the third fitness level (i.e., highest body fat percentages and lowest grip strength) increased. Flexibility was generally improved during this time, with a low proportion of individuals in the third level and increases in the top level. Over 90% of the population met criteria for the top fitness level for resting heart rate (<80 bpm). With the exception of 2006, aerobic capacity had a steady increase in the number of individuals achieving Level I fitness classification (VO_2max ≥ 48) and a steady decline in those within the lowest fitness category (VO_2max ≤ 43).

For the comprehensive fitness measure, after an initial decline in 2006 (32.8% to 23.1%), the proportion of individuals in the “high fit” category gradually increased over the study period, while the percent of “less fit” declined by nearly two percent annually.

Concurrently, the average age of high fit individuals declined over the study period, while the age of the less fit increased and age of the fit individuals did not vary.

Discussion and take-home messages:

The purpose of measuring fitness in this population should not only provide an assessment of the employees' maximal potential to meet extreme scenarios, but also their ability to recover and continue to meet the demands of other unanticipated emergency responses.

Aerobic capacity is one of the most widely used measures for assessing the ability to meet the physical demands associated with the extreme scenarios and environments related to fire suppression, search and rescue, ventilation, technical rescues, etc. However, given the amount of intra-variation shown, (estimated) VO_2max may not be sufficient to represent readiness for the day-to-day job responses and tasks of the fire service (e.g., patient transport, motor vehicle crashes, etc.), as not all tasks require physical responses near maximal effort. The additional components of fitness included in the broader measure of "fire fitness" (e.g. total grip strength, flexibility, percent body fat, and resting heart rate) have the potential to improve the assessment of an individual's functional readiness for meeting all the physical demands, loads and hazards associated with the myriad of job tasks that exist both on and off of the fireground. The ability to assess change in these fitness measures in relation to the likelihood of adverse health outcomes (particularly injury) is an important means for establishing focused prevention strategies.

Executive Summary of Primary Aims Methods and Findings – Aim III

[The Association of Aerobic Capacity and Fitness with Injuries in the Fire Service]

II. C. Specific Aim III: To measure the effect of aerobic capacity and other components of fitness on injury occurrence

The following is an abstracted summary of the methods, results and conclusions for the third and final aim. The prepared manuscript for peer review can be found in Appendix D.

Methods:

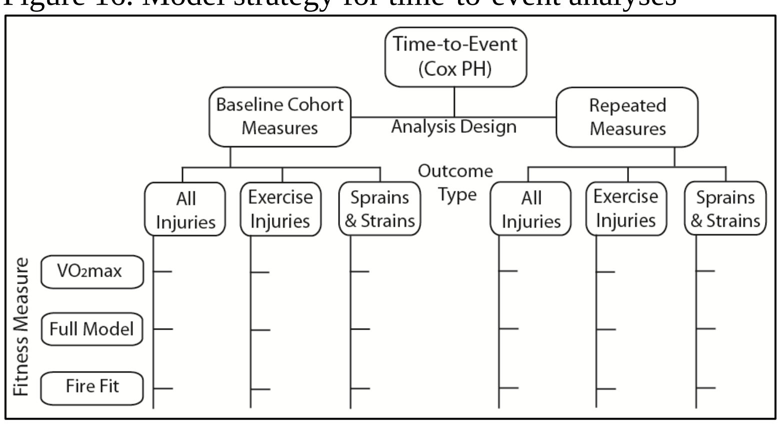
In this comparison of fitness between injured and uninjured individuals, two data sources were merged and appended for the years 2005-2009: surveillance data that documentsed injured and ill employees and results from annual physical exams. To evaluate the relationship between fitness measures and injury, two statistical modeling strategies were developed and tested: log-binomial regression and time-to-event analyses (i.e., Cox Proportional Hazards (Cox PH)).

For all analyses, outcome measures included occurrence or time to (1) any injury type, (2) any physical exercise injury, and (3) any sprain or strain. The primary exposure or fitness measures were (1) aerobic capacity (VO_2max), and (2) the developed category level of fire fitness.

Log-binomial analyses assessed the association between ever or never having an injury outcome and the individual's summarized fitness measures (e.g., best, worst, or mean VO_2max) during their study time.

For the time-to-event models, two analysis designs were utilized. Figure 16 summarizes a 3x3 matrix of modeling strategies. The baseline cohort method includes in the model the subject's initial clinical fitness measures and then estimates their association with time to injury or censoring. The repeated measures approach was used to account for the variable number of physical exams that an individual employee had during the follow-up period. This method allows changes in the individual's clinical fitness measures over time, in addition to measuring specific at-risk time within the established levels of fitness.

Figure 16. Model strategy for time-to-event analyses



For each analysis design (baseline or repeated measure) and outcome type (all, exercise, or sprain/strain injuries), the association with three measures of fitness was assessed using Cox PH models. The first association assessed the relationship between aerobic capacity (VO_2max) and injury, adjusted by any potential confounding effect(s) from gender or age. The second modeling strategy (labeled "full model") measured the association of injury with aerobic capacity, adjusting for all other components of fitness variables in addition to age and gender. The last measured association was between injury and the newly developed "fire fitness" score that ranked individuals' comprehensive fitness status into one of three fitness categories, based on the combined score from each of the seven original fitness variables.

Results:

Between 2005 and 2009, 799 employees were evaluated for at least one physical exam and included in this database. On average, approximately 87 percent of the workforce population was accounted for in the clinic database with a mean age of 39.2 years. Risk-ratios for all of the comparisons produced from log-binomial analyses were overwhelmingly null or non-significant, signifying no discernible associations between the fitness measures and occurrence of any injury during the time period.

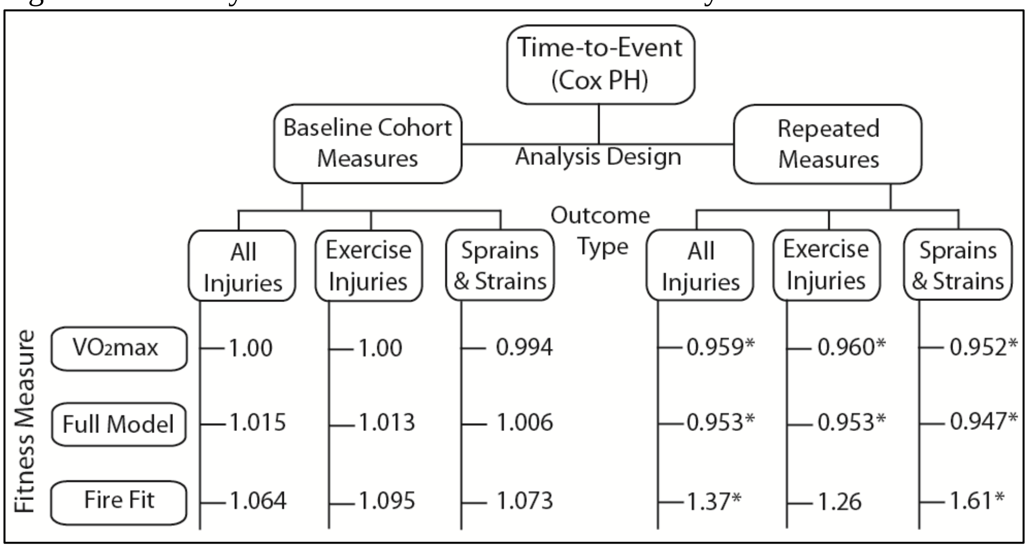
In time-to-event analyses, the number of individuals with at least one injury of any type was 357, whereas, 174 and 294 individuals specifically sustained at least one exercise or sprain/strain injury, respectively, with median length of follow-up times of 2.5, 3.2 and 2.8 years. Kaplan-Meier and log-rank analyses demonstrated a statistically significant decrease in injury incidence rate (IR) with increases in 10-year age categories, as well as a longer median time to injury. There were no differences in the association between fitness and injuries between genders, however, only five percent of the study population was female. Increases in percent body fat were related with a significant increased IR, driven most notably by the highest tier (>36% body fat).

Using baseline cohort measures, log-rank tests showed non-significant differences in injury IR between the three levels for aerobic capacity (Level I > 48, II 43-48, III < 43 mL/kg/min), as well as comprehensive Fire Fit levels. However, repeated measures modeling demonstrated significant increases in IR with a decline in VO_2max (Appendix C, Table 1). In addition, those with lower VO_2max levels were likely to sustain any injury sooner, as indicated by a median injury time of 2.24 years in Tier III compared to 4.07 years for Tier I (Appendix C, Figure 1).

Repeated measures modeling also demonstrated significant modest increases in IR of all injuries with decreases in overall fire fitness levels, from 17.8 injuries per 100 person-years in level I (best) fitness to 20.6 and 29.2 injuries per 100 person-years in levels II and III, respectively, although these changes were not statistically significant. In contrast, however, IR for sprain and strain injuries increased from 9.1 to 23.2 injuries per 100 person-years (Appendix C , Table 1) as comprehensive fire fitness decreased (Fire Fit Levels I and III, respectively) and this increase was statistically significant ($p = 0.0135$).

No statistically significant associations were found between fitness at baseline and time to subsequent injury. However, utilizing the repeated measures method to model the multiple examination periods allowed a fuller description of the relationships between fitness and injury, as indicated by significant hazard rate associations displayed in Figure 17.

Figure 17. Primary hazard ratios for time-to-event analyses



* Statistically significant at $p < 0.05$

The hazard ratios for “VO_2max” and “full model” relate to the continuous variable for the fitness measure of VO_2max, whereas “Fire Fit” is a categorical variable by which the higher categories of “Fire Fit” indicate decreased comprehensive fitness. Thus, between all three measures, one can summarize the results by stating increases in cardiorespiratory fitness (VO_2max) are associated with a protective effect (i.e., decreased risk) against injury. Similarly, decreases in comprehensive fitness (“Fire Fitness”) are associated with an increased risk of injury. Appendix C, Table 3 further exhibits that the risks of injury are increased in magnitude with decreases in the level of fitness.

Based on some of the preliminary modeling, there was a suggestion for decreased injuries with age. To assess for the potential of effect modification of the relationship by age, a simple age-stratified analysis was completed for all injury outcomes, as well as sprains and strains. For both outcome types, the risk of injury among those with decreased VO_2max was compounded by being younger than 30 years of age, as compared to the risk of injury of those over the age of 30 years.

Discussion and take-home messages:

While seemingly obvious, the findings provide empirical evidence that lower fitness levels are associated with increased risks in injury, among an occupationally active population of career fire service employees. Furthermore, these increased risks are modified by age, which is more likely to relate to the rank, job task and risk profile often associated with age in this population.

Improvements can be made to more accurately define and assess at-risk time. Specific objectives in the future should be to validate the various levels of fitness, in addition to determining accurate exposure time to the various activities and hazards associated with such a physically active occupational population.

The issue of fitness in the fire service is complex. As injuries continue to be a relevant health concern in the fire service, the contribution of fitness to the likelihood of injury is significant. The goal should not be to focus on establishing fitness standards, but rather to establish and promote standard mechanisms by which fitness (and overall health and wellness) can be maintained, if not improved. The manner by which health and fitness in the fire service is managed and supported with dedicated resources requires attention. Given our reliance on these men and women to respond to practically any and all emergency situations, they should be afforded the same (if not greater) opportunities and resources to maintain daily health and fitness, through structured on- and off-duty fitness programs with embedded injury prevention efforts.

In order to make clear, proactive improvements to the health and safety of this high-risk population, all components of fitness must be addressed and promoted so that the individual employee can maintain a healthy career and retire with function.

STRENGTHS & LIMITATIONS

This research made use of a retrospective occupational cohort study design that utilized secondary data available for multiple years for employees of the Tucson Fire Department. Injury data were obtained from mandated required injury reporting system. Fitness and health data were obtained from clinic records obtained from the required annual health examinations. As a retrospective cohort, analyses were completely dependent on pre-recorded data values that were not obtained for research purposes. Limitations with these data include the issues with how the injury data were reported by the employee and problems with how the data systems were maintained. There was lack of standardization of reporting methods, both for injuries and for the fitness measures over the time period. There was also variation in how the different variables were coded within the medical records over time. These variations limited the amount of detail that could be gleaned from each event

The greatest potential for bias in this study design comes from any measurement error that could lead to differential misclassification from the various measures of fitness assessed in this study. Clinical measurements completed at the time of annual physical exams were checked for quality assurance against medical chart reviews and found to be acceptable. The level and type of missing data was not found to be of concern among the primary variables of interest. The levels of fitness established in the second aim of this research may also introduce some information or misclassification bias. However, differential misclassification is not thought to have occurred in this study, as any systematic difference in the way information from fitness measures or injury outcomes was not identified. The broader question is whether or not the variables used to classify an individual's fitness were reliable enough, and the best methods for fitness assessment that a fire department can obtain and utilize (especially considering increasing financial constraints).

An objective of the first manuscript was to include a measure of injury severity that was based on the anatomical nature of the injury, utilizing the widely accepted AIS scoring method. The rationale was that this variable or approach could eliminate some of the limitations from the accounting of lost time from work. However, this process identified a lack of ability to accurately capture the nature of severity, given that a large percentage of the injuries were not severe enough to be associated with immediate trauma and loss of time, but did result in an acute loss of occupational function for relatively short periods of time (e.g., days to weeks). Further work is needed to identify a more appropriate severity scale. The principles behind the Abbreviated Injury Scale (AIS) and Functional Capacity Index (FCI) could be combined to generate a new severity scaling system based on acute functional loss, particularly from normal job activities, to better aid occupational health surveillance.

It is assumed that this population has, on average, higher fitness levels than the general public, simply due to the active nature and physical demands of the job. There is no expectation to make comparisons to the general population. While the risks and associations described in the results are generalizable to the employees of a fire service, it is unlikely that the findings can be projected on to the general population. It is uncertain whether or not there is a peak level for fitness that, once surpassed, the decreased risk for injury may be diminished. Nevertheless, the hazard profile and the level of fitness required to meet the work demands within the fire service exceed that of the general population, suggesting a possible need for population-specific metric(s) for fitness. As indicated by the second manuscript for this dissertation, the levels of fitness and scaled cutoff values used for each of the seven measures of fitness require validation.

A major strength of this research was the ability to compare injured to non-injured employees over a five year time span for an overwhelmingly majority (87%) of the workforce. In addition, the ability to complete time-to-event analyses enabled a significant advantage for interpreting at-risk time and to account for individual level fitness changes over the time period. Despite these advantages, some analytical limitations are present. Most notably, the individual's previous history of injury or other adverse health history at the time of study entry was unknown. The analyses were focused on time-to-first event, therefore, the risk for repeated injuries was not assessed. An important distinction to make in future studies will be to differentiate between individuals who sustain a recurrent injury versus those that are repeatedly injured. In addition, with the theory that a more "fit" person will have a greater reserve to do work than an "unfit" person and by having a lower capacity to do work, the "unfit" person is more susceptible to risk of injury, the type of injury (or injuries) is important to consider. Improvements (or changes) in fitness and one's ability to resist the forces that result in injury are more likely to be observed among specific outcomes. For example, it seems intuitive that fitness is more likely to be associated with the likelihood of a sprain/strain than a laceration.

Exposure time is also an area of research requiring future attention. Time spent on-shift performing the job tasks described in this study has not been addressed. It is likely that exposure time, or time at risk of an injury, varies between fire departments and service types (volunteer versus career) and by job duties. Evaluating the time spent performing both operational job tasks (e.g., fireground, medical responses) and other job activities (e.g., physical exercise, equipment maintenance), and the environments in which they occur, would better define hazard profiles and generate a more accurate estimate of injury risk through specific exposure time estimates.

By improving (and standardizing) injury and illness surveillance systems, methods for assessing comprehensive fire fitness, and estimates of job-task exposure times, the identification and characterization of risks would occur more efficiently so that the development and application of relevant resources (i.e., hazard controls) could be implemented to mitigate potential injuries and other adverse health effects in the future.

CONCLUSIONS

The following is a summarization of conclusions found in the *Present Study* section in addition to the completed manuscripts found within the appendices.

The key findings of this research can be summarized in these three points:

(1) Injuries (of all degrees or severity) are pervasive in the fire service and not restricted to the hazards faced during fireground operations.

(2) While difficult to define, fitness in the fire service should reflect one's maximal potential to complete work, in addition to his or her ability to recover and continue to perform emergency response demands. When estimated based on sub-maximal testing, a single measure of fitness (such as aerobic capacity) may entail too much individual level variability to fully represent one's fitness status. A comprehensive fitness score that combines the various components of the occupational work demands may attenuate those variations and better reflect individual fitness status.

(3) Fitness, whether defined by aerobic capacity or a combination of metrics, is associated with injury risk. Specifically, individuals with increased aerobic capacity had a decreased risk of injury. In addition, those with a lower comprehensive fitness status had an increased risk of injury compared to others at the highest fitness level.

There were a few fundamental areas of improvement identified that should significantly enhance future epidemiologic research, in addition to providing direct benefit to the fire service. To begin, there is a clear need for a standardized reporting construct for injuries (and illnesses/exposures), in addition to the documentation of pre- and post-incident conditions. Most small, medium and volunteer fire departments do not have the resources of large, metropolitan departments and generally cannot afford to develop their own unique reporting system with the appropriate amount of redundancy. This results in a wide variety of reporting systems that ultimately impedes the opportunity to determine detailed root causes of injury trends, or to make any meaningful comparisons between departments of similar size and organizational makeup.

In addition to reporting standards, consistent and reliable metrics for fitness assessment are needed that are subject to minimal measurement error and can be implemented without overwhelming already constrained budgets by which most departments are restricted. There is good support that fitness is related to the performance of firefighter job tasks.(Williford 1999; Rhea, 2004; Michaelides, 2011) However, these findings should encourage the direction of research to focus on the relationship between fitness, performance and specific health outcomes.

Exposure time was another limiting factor that could benefit from focused research efforts. Specifically, a large observational analysis should be conducted to determine the amount of time spent completing the various daily job tasks and documentation of hazards associated with activities performed within each job task, therefore producing an accurate assessment of at-risk time.

Rothman's "sufficient cause model" denotes that a disease (in this case, injury) can originate from different sufficient causes, whether acting synergistically, simultaneously or consecutively over a longer period of time. While this study does not attempt to claim causation, it is hoped that association between fitness and injury is strengthened and better understood by the methods and results of this research.

The most obvious significance to be gained from this research is the need for structured exercise and wellness programs that are managed with dedicated personnel and resources. There is no one best method for structuring or prescribing exercise programs for a collective population. Individual level fitness improvements should be objectively measured and designed within the functional limitations of that individual, which over time, should improve with complementary gains in comprehensive fitness and without subjecting oneself to injury in that process.

The manner by which health and fitness in the fire service is managed and supported with dedicated resources needs improvement. The Centers for Disease Control (CDC) recommends that the average American adult receives *at least* 2.5 hours of moderate-intensity aerobic activity and major muscle group strengthening activities two or more days per week (CDC, 2011). The work demands of the fire service require above average fitness, and thus additional exercise is required to meet those demands. In general, the individual firefighter is no more an expert in maintaining their own health, wellness and fitness than anyone else is this country. Given our reliance on these men and women to respond to practically any and all emergency situations, they should be afforded the same (if not greater) opportunities and resources to maintain daily health and fitness, through structured on- and off-duty fitness programs.

This research is intended to benefit the fire service and bring attention to an admittedly complex issue. There is an understandable struggle between establishing fitness standards and maintaining fit-for-duty status. Regardless of any differences that may arise in that conversation, it should come as no surprise – and should not be of contention – that improving one's fitness reduces the likelihood of adverse health events, such as heart disease, respiratory disease, stress and injury. Findings from this research hopefully add to that understanding, and illustrate the growing need of providing dedicated resources and direction for promoting the advancement of all health and safety objectives.

APPENDIX A: MANUSCRIPT 1

Original article

PRESS RELEASE

Beyond the fireground: injuries in the fire service

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ABSTRACT

Background Although firefighting and emergency medical services are high-risk professions, few studies have identified the aetiology of injury in the fire service beyond the fireground.

Methods Data were collected for work-related injuries in a medium-sized metropolitan fire department. In a descriptive study, the factors explored included the nature of injury, agent, mechanism, body location, environment, abbreviated injury scale (AIS), functional capacity index (FCI) and lost time status.

Results From 2004 to 2009, the annual injury incidence rate averaged 17.7 per 100 employees. One-third of all injuries (32.9%) resulted from physical exercise activities, while patient transport, training drills and fireground operations resulted in 16.9%, 11.1% and 10.2% of injuries, respectively. For all job operations, sprains and strains were the most prevalent type of injury (40.2—85.2%), followed by contusions and lacerations (7.7—26.1%). The third most common injury was related to the conventional hazards of the individual job operation. Most injuries (n—862, 95.6%) were minor in severity, while 4.3% of injuries were classified as having some impedance of normal function (FCI 3). Moderate injuries (AIS 2) were infrequent, but comprised a greater proportion of fireground injuries (8.7%) than the other activities (1.0—4.1%); however, lost time injuries were more frequent for patient transport (46.1%) than other operations (22.0—29.1%).

Conclusions Physical exercise, patient transport and training activities were responsible for a greater percentage of injuries than fireground operations. Focused efforts to improve the characterisation of risks during these more diverse set of work processes should help guide the development of salient strategies for injury prevention.

Globally, the burden of occupational injury is significant and largely preventable.[1 2] In the USA, 4340 fatal work-related injuries were reported in 2009.[3] The incidence rate of non-fatal injuries among private industry workers was 3.4 per 100 workers, while public sector workers showed a significantly higher rate of 5.8 per 100 workers.[4] Using year 2000 data, it was estimated that the economic burden of medical treatment and lost productivity due to injury totalled more than US $406 billion, with most of the costs attributed to lost productivity.[5]

Combined, firefighting and emergency medical services have been shown to have one of the highest occupational incident rates for injury and fatalities.[6–8] Among the 1.1 million career and volunteer firefighters in the USA in 2009, 78150 injuries were reported, a rate of 6.8 injuries per 100 firefighters.[9 10] Since the late 1970s, the number of structural fires has decreased steadily,[11] most notably due to the advent of improved fire suppression and protection systems. However, firefighters have taken on additional responsibilities and are considered first responders for all emergencies (eg, fire, hazardous materials, medical responses, natural disasters and terrorist acts). In one jurisdiction, the City of Tucson, 84.4% of the 79380 fire department emergency dispatches recorded in 2009 were medical emergencies (Tucson Fire Department, personal communication, 2011). This high proportion of calls due to medical emergencies is consistent with many fire departments now in which medical responses constitute the predominant type of response activity. With these additional roles and responsibilities comes a host of dynamic occupational hazards and risk-laden environments that must be identified and managed.

Studies that have investigated injuries within the fire service have generally focused on aspects of fireground operations.[7 12–15] The International Association of Fire Fighters recently summarised contributory factors to injuries, emphasising how the limited scope of research has been directed only to the variety of physical tasks and hazardous exposures on the fireground.[16] In order to obtain a better understanding of the circumstances in which injury events occur, the present study seeks to build on this earlier work and explore injuries not only on the fireground, but also during other fire service activities.

METHODS

This analysis reflects the first phase of a 4-year project to introduce a participatory-based, risk management system within the fire service in an effort to identify and develop relevant control strategies for preventing injuries.

Setting and population

This descriptive study was designed to explore injuries occurring in the Tucson Fire Department (TFD), a medium-sized metropolitan fire department in the southwest USA. Fire service personnel include firefighters, paramedics, engineers, inspectors, battalion chiefs, etc., referred to in this report as emergency service employees (ESE). The TFD consists of approximately 650 career ESE, operating 21 fire stations and responding to nearly 538000 residents. In 2009, 84.4% of dispatches involved either basic or advanced life support, while 9.4% encompassed fire-related suppression activities. The remaining 6% focused on basic rescue, hazardous materials and technical rescue (eg, swift water, trench, confined spaces). TFD ESE averaged 41 years of age, 5% were women, and race/ethnicity was reported as 76.4% non-Hispanic white, followed by Hispanic (19.6%), with all other groups each comprising less than 3% of the total.

For all emergency responses, the priorities of TFD include life safety, stabilising the incident and property conservation. As a simplified description of roles during a one-alarm fire, a fire engine consists of two firefighters, one engineer and a captain. The captain oversees, assesses and directs all activities of his or her crew. The engineer operates all functions of the fire apparatus (eg, pressure gauges, etc.) and equipment needed for suppression and rescue activities, while the firefighters' primary role is to engage in any search and rescue efforts while actively suppressing the fire. All members of this population are certified as basic-level emergency medical technicians. Paramedics in this department are all trained firefighters who have additional specialty training and certifications to administer advanced life support in the field and during transport to a definitive care facility. As a situation becomes larger or more complex, additional personnel and resources are allocated and responsibilities may change.

Data sources and analyses

Data were abstracted from TFD injury reports, which contained information about the employee (eg, age, rank), the injury, and contributory factors to the injury event. Summarised annual surveillance databases were received for work-related injuries and illnesses that occurred from 2004 to 2009. End-of-year counts of ESE (by rank) and workforce demographics (eg, age, race/ethnicity) and dispatch data were obtained from the human resources department of TFD in order to generate incidence rates.

Inclusion criteria for the present study consisted of all enrolled ESE. While cardiac events (eg, stroke, heart attack, etc.) are the most frequent cause of line of duty deaths in the fire service,[17] these events (along with heat exhaustion, stress and other medical issues) were excluded because these conditions are neither musculoskeletal nor integumentary, which are the foci of our analysis.

For TFD, a reportable injury is defined in accordance with Occupational Safety and Health Administration (OSHA) regulations (29 CFR, 1904.7) (ie, medical treatment, restricted work time, or lost work time), in addition to any injury that occurred to specific body regions: eye, neck, back, knee, ankle and shoulder. The surveillance database includes internally documented injuries (ie, those deemed non-OSHA reportable, but recorded in the TFD system), which had no immediate loss of job function or capabilities, but are documented in the event the injury later progresses to a point requiring a report and or treatment (eg, due to cumulative or repeated trauma).

Classification of injuries

The general characteristics of injury events evaluated and classified in this study included: (1) nature of injury, describing the physical characteristics of the injury; (2) part of the body directly affected; (3) energy source (or agent) that directly inflicted the injury or illness; (4) mechanism of injury, which describes the manner in which the injury was inflicted by the source; and (5) secondary sources that contributed to the event or exposure. Injuries were assessed for anatomical severity using the 2008 version of the abbreviated injury scale (AIS).[18] Included in the most recent AIS coding structure is a prediction score for functional impairment (ie, the functional capacity index; FCI), which ranks the anticipated level of functional ability 1 year after the injury event. AIS and FCI were evaluated to add a standardised measure of severity and expand on the more common occupational use of indicating lost time. When available, a review of the narrative section was used to classify better the risk factors (ie, actions, agents and environmental characteristics) involved in the injury event.

Statistical analyses were focused on the descriptive and distributional characteristics of injury events and their outcome, as well as estimates for the annual population incident rate of injuries. Analyses were conducted using Stata software, V.11.1 (StataCorp, College Station, TX, USA). Human subjects' approval and monitoring was provided by the University of Arizona Institutional Review Board.

RESULTS

As shown in table 1, 902 injuries were reported among ESE between the years 2004 and 2009, with annual incidence rates ranging between 13.6 and 21.5 injuries per 200 000 h (equivalent to 100 full-time employees). The mean age of those injured was 37.9 years (range 20–64 years), compared with 41 years among the entire workforce. Sixty-four per cent of injuries were among those in their 30s and 40s.

The 902 reported injuries were sustained among 409 individuals. Therefore, 45.3% of injuries were repeated injuries, ranging between two and nine injuries to the same person over a 6-year time period. The median time between repeat injuries was 345 days (approximately 11 months) and ranged between 2 and 2067 days (approximately 5.7 years). The current analysis did not determine the extent to which the sustained repeated injuries were to the same body location.

The majority of ESE in this study worked five 24-h shifts over the course of a 9-day tour, followed by six consecutive days off. The day of tour for an injury occurrence was available for 87.3% of the injuries (n=282) that occurred during the most recent 2 years of these data. Most injuries (23.2%) were reported on the third day of tour, while the fifth day of the tour amassed 19.5% of injuries. The first, second and fourth days of tour accounted for 15.5%, 15.8% and 13.3% of the reported injuries, respectively.

The beginning of shifts (from 07:00 to 13:00 hours) showed a considerably higher occurrence of injuries (56.0%) compared with other periods of the shift (figure 1), and appears to be related to the tendency to conduct physical exercise and

Table 1 Annual injury frequency (N=902) and incidence rate, 2004–9

Year	Injury frequency	No employed	24-h Employees	8-h Employees	Total hours worked*	Incidence rate (per 200 000 h)
2004	129	530	477	53	1 441 600	17.9
2005	128	577	490	87	1 546 000	16.6
2006	148	625	518	107	1 664 400	17.8
2007	174	659	566	93	1 770 800	19.6
2008	199	694	580	114	1 852 000	21.5
2009	124	667	613	54	1 824 400	13.6

*Based on an average of 2800 and 2000 h worked by 24 and 8-h employees, respectively.

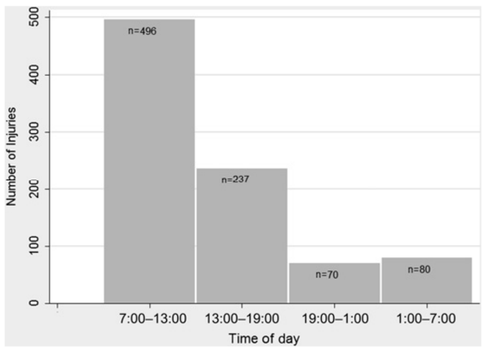

Figure 1 Distribution of reported injuries by time of occurrence (N=883), 2004–9.

training drills at the beginning of shifts, as 74% of exercise injuries and 51% of training-related injuries occurred during this time of day.

Sprains and strains accounted for 67.1% of injuries, primarily to the lower and upper extremities and back (table 2). Contusions and lacerations were also prevalent, accounting for 18.6% of all injuries. Approximately 52% of injuries were among firefighters and paramedics (53.2% of the 2009 population), while 44% encompassed recruits, engineers and captains (39.1% of the 2009 population). Firefighters had the most number of injuries, regardless of the nature. The distribution of injuries was reflective of the proportion of job ranks and primary job responsibilities, as the majority of ESE are firefighters. Captains, engineers and paramedics contributed an equal proportion of the workforce; however, the variability of job activities was greatest among firefighters and paramedics.

Of the 902 injuries, 95.6% were classified as minor (AIS 1), while 3.2% were scored as moderate (AIS 2), consisting of fracture, dislocation, inhalation and electrical injuries, and none were scored as serious or greater (AIS 3–6). Eleven injuries (1.2%) lacked sufficient detail for scoring. The FCI indicated that most injuries (82.0%) were classified as having 'most but not all normal function' (FCI 5), while 4.3% had some impedance of normal function (FCI 3). Thirty per cent of injuries were reported as requiring lost time from work, most often the result of a sprain or strain. Among the lost time injuries, the median number of days lost was 6.0 with a range from 1 to 199.

One-third of all injuries (32.9%) were the result of physical exercise activities (excluding training drills), while 16.9%, 11.1% and 10.2% occurred during patient transport, training and fireground operation processes (table 2). Table 3 further details the

Table 2 Distribution of injury type by descriptive variables, 2004–9

	Injury Type, N (%)						
	Burn (n=26)	**Contusion, laceration (n=168)**	**Fracture, dislocation (n=30)**	**Puncture (n=24)**	**Sprain, strain (n=605)**	**Other* (n=49)**	**Total (N=902)**
Body region							
Lower extremity	5 (19.2)	36 (21.4)	12 (40.0)	6 (25.0)	270 (44.6)	5 (10.2)	334 (37.3)
Upper extremity	14 (53.8)	72 (42.9)	9 (30.0)	13 (54.2)	97 (16.0)	4 (8.2)	209 (23.2)
Back/spine†	0 (0)	3 (1.8)	0 (0)	0 (0)	195 (32.2)	0 (0)	198 (22.0)
Head/face/neck	6 (23.1)	40 (23.8)	8 (26.7)	4 (16.7)	11 (1.8)	32 (65.3)	101 (11.2)
Torso	0 (0)	14 (8.3)	1 (3.3)	1 (4.1)	16 (2.6)	4 (8.2)	36 (4.0)
Other‡	1 (3.9)	3 (1.8)	0 (0)	0 (0)	13 (2.2)	4 (8.2)	21 (2.3)
Missing	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.5)	0 (0)	3 (0.3)
Lost time							
No	21 (80.8)	132 (78.6)	17 (56.7)	22 (91.7)	395 (65.3)	44 (89.8)	631 (70.0)
Yes	5 (19.2)	36 (21.4)	13 (43.3)	2 (8.3)	210 (34.7)	5 (10.2)	271 (30.0)
AIS							
Minor	26 (100)	168 (100)	9 (30.0)	23 (95.8)	605 (100)	31 (63.3)	862 (95.6)
Moderate	0 (0)	0 (0)	21 (70)	0 (0)	0 (0)	8 (16.3)	29 (3.2)
Missing	0 (0)	0 (0)	0 (0)	1 (4.17)	0 (0)	0 (0)	11 (1.2)
Rank							
Firefighter	16 (61.5)	65 (38.7)	15 (50.0)	7 (29.1)	155 (25.6)	19 (38.8)	277 (30.7)
Paramedic	3 (11.5)	35 (20.8)	4 (13.3)	6 (25.0)	134 (22.2)	8 (16.3)	190 (21.1)
Captain	0 (0)	21 (12.5)	3 (10.0)	4 (16.7)	101 (16.7)	13 (26.5)	142 (15.7)
Recruit	5 (19.2)	11 (6.5)	5 (16.7)	1 (4.2)	109 (18.0)	3 (6.1)	134 (14.9)
Engineer	2 (7.7)	26 (15.5)	2 (6.7)	6 (25.0)	80 (13.2)	5 (10.2)	121 (13.4)
Inspector	0 (0)	5 (3.0)	1 (3.3)	0 (0)	17 (2.8)	0 (0)	23 (2.6)
Chief§	0 (0)	5 (3.0)	0 (0)	0 (0)	9 (1.5)	1 (2.0)	15 (1.7)
Job operation							
Patient transport	0 (0)	26 (15.5)	1 (3.3)	5 (20.8)	116 (19.2)	4 (8.2)	152 (16.9)
Fireground	14 (53.9)	24 (14.3)	2 (6.7)	5 (20.8)	37 (6.1)	10 (20.4)	92 (10.2)
Physical exercise	0 (0)	23 (13.7)	14 (14.7)	1 (4.2)	253 (41.8)	6 (12.2)	297 (32.9)
Training and drilling	7 (26.9)	20 (11.9)	2 (6.7)	1 (4.2)	68 (11.2)	2 (4.1)	100 (11.1)
Other¶	5 (19.2)	75 (44.6)	11 (36.7)	12 (50.0)	131 (21.7)	27 (55.1)	261 (28.9)

*Includes electrical, eye, inhalation and non-descriptive 'medical' injuries.
†Assumed to be primarily lower back or lumbar region.
‡External and multiple injuries, as classified by the abbreviated injury scale (AIS).
§Combination of battalion, deputy, assistant and fire chiefs.
¶May include technical rescues, motor vehicle crash, cleaning, maintenance, travel to/from work, etc.

Table 3 Distribution of injury type and mechanism by job operation, 2004–9

	Physical exercise n=297	Patient transport n=152	Training drills n=100	Fireground operations n=92	Other* n=255	Total N=902
Injury type						
Sprain/strain	253 (85.2)	116 (76.3)	68 (68.0)	37 (40.2)	131 (50.2)	605 (67.1)
Contusion/laceration	23 (7.7)	26 (17.1)	20 (20.0)	24 (26.1)	75 (28.7)	168 (18.6)
Fracture/dislocation	14 (4.7)	1 (0.7)	2 (2.0)	2 (2.2)	11 (4.2)	30 (3.3)
Burn	0 (0)	0 (0)	7 (7.0)	14 (15.2)	5 (1.9)	26 (2.9)
Medical†	5 (1.7)	2 (1.3)	0 (0)	0 (0)	17 (6.5)	24 (2.7)
Puncture	1 (0.3)	5 (3.3)	1 (1.0)	5 (5.4)	12 (4.6)	24 (2.7)
Eye, not further specified	1 (0.3)	0 (0)	2 (2.0)	4 (4.4)	10 (3.8)	17 (1.9)
Inhalation	0 (0)	2 (1.3)	0 (0)	4 (4.4)	0 (0)	6 (0.7)
Electrical injury	0 (0)	0 (0)	0 (0)	2 (2.2)	0 (0)	2 (0.2)
Mechanism of injury						
Acute overexertion	243 (81.8)	103 (67.8)	40 (40.0)	24 (26.1)	69 (26.4)	479 (53.1)
Cutting, piercing	7 (2.4)	20 (13.2)	5 (5.0)	16 (17.3)	40 (15.3)	88 (9.8)
Struck by/caught between	18 (6.1)	10 (6.6)	10 (10.0)	6 (6.5)	31 (11.9)	75 (8.3)
Fall	8 (2.7)	4 (2.6)	5 (5.0)	12 (13.0)	14 (5.4)	43 (4.8)
Thermal effect	0 (0)	0 (0)	6 (6.0)	14 (15.2)	3 (1.2)	23 (2.6)
Transportation-relate	0 (0)	1 (0.7)	2 (2.0)	0 (0)	17 (6.5)	20 (2.2)
Foreign body in orifice	1 (0.3)	1 (0.7)	1 (1.0)	6 (6.5)	9 (3.6)	18 (2.0)
Electrical, radiation or other	0 (0)	0 (0)	0 (0)	2 (2.2)	11 (4.2)	13 (1.4)
Chemical effect	0 (0)	2 (1.3)	1 (1.0)	3 (3.3)	3 (1.2)	9 (1.0)
Mechanism of injury, unspecified	20 (6.7)	8 (5.3)	29 (29.0)	5 (5.4)	42 (16.1)	104 (11.5)
Missing	0 (0)	3 (2.0)	1 (1.0)	4 (4.4)	22 (8.4)	30 (3.3)

*May include technical rescues, motor vehicle crash, cleaning, maintenance, travel to/from work, etc.
†Lacks detail and coded as a non-descriptive 'medical' injury.

distribution of injuries by job operation. Sprains and strains accounted for 67.1% of all injuries, primarily to the extremities and back, but only 40.2% of injuries during fireground operations. Contusions and lacerations were also prevalent, accounting for 18.6% of all injuries, but comprised only 7.7% of physical exercise-related injuries. The third most common injury type parallelled the expected hazards to the individual operation: burns during fireground operations (15.2%) and training drills (7.0%); punctures during patient transport (3.3%); and fractures and dislocations (4.7%) during physical exercise. Moderate injuries (AIS 2) comprised a greater proportion of fireground injuries (8.7%, n=8) than the other activities (range 1.0–4.1%), while lost time injuries were proportionally higher (46.1%, n=70) in patient transport injuries than other job operations (range 22.0–29.1%). The mechanism by which an injury occurred was most often acute overexertion (53.1%), followed by cutting or piercing (9.8%), and being struck by or caught between an object (8.3%). Thermal mechanisms were identified with only 2.6% of all injuries.

DISCUSSION

Most emergency response activities require awkward positioning and significant exertion, increasing the likelihood of injury as well as the need for above-average functional movement. Moore-Merrell *et al*[16] suggested that on-duty injuries were likely to be the result of multiple contributory factors acting in concert with each other; however, no known studies of the fire service have provided a comprehensive description of the hazards and risks of operational responsibilities. While most studies related to the fire service have focused attention on the hazards and injuries during fireground operations, findings from the current study indicate that the largest percentage of injuries result from participation in some form of mandatory physical exercise during one's shift. These injuries occurred at twice the frequency of the next highest job task (ie, patient transport).

The purpose of physical exercise is to prepare one for their job and to condition a person to perform those job tasks with the utmost amount of efficiency, so that injuries are prevented. Therefore, it is somewhat of a paradox that physical exercise, which aims to prevent injuries (and other adverse health outcomes), is actually the most frequent cause of injury. The role that physical exercise plays in the occurrence and severity of injury has not been well documented in the emergency services. Exploring the root causes of these events and the manner in which physical exercise is performed, monitored and evaluated should be of greater emphasis within the fire service. The types of exercise practised by TFD include a wide range of activities (eg, jogging, basketball, circuit training, olympic lifting, metabolic conditioning, interval training, etc.), and vary in exercise programming structure and management. As supported by Barklage,[19] fire departments should institute, promote and maintain a comprehensive fitness and performance programmes to ensure opportunities for maintaining the proper level of fitness necessary to complete the myriad of physical job tasks performed by ESE, and thereby decreasing the potential for acute and cumulative injuries. There are also obvious benefits to comprehensive fitness programmes, most notably the potential prevention of cardiovascular disease, which as mentioned earlier is the leading cause of line-of-duty deaths in the fire service. The National Fire Protection Association standard 1583 (standard on health-related fitness programmes for fire department members) provides relevant policies governing this aspect of work.

In addition to physical exercise, injuries were frequent during patient transport, training drills and fireground operations. Nearly 85% of emergency dispatches are in response to some type of medical issue(s), representing the most frequently performed activity by fire service personnel in TFD; whereas the most frequently trained activity understandably focuses on fireground operations, as this environment typically involved the most variability and the greatest number of hazards that pose a threat to life. Patient transport research has predominantly focused on the risk and consequences of ambulance crashes, in addition to assaults, gurney design and the ergonomic lifting and transfer of patients.[20 27] Fireground research is often performed in training and drilling settings and has focused on individual issues such as heat stress, lung injury, noise, chemical and thermal hazards, slips/trips/falls and overexertion during tactical and overhaul operations.[7 28 32] A comparison with previous research findings is not possible, as the job operations described in the current study are broadly defined and lack the level of specificity with regard to the hazards and job tasks/activities (eg, noise, patient lifting, bench press), that is often presented in other research. How operations are defined is important and will dictate the activities and job tasks undertaken, and therefore the potential hazards. For example, patient transport may be defined as simply the physical lifting and lateral transfer of a patient, or encompass the entire process from call dispatch to release of the patient at a definitive care facility. The extent of detail will depend on the individual department.

From 2004 to 2009, the annual incidence rate of injury in TFD ranged between 13.5 and 21.5 injuries per 100 employees, compared with the 2009 estimated national incidence rate of 6.8 injuries per 100 firefighters.[9 10] It is conceivable that the increased injury rate seen in TFD is a reflection of their reporting and tendency to document all OSHA and non-OSHA reportable injuries. Injuries are reported in the TFD for purposes of documentation, accountability and tracking of potential injury progression. While this practice makes logical sense given the nature of working 24-h shifts and encountering multiple hazards during that time, it does, however, lead to an increase in the proportion of minor injuries reported. This may also explain why a well-accepted method for scoring injury severity, the AIS, did not provide much added detail on the nature of injuries in this population of ESE, because an overwhelming majority of injuries were minor in severity. In attempting to describe injury severity better in this population, identifying an appropriate metric proved challenging. The use of a trauma-based scale (ie, AIS) to measure all injuries in this setting did not represent the types of injuries well. When developing the minor injury severity scale for child injuries, Peterson *et al*[33] noted the lack of an available scale or widely accepted method to measure the severity of minor injuries. An evaluation of functional capacity loss was considered to be a useful alternative measure for this population. The classification scheme from the FCI appears to match the general characteristics of injuries in this population well. However, given the median time loss was 6 days, FCI may not accurately measure the short-term (or acute) loss of function described in this injury study as FCI reflects the likely extent of functional limitation or reduced capacity 1 year post-injury.[34 35]

Thirty per cent of all injuries were noted to have resulted in lost time. Patient transport operations produced the greatest proportion of lost time injuries, consisting mostly of back sprains/strains (60.0%). In most occupational settings, a lost time injury is designated when the individual misses the following shift of work from when the injury occurred. Against conventional thinking, approximately half (55.2%) of the moderate injuries—comprised primarily of fractures and dislocations—were classified as having no lost time. Upon further examination, an injury was classified as lost time only in situations when the employee was not performing any department-related duties (including regular job tasks or light duty assignments), and was compensated (eg, workers' compensation). Therefore, the lost time designation could be considered more of an indicator of cost than as a measure of severity; however, this observation requires further study.

Results from evaluating AIS, FCI and lost time indicate that a more relevant measure of severity is needed for this occupational population of ESE. While the vast majority of injuries can be considered minor using a trauma-based scale, the acute loss of function can be significant. When evaluated over the span of a career, these injuries have the potential to accumulate and result in some loss of function towards the end of one's career. This is supported by the 45% of repeated injuries identified in this study's 6-year time period. In theory, a combination of an ordinal scaling system based on acute functional loss, matched to a true accounting of time loss from normal job activities, could provide an improved indication of severity to the individual, and thus the department.

This analysis was limited by a lack of detail provided by the injury database. Improvements to the description of injury events can be made by including standardised metrics for specific activity performed at the time of injury, the individual's condition before injury, equipment used, known causes, objects and equipment, or other factors (eg, environmental conditions). In order to improve any assessment of severity or functional loss, improved surveillance systems are needed that incorporate standardised metrics for injury and illness. As described by Reason,[36] one of the primary steps in establishing a strong safety culture in an organisation is to improve on its reporting culture, which would enhance the ability to detail circumstances at the time of injury. The National Fire Incident Reporting System presents an excellent resource and template for departments to adopt standardised reporting structure and details.[37]

The at-risk exposure time is another area of study requiring further exploration. Time spent on-shift performing the job tasks described in this study has not been assessed. Evaluating the time spent performing these activities (ie, exposure time), and the environments in which they occur, would improve hazard profiles and generate a more accurate estimate of injury risk. By improving the reporting system and estimates of exposure time, the identification and characterisation of risks would occur more efficiently so that the development and application of relevant resources (ie, controls) can be implemented to mitigate potential hazard effects in the future.

This study has demonstrated that the events associated with injury among ESE occur well beyond that of the fireground. Due

What is already known on the subject

- Firefighting and emergency medical services are high-risk professions.
- Previous research has largely been focused on the physical tasks and exposures on the fireground.

What this study adds

- The magnitude and range of hazards faced during a typical work shift extend well beyond the fireground.
- Physical exercise and patient transport activities are two of the most frequent injury-related job tasks.
- Identification and characterisation of hazard profiles for the most frequent injury-related job tasks can help target prevention efforts.

to the number and variation of emergency situations ESE are responsible for responding to, focused efforts should be made to identify and address the injury risks encountered during physical exercise, patient transport and training activities, in addition to the existing focus on fireground hazards. Furthermore, there is a clear need to evaluate the structure and management of physical exercise in the fire service. While most studies indicate the need for improved fitness (eg, cardiovascular health and functional mobility) in order to carry out response activities, efforts should also be concentrated on providing these men and women with improved resources and structure to maintain fitness levels and training-based skills without exposing themselves to injury in those processes.

Ongoing efforts of this research are focused on characterising the risks of injury throughout the processes of patient transport, fireground operations and physical exercise. The identification and implementation of prevention control strategies are being led by a partnership between the TFD workforce and project researchers. Intervention effectiveness will be assessed by process evaluation techniques and a comparison of overall injury rates and rates specific to each operation.

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Contributors All authors gave significant contribution to the concept and design of this study, in addition to providing critical review, intellectual content and final approval for the manuscript.

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APPENDIX B: MANUSCRIPT 2

Title:
Fire Fit: Assessing Comprehensive Fitness in the Fire Service

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BACKGROUND & INTRODUCTION

The job duties related to firefighting and paramedicine require an active lifestyle and high physical demand (Barnard and Duncan, 1975; Bos et al, 2004; Davis et al, 1982; Davis and Dobson, 1987; Duncan et al, 1979; Gledhill and Jamnik, 1992; Holmer and Gavhed, 2007; Kilbom, 1980; Lemon, 1977; Matticks et al, 1992; Rhea, 2004; Sharkey and Gaskill, 2009; Smith et al, 2001; Williford et al, 1999; von Heimburg et al, 2006). Most studies evaluating the physiologic responses to firefighting have focused on simulated fire suppression activities, as these scenes require a wide variety of heavy work and stress. Barnard and Duncan (1975) were one of the first to document how strenuous firefighting activities led to near maximal heart rates, which can remain elevated for extended periods. Measured responses to the typical fireground activities most often pertain to heart rate and oxygen consumption, which are extrapolated to estimate the required capacity to perform work.

The majority of simulated experiments testing the aerobic capacity needed to perform the activities regularly encountered on the fireground suggest that a minimum aerobic capacity between 33.6 – 49 mL/kg/min is needed (Gledhill, 1992; Lemmon, 1997; Malley, 1999; Southman, 1990) to safely perform tasks. Adopted by the majority of U.S. fire departments, the National Fire Protection Association's (NFPA) *Standard on Comprehensive Occupational Medical Program for Fire Departments* (NFPA 1582) recommends that individual fire service employees maintain a minimum aerobic capacity of 42 mL/kg/min (NFPA, 2007). A more extensive assessment of the physiologic stresses associated with structural firefighting was conducted by Brown *et al.* (2009). After evaluating the four most physically demanding job tasks on the fireground (i.e., fire attack, search and rescue, exterior ventilation, and overhaul operations), the need for regularly simulating (training) job tasks within a range of 60-95% of one's maximal capacity was identified.

The cardiorespiratory work required to perform firefighting duties has been a contentious debate, and is well described in two articles by Mark Sothmann (Sothmann et al, 1992a, b). The general theory is that a more "fit" person will have a greater reserve to do work than a "less fit" person. Physical ability or capacity to do work (and thus fitness) will dictate one's performance. Fit individuals will be more efficient in their job tasks. That is, they will accomplish more with less fatigue; cope and recover faster from long shifts, hot environments, reduced rest; and miss fewer days from work due to illness or injury.

Fitness versus 'fire-fitness'

There are various metrics used to measure and define one's fitness, which often can differ between disciplines. The American College of Sports Medicine describes fitness as comprising five components: (1) cardiovascular fitness, (2) muscular strength, (3) muscular endurance, (4) flexibility, and (5) body composition (ACSM, 2010). Given that aerobic capacity (VO_2max) can be defined as the highest rate at which oxygen can be taken up and utilized by the body during rigorous exercise (Bassett, 2000), it is often used as a proxy measurement for overall fitness. However, a single component measure for fitness may not necessarily represent an individual fire service employee's fit-for-duty status and/or their ability to perform all job-related tasks in a safe and efficient manner. As presented by Denise Smith (2011), firefighting requires high level of aerobic fitness, anaerobic capacity, muscular strength and muscular endurance. This study aims to present a more comprehensive account of fitness by integrating a range of annual fitness measures into a summary score that reflects the five ACSM's components. These five components of fitness should better represent one's performance potential as related to the multitude of job tasks and hazards faced by a firefighter.

METHODS

This study includes all commissioned employees of a medium-sized metropolitan fire department in the Southwest United States (U.S.). The fire department operates 21 fire stations that respond to nearly 520,000 permanent residents. Like most municipal fire departments, this fire department requires all commissioned employees to have periodic (e.g., annual) individual fitness testing and medical clearance by means of a medical and physical exam. Data for this study were obtained from annual physical assessments for the years 2005-2009. All of the physical measures assessments are made by one contracted medical group that utilized standardized protocols for conducting the assessment. All employees are required to come to this facility for the assessment every 12 months (plus/minus 3 months). Inclusion criteria for the present study consisted of all commissioned (non-civilian) employees of the fire department during the study period.

Measuring Components of Fitness

The physical assessment included the following seven measures of fitness: cardiovascular fitness (aerobic capacity, resting heart rate), muscular strength (handgrip strength), muscular endurance (push-up and sit-up repetitions), flexibility (sit-and-reach distance), and body composition (percent body fat).

The primary measure for cardiovascular fitness was estimated using the Gerkin submaximal treadmill protocol, resulting in a predicted relative maximal aerobic capacity, or VO_2max (mL/kg/min) (Gerkin et al, 1997). This method is widely used by the fire service and is recommended by the National Fire Protection Association (NFPA) with adoption of a 42 mL/kg/min minimum standard to maintain fit-for-duty status (IAFF, 2008).

Resting heart rate (HR) was assessed prior to the treadmill test. It is generally not recommended as a measure of cardiovascular fitness (Heyward, 2010), due to the potential for wide individual variability. Regardless, it was included to broaden the cardiovascular assessment given that cardiovascular disease is the leading cause of line-of-duty deaths within the fire service (Moore-Merrell, 2008).

A handheld dynamometer was used to assess static muscular strength. The best of three measurements for each hand were recorded and summed for total grip strength (lbs). The maximum number of push-ups tests the endurance of upper body musculature, while maximum sit-ups assesses abdominal endurance and may also aid in indentifying individuals at risk for low back pain or injury (Heyward, 2010). Push-ups and sit-ups were assessed with the use of a standard metronomic pace for two and three minutes, respectively, recording the maximum number of continuous repetitions completed. The assessment was stopped if the individual reaches the maximal time, performs three consecutive incorrect push-ups, or did not maintain continuous motion with the metronome cadence.

Low back and hamstring flexibility was assessed using the standard sit-and-reach box test. The ideal minimum target value is to reach a stretch point equivalent to touching your toes (a value of zero inches) from the seated position with the legs straight and flat on the floor.

Body mass index (BMI) and waist circumference were measured during the annual physical exam; however, percent body fat was the principal metric for assessing individual body composition and was measured by the use of an electrical bio-impedance device.

Fitness Levels

For each component of fitness measure, three levels were established (Table 1) in order to score a more comprehensive measure for representing one's fit-for-duty status (i.e., "fire fitness"). A combination of factors was considered when establishing these cutoff values, as few normative standards exist for this occupational population. In particular, referenced materials included fitness norms (Heyward, 2010), National Fire Protection Association (NFPA) recommendations (IAFF, 2008), currently adopted department standards, medical personnel expertise, distribution of the population data and the assessment methods used during annual physicals. Fitness Level III represented the values where the ability to safely perform all emergency job tasks could be questioned. Level I represented high level of performance and Level II represented a mid-level of performance of the assessment. The premise for using three levels was based on a current approach used for annual physical exams in this population (as per contractually agreed between the fire department and clinic).

Similar to the concept used by Lee et al. (1999), the 25th and 50th percentiles were used as the cutoff points between "less fit" and "high fit" aerobic capacity, respectively. A resting heart rate (HR) above 100 beats per minute (bpm) resulted in a Level III designation and is regarded as tachycardia (rapid HR). A resting HR below 80 bmp was considered "high fit" in this assessment.

Found in Heyward's 6th edition of "Advanced Fitness Assessment and Exercise Prescription", the "good" and "below average" scores for left and right static grip strength norms were combined to determine fitness level cut-points for total grip strength (Heyward, 2010). In addition, the 30-39 year age bracket of Heyward's norms for the standard sit-and-reach test were used to establish flexibility levels, as the median age for the population was 39 years. Values were adjusted by +2 inches to match the clinic's practice of equating touching the box to two inches past toes, given that shoes are worn. The levels used for percent body fat were based on current values used by the contracted medical group facilitating the annual physicals.

While push-up and sit-up levels were also established for this population based on current annual physical procedures, there is an overwhelming tendency for individuals to stop once 30 repetitions are completed as (1) it does not classify them into any higher of a fitness classification, and (2) to deter away from any potential competitive-based injury. These measures were therefore treated as pass/fail in reaching the 30 repetition mark, as very few cases failed to reach that mark, and since maximal effort cannot be assumed.

Table 1. Cutoff values for levels for various fitness measures of fire-fitness

Fitness measure		Level I (high)	Level II (medium)	Level III (low)
VO_2max (mL/kg/min)		≥ 48	> 43 - < 48	≤ 43
Resting HR (bpm)		≤ 80	81 - 100	>100
Total Grip Strength	*male*	> 258	200 - 258	< 200
(lbs)	*female*	> 157	103 - 157	< 103
Flexibility (inches)	*male*	≥ 4.5	1.0 - 4.5	< 1.0
	female	≥ 5.5	2.0 - 5.5	< 2.0
Percent body fat	*male*	≤ 21%	> 21 - 29%	> 29%
	female	≤ 25%	> 25 - 36%	> 36%
Sit-up (N)		≥ 30	20-29	< 20
Push-up (N)		≥ 30	16-29	< 16

Scoring Comprehensive Fitness ("fire fitness")

An equally-weighted comprehensive fitness score was calculated for each person-year observation by tallying the respective fitness levels for each of the seven measures shown in Table 1. For example, if six measures were assessed within the Level I range and the final measure was Level III, the individual's total fitness score equaled 9. Three categories – "high fit," "fit," and "less fit" – were established for comprehensive fitness and related to scores of 7-8, 9-10, and ≥ 11, respectively. Figure 1 displays the total distribution of fire fitness scores for 2005-2009.

This scoring permitted some performance variation. The top fire fitness category ("high fit") aimed to allow for only one mid-level fitness measure capture, in addition to capturing at least the top 20% of the population. The middle fire fitness category ("fit") permits for less than half the seven fitness measures to be in the medium range (Level II) or, at most, one measure in the lowest range (Level III). If two or more measures were in the lowest range (Level III), or more than half were in the medium range (Level II), the individual would be classified as "less fit." Note that any measure in the lowest range would prompt further medical evaluation, regardless of this fire fitness categorization.

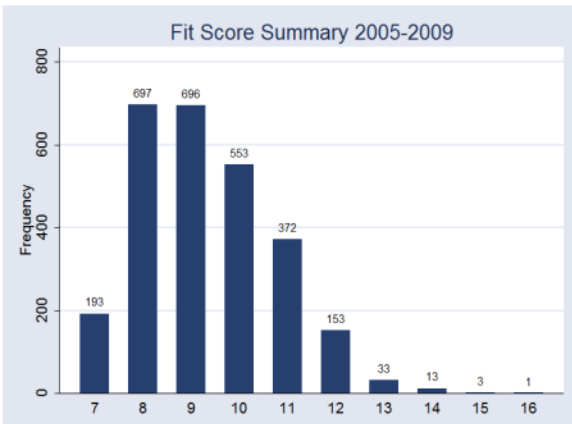

Figure 1. Distribution of comprehensive fitness scores for 2005-2009

Statistical Analyses

Statistical analyses were focused on the descriptive and distributional characteristics of individual and comprehensive fitness measures and their relationship to each other, as well as over time. Repeated measures enabled an assessment of the reliability of the measures, through person-level mean summary statistics, as well as intraclass correlations. Factor analyses were also conducted to explore the potential for meaningful combinations of variables that express the information contained in the original data in a more simplified manner (Afifi and Clark, 1996).

Analyses were conducted using Stata software, version 11.2 (StataCorp, College Station, TX). Human subjects' approval and monitoring was provided by the University of Arizona Institutional Review Board.

RESULTS

For years 2005-2009, 799 fire service employees were seen for at least one physical exam visit, with an average of 3.5 visits per firefighter or employee (at variable time intervals). On average, these 799 subjects represented approximately 87.9% of the annual workforce population, making it well representative of the total workforce (Table 2). The lower percentages in the first and last year were likely related to the differences between employee numbers captured at the end of the calendar year, while annual physicals were assigned according to a July-based fiscal year. The number employed may vary throughout the year due to timing of new hires, retirements, etc. As expected, the population was overwhelmingly male, with females encompassing only 4.9 percent of the total. Overall, the average age was 39.2, ranging annually between 38.4 and 40.2 years.

Table 2. Estimated percent of fire service population who completed physical exams

Year	Number Employed*	Physical Exam Visits†	Percent of Workforce
2005	577	494	85.6
2006	625	649	103.8
2007	659	568	86.2
2008	694	630	90.8
2009	667	480	72.0

* Represent the number employed at the end of the calendar year
† Number of employees seen for their annual physical exam during fiscal year

Table 3 displays the fitness summary measures across the study period. The overall population mean for VO_2max across time was 49.2 mL/kg/min, with a 12.2 unit difference between the mean minimum and maximum values. Interestingly however, a person's last observation was, on average, greater than their first.

With repeated annual measures, components of variance and intraclass correlations (ICC) were calculated to assess the variability within and between individuals (Table 4). In general terms, it is desirable for the between variance to account for a greater proportion of the total variance, thus an ICC greater than 0.50. Supported by the range of variation shown in Table 3, the mean VO_2max was shown to be an unreliable measure with an ICC of 0.2695, and almost triple the variation within an individual versus between individuals. Sit-ups and push-ups had low ICC values, however this is thought to be related to the nature of the testing that did not require completion to maximal effort.

Table 3. Mean person-level descriptive statistics

Variable	N	Mean	Min Mean	Max Mean	First Obs Mean	Last Obs Mean	Mean Change
VO_2max	782	49.6	43.6	55.8	46.7	52.5	5.8
Resting HR	797	62.9	57.2	69.2	62.6	62.9	0.2
Total Grip Strength (lbs)	797	229.5	211.4	247.5	234.7	227.4	-7.1
Flexibility (inches)	782	5.8	4.5	7.0	5.5	6.1	0.6
Percent Body Fat	790	18.3	15.4	20.9	17.0	18.9	1.8

Table 4. Components of variance and intraclass correlation for repeated measures of fitness

Variable	Between Variance	Within Variance	Intraclass Correlation
Flexibility	5.37	2.33	0.6974
Total Grip	879.93	519.03	0.6290
Percent Body Fat	19.02	12.56	0.6023
Resting HR	68.34	56.96	0.5454
Push-up	8.72	20.22	0.3013
VO_2max	18.87	51.16	0.2695
Sit-up	46.93	159.83	0.2270

Table 5 displays a matrix of correlations between the principal measures of fitness. While some correlations were statistically significant, the magnitudes of these correlations were generally not strong. Increases in age were correlated with decreased VO_2max, resting heart rate, flexibility, and increased percent body fat. Greater VO_2max levels were correlated with lower resting heart rate and body fat percentage, in addition to increased push-up repetitions. Increased percent body fat was also shown to be correlated with reduced repetitions in sit-ups and push-ups.

Results from factor analyses indicated that the variables assessed did not "load" well together, suggesting no natural combination of related variables. These variables can therefore be considered different measures of fitness, lending credence to the potential value of combining them for a "comprehensive fitness" score.

Table 6 demonstrates the percent distribution of individual fitness levels. Meeting the top level mark of 30 repetitions for push-ups and sit-ups was achieved by at least 99% and 94% of the population for each year of this assessment, respectfully. In general, the top tier fitness level for percent body fat declined, while the third fitness level increased and the middle level remained steady. Flexibility was generally improved during this time, with a low proportion of individuals in the third level and increases in the top level. Total grip strength saw some inverse trends over time in the first and third levels, with general decline in the first level and increases in the proportion of individuals in the third level of fitness. The distribution of resting heart rate was consistent with over 92% of the population meeting the top fitness level (<80 bpm) and few cases of potential tachycardia. With the exception of 2006, aerobic capacity had a steady increase in the number of individuals achieving Level I fitness classification ($VO_2max \geq 48$) and a steady decline with those in the lowest fitness category ($VO_2max \leq 43$).

Table 5. Correlation matrix for variables of interest using first observations

	Age	VO_2max	Resting HR	Grip Strength	Flexibility	Body Fat%	Sit-up	Push-up
Age	1							
VO_2max	-0.3675*	1						
Resting HR	-0.1216*	-0.3090*	1					
Grip Strength	-0.0098	-0.0303	0.0544	1				
Flexibility	-0.1599*	0.1534*	-0.0748*	-0.0312	1			
Body Fat%	0.2658*	-0.4475*	0.1911*	-0.0786*	-0.1346*	1		
Sit-up	0.0254	0.0275	0.0015	0.0028	0.0973*	-0.1469*	1	
Push-up	-0.0534	0.1198*	-0.0706*	0.0236	0.0884*	-0.2892*	0.5455*	1

* Statistically significant at $\alpha = 0.05$

Table 6. Distribution of firefighters by fitness level by year (N, total clinic visits)

Fitness Measure		**2005** (494)	**2006** (649)	**2007** (568)	**2008** (630)	**2009** (480)
VO_2max	Level I	214 (44.5)	234 (37.1)	286 (50.6)	367 (58.3)	303 (63.1)
	Level II	147 (30.6)	173 (27.4)	156 (27.6)	168 (26.7)	98 (20.4)
	Level III	120 (24.9)	224 (35.5)	123 (21.8)	95 (15.1)	79 (16.5)
Resting HR	Level I	456 (94.6)	605 (94.4)	524 (92.7)	580 (92.1)	445 (92.7)
	Level II	26 (5.4)	34 (5.3)	38 (6.7)	46 (7.3)	34 (7.1)
	Level III	0 (0.0)	2 (0.3)	3 (0.5)	4 (0.6)	1 (0.2)
Total Grip Strength (lbs)	Level I	191 (38.7)	157 (24.3)	144 (25.4)	167 (26.5)	93 (19.4)
	Level II	274 (55.5)	415 (64.3)	345 (60.7)	396 (62.9)	307 (64.0)
	Level III	29 (5.9)	73 (11.3)	79 (13.9)	67 (10.6)	80 (16.7)
Flexibility (inches)	Level I	285 (58.8)	450 (71.2)	368 (65.0)	415 (66.0)	340 (70.8)
	Level II	171 (35.3)	154 (24.4)	190 (33.6)	202 (32.1)	133 (27.7)
	Level III	29 (6.0)	28 (4.4)	8 (1.4)	12 (1.9)	7 (1.5)
Percent Body Fat	Level I	387 (81.5)	449 (70.6)	405 (71.6)	466 (74.0)	349 (72.7)
	Level II	84 (17.7)	170 (26.7)	134 (23.7)	133 (21.1)	106 (22.1)
	Level III	4 (0.8)	17 (2.7)	27 (4.8)	31 (4.8)	25 (5.2)
Sit-up	Pass	483 (99.8)	632 (99.7)	566 (1.000)	628 (99.8)	479 (99.8)
	Fail	1 (0.2)	2 (0.3)	0 (0.0)	1 (0.2)	1 (0.2)
Push-up	Pass	453 (94.0)	606 (95.6)	548 (97.0)	623 (99.0)	480 (100.0)
	Fail	29 (6.0)	28 (4.4)	17 (3.0)	6 (1.0)	0 (0.0)

Table 7 and Figure 2 provide a summary description of the comprehensive fitness category distributions. After an initial decline in 2006 (32.8% to 23.1%), the proportion of individuals in the "high fit" category gradually increased over the study period, while the percent of "less fit" declined by nearly two percent annually. Concurrently, the average age of high fit individuals declined over the study period, while the age of the less fit increased and age of the fit individuals did not vary.

Table 7. Distribution of firefighters by comprehensive fitness by categories of fitness and the average age of employee, 2005-2009

	High Fit		**Fit**		**Less Fit**			
Year	N (%)	Avg age	N (%)	Avg age	N (%)	Avg age	missing	**Total**
2005	162 (32.8)	38.4	192 (38.9)	39.8	87 (17.6)	42.6	53 (10.7)	494
2006	150 (23.1)	38.2	301 (46.4)	37.9	159 (24.5)	39.1	39 (6.0)	649
2007	172 (30.3)	38.9	256 (45.1)	38.6	130 (22.9)	40.1	10 (1.8)	568
2008	237 (37.6)	35.4	274 (43.5)	40.0	117 (18.6)	44.5	2 (0.3)	630
2009	169 (35.2)	35.7	227 (47.3)	40.8	82 (17.1)	47.5	2 (0.4)	480

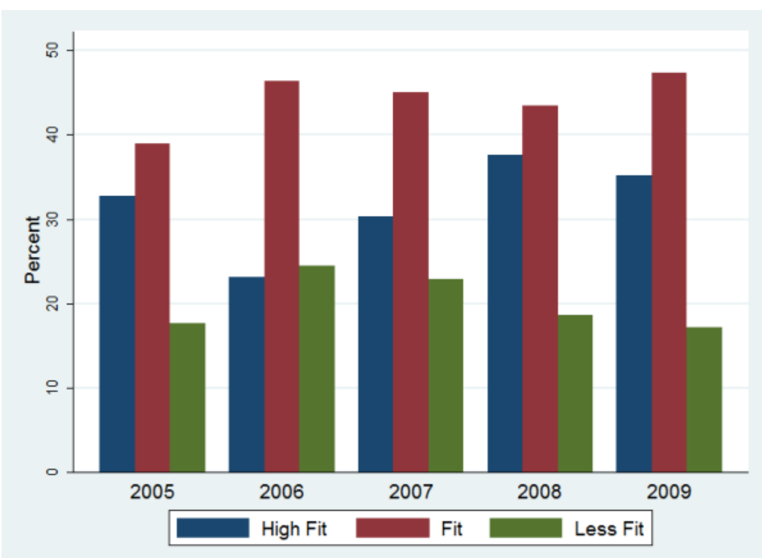

Figure 2. Annual percent distribution of fitness levels for select metrics, 2005-2009

Discussion

The goal of this study was to develop a more comprehensive measure of fitness that could better reflect an individual firefighter's ability to perform the multitude of job tasks and hazards faced. A comprehensive fitness measure may help describe a person's overall occupational functionality, as most response activities can require dynamic movements and physiologic demands. The methodologies used highlight an important distinction, as it pertains to the measurement of occupational fitness. Most notably, while some level of correlation exists, the components of fitness assessed (i.e., cardiovascular, muscular strength, muscular endurance, flexibility and body composition) are, in fact, distinct from each other. That is, the measures do not assess the same physiologic component, as indicated by the averaged descriptive statistics, correlations, ICC and factor analyses.

A unique advantage to this study was the ability to review and assess five years worth of repeated fitness measures for an occupational cohort of fire service employees. The reliability of these measures can be assessed using Rosner's scale for intraclass correlation (ICC), in which poor, fair to good, and excellent reliability are indicated by ICC values of < 0.4, ≥ 0.4 to < 0.75, and ≥ 0.75, respectively (Rosner, 2011). Using this scale, the most reliable measures of fitness were shown to be flexibility, total grip strength, percent body fat and resting heart rate. The poor reliability associated with push-ups and sit-ups was not surprising, considering the common practice of stopping after the 30 repetition mark was reached. What was surprising is the poor reliability associated with aerobic capacity (VO_2max), with greater variability across the annual measurements within an individual versus the variability between individuals. As exhibited in Table 3, the mean maximum and minimum VO_2max values were not directly analagous to the first and last values of this five year time period. Over long enough time, a general decline in aerobic capacity is expected, as an inverse relationship is associated with adult age (Astrand et al, 1997; McGuire et al, 2001a, b; Hollenberg, 2006); however, we found individual-level values to fluctuate with no discernible trend.

Direct measurement of VO_2max can be obtained in a laboratory setting with oxygen and carbon dioxide analyzers, while monitoring electrocardiogram (EKG) output; however, this is typically too expensive (and uncomfortable) for most fire departments to employ. Protocols (such as the Bruce and Gerkin treadmill protocols) have been established that predict VO_2max. It has been noted that using the Gerkin submaximal estimation protocol for maximal VO_2 may overestimate the true value by approximately 8 mL/kg/min (Tierney, 2010) and potentially by more than 25% (Mier and Gibson, 2004). An explanation could be that timed 1-minute increases in treadmill speed and incline do not permit the heart and respiratory rates to attain equilibrium prior to the next phased increase. Thus, while a potential measurement bias of the Gerkin protocol has been suggested, this study documents the poor reliability associated with a single measure of VO_2max.

These findings on reliability may be supportive of recent fitness research conducted to predict one's ability to complete firefighting tasks. Prior to fire academy training, candidates must often pass a standard physical test. The Candidate Physical Ability Test (CPAT) was developed by select fire departments to test the candidates' ability to perform basic firefighting tasks, and involves a continuous circuit of 8 fire simulation tasks, while wearing a weighted (50lbs) vest, safety gloves and helmet (IAFF, 2000). Williams-Bell (2009) found that 65% of the variability in time to complete the CPAT was predicted by VO_2max, body mass index (BMI) and hand-grip. Average VO_2max for men and women that passed the test was 38.5 and 36.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively, with heart rates reaching 90% and 91% of the predicted maximum. Similarly, Michaelides et al (2011) identified abdominal strength, relative power (via step test), upper-body strength and upper-body endurance to be associated with time to completion of a fire simulation ability test, while high resting heart rate, BMI and percent body fat were associated with poor performance in the ability test.

What is the purpose of measuring fitness? For this population of fire service employees, the purpose should not be to only assess the ability of meeting the demands of a one-time, maximal effort emergency scenario. While such information is relevant, there is more involved in assessing ability. The individual firefighter, paramedic, engineer, etc. cannot anticipate how many emergency calls he or she will need to respond to during a given shift. The assessment of one's fitness needs to not only account for their maximal potential to meet extreme scenarios, but also their ability to recover and continue to meet the demands of other unanticipated emergency responses. Thus, a summary measure for comprehensive fitness could potentially serve as a broader measure of "fire fitness."

The cardio-respiratory demands associated with firefighting have been well documented (Barnard and Duncan, 1975; Bos et al, 2004; Davis et al, 1982; Gledhill and Jamnik, 1992; Holmer and Gavhed, 2007; Kilbom, 1980; Lemon, 1977; Sharkey and Gaskill, 2009; Smith et al, 2001; von Heimburg et al, 2006; Brown et al, 2009). Aerobic capacity is one of the best measures for determining the ability to meet the physical demands associated with the extreme scenarios and environments related to fire suppression, search and rescue, ventilation, technical rescues, etc. However, given the amount of variation shown within the individual, (estimated) VO_2max may not suitably represent the day-to-day job responses and tasks of the fire service (e.g., patient transport, motor vehicle crashes, etc.), as not all tasks require physical responses upwards of 90% maximal effort. The additional components of fitness presented (e.g. total grip strength, flexibility, percent body fat, and resting heart rate) may improve the assessment of an individual's functional readiness for meeting all the physical demands, loads and hazards associated with the myriad of job tasks that exist both on and off of the fireground.

Given that no validated normative standards exist for establishing fitness levels applicable to this population (most notably VO_2max), the resources and methods used are believed to be apt and, most importantly, relevant to the fire service. The fitness level cutoff values established for VO_2max were similar to those shown in other studies assessing the relationship between cardio-respiratory fitness and cardiovascular disease in firefighting populations (Baur et al. 2012a, b).

Exhibited in Table 7, the contrasting changes in proportion and average age of individuals in each of the three fitness categories may be an indicator for population-level improvements in comprehensive fitness. It is uncertain what, if any, specific programs were promoted during these years; however, it is fairly typical for most fire departments to actively pursue focused health and wellness intervention efforts.

The primary limitation of this study is the lack of validation of the measurement values used to establish levels and comprehensive fitness. There can be multiple opportunities for measurement error, classification and information bias. At the person-level, there may also be day-to-day limitations in performance, and individuals that naturally border the categorized thresholds will fluctuate between fitness levels and status. The choice of having three levels in this study was predicated on it being most relevant to methods already in use for the population during their annual physical exams. In the future, and with more reliable measures, there may be potential to use a weighted scale in the scoring of fire-fitness categories, developed from a cross-section of leading occupational health experts and through a consensus-driven process. Finally, this study was not able to account for individuals who may have been recovering from previous injury or illness at the time of their annual physical.

This five-year period represents a random “snapshot” in time for this occupational cohort, making it difficult to assess or account for the semi-regular introductions of health and safety protocols and/or intervention efforts to improve wellness. Evaluated over a longer time, more apparent trends and distinct changes in effect size may be discernible. However, the ability to review five consecutive years of a near-complete occupational cohort is a clear and unique strength.

The outcomes presented here are one of the first attempts to describe a comprehensive assessment of fitness for a population of fire service employees. There continues to be a need for defining and validating comprehensive fitness measures that are also of utility, especially to departments and operations that have limited resources. The components of fitness assessed (i.e., cardiovascular, muscular strength, muscular endurance, flexibility and body composition) are apt; however, the metrics used to represent each component may be improved, either by different assessment instruments and/or protocols enabling additional accuracy and precision. For example, a modified sit-and-reach test can be used to account for differences in limb length. Muscular strength can be more accurately gauged by a one-repetition maximal bench press, while muscular endurance would be better represented by completing sit-ups and push-ups to failure. Nevertheless, when considered with the pragmatic limitations and financial constraints of most fire departments, the measures for best-practice may not match the gold standards of exercise physiology.

Conclusion

The occupational demands of fire service employees support the need for integrated methods to assure that reliable measures of comprehensive fitness are available for the regular assessment of "fire fitness". The ability to prospectively monitor individual health and wellness throughout a career is of necessity, as the increasing number and types of hazards exposed to on a daily basis should be of continual concern. Information from improved measures of fitness should be used to assess changes in health/fitness status over time and to determine risks associated with injury, illness, or other morbidities.

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APPENDIX C: MANUSCRIPT 3

Title:
The Association of Aerobic Capacity and Fitness with Injuries in the Fire Service

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BACKGROUND & INTRODUCTION

The job duties for the fire service have expanded over the last few decades, resulting in their general recognition as first responders to all emergencies. Consequently, both physical and mental fatigue can easily result during a standard 24-hour shift, increasing the likelihood of injury.

The work demands for fire service employees are well documented as being diverse and requiring increased physical abilities. Southmann et al. (1992) recommended that the average workload for firefighters should necessitate an aerobic capacity (VO_2max) between 38 – 42 $mL \cdot kg^{-1} \cdot min^{-1}$. Since then, most fire departments have adopted minimum fitness standards, often emphasizing aerobic capacity as a definitive measure of overall fitness. Individuals with higher aerobic capacities by definition should be able to consume more oxygen and are likely to be more efficient in its circulation to all systems and in energy production. Hence, those with higher VO_2max should have a lower potential for injury.

Fitness levels, as measured by muscular strength, muscular endurance, aerobic capacity, flexibility and body composition help predict one's ability to do work. Individuals that are in the top levels of a fitness spectrum may not be as susceptible to microtraumas and can tolerate and recover better than their less fit counterparts (Crill and Hostler, 2005; Crosisier, 2004; Anderson, 2010; Giovannetti et al, 2012; Henning et al, 2011; Hollander and Bell, 2011; Kaufman et al, 2000). Conversely, a high fitness level may also be an indicator for increased injury risk as these individuals have greater exposure time to exercising hazards and may be prone to increased loads. In addition, individuals (of similar fitness levels) will respond to stressors differently (Raglin 1999). Other intrinsic factors that may predispose one to injury include psychological and psychosocial factors, previous injury, predisposing musculoskeletal disease or preexisting illness (Fields et al, 2011; Marras et al, 2008; Caruso et al, 2004).

The opportunities for injuries in the fire service are diverse, and in some cases exercise has been shown to be the leading activity associated with on-duty injuries (Poplin et al., 2012a). An injury is the result from an overloading of force (or load) in relation to a tissue's load-bearing capacity (Wilson, 2002). Factors that may contribute to the occurrence or severity of an injury are generally labeled as intrinsic or extrinsic factors, including (but not limited to) age, gender, physiological condition, nutrition, psychological status, fatigue, environmental conditions, equipment, previous injury, co-morbidities, drug use, human interactions, ergonomics, inadequate rehabilitation, skill level, experience, pain, and anthropometric variability (height, weight, body composition, etc.).

The objectives of this study are to establish and understand the risk of injury in relation to one's fitness status in a five year occupational cohort of relatively fit individuals who are members of a suburban fire service. Three injury outcomes were assessed. The primary outcome measured whether or not an individual reported any injury during the surveillance period. A secondary outcome included any reported injury related to physical exercise. The final outcome included any sprain or strain injury, since fitness related injuries are likely to be musculoskeletal in nature rather than contusions, lacerations, etc. The analyses initially assessed the relationship between VO_2max and injury. In addition, since aerobic capacity accounts for only one component of functional fitness within this occupational cohort, a more comprehensive measure of fire fitness was utilized to determine if this measure increased the ability to estimate risk for sustaining injury. This measure of fire fitness accounted for muscular strength, muscular endurance, flexibility, and body composition, in addition to aerobic capacity.

METHODS

Population description, Data sources & years

Previously described (Poplin et al., 2012a), this study includes data from all commissioned employees of a medium-sized metropolitan fire department in the Southwest United States (U.S.). Briefly, this fire department operates 21 fire stations and responds to nearly 520,000 permanent residents (with seasonal increases nearing 720,000). Like many municipal fire departments, periodic (e.g., annual) fitness testing and medical clearance by means of a medical and physical exam are required for each commissioned employee. For years 2005-2009, data for this study were obtained from two sources: physical assessments from annual clinic visits and department injury and illness surveillance data. Inclusion criteria for the present study consisted of all commissioned (non-civilian) employees of the fire department who were employed at some point in time during the surveillance period.

Injury defined

The prior study described all injuries that were recorded in the departmental database. These injuries included a combination of OSHA-reportable and internally documented injuries deemed non-OSHA reportable, but were recorded in the case the injury progressed to a point requiring an insurance claim (e.g., due to cumulative or repeated trauma). For purposes of these analyses, reported injuries known only to be internally documented incidents (by review of injury report details) were excluded. In addition, cardiac events (e.g., stroke, heart attack, etc.), along with heat exhaustion, stress and other medical issues) were excluded from injury analysis. These events were considered more indicative of an underlying set of symptoms, conditions and disease than related to an injury. To help characterize injury incidents, the Occupational Injury and Illness Classification System (OIICS), developed by the Bureau of Labor Statistics was employed for the classification of injury (BLS, 2007).

Physical Fitness Measures

Results from the required annual medical exams and performance testing are gathered for all active fire service employees to monitor for any potential deleterious effects or conditions (e.g., hearing loss, vision impairment, cancer risk, cardiovascular disease). Information collected from annual exams includes, but is not limited to, anthropomorphic measures (e.g., height, weight, body fat percentage), aerobic function and capacity, muscular strength, muscular endurance, flexibility, blood analytics (e.g., cholesterol, blood pressure, triglycerides, etc.), and other medical indicators (e.g., smoking status, C-reactive protein, prostrate-specific antigen, etc.).

An assessment of subjects' fitness status was completed using a previously established comprehensive fitness score that categorized individuals into one of three fitness levels. (Poplin et al., 2012b) The level of "fire fitness" represents a scoring of seven fitness measures (i.e., aerobic capacity, resting heart rate, total grip strength, flexibility, sit-up repetitions, push-up repetitions, and percent body fat) in relation to normative standards developed for this occupational population. For each variable, a value in the Tier I range represented high performance or fitness (for that measure), whereas values that were categorized in Tier III may limit the ability to safely perform all emergency job tasks. Subsequently, Tier II indicated a mid-level of performance during the assessment. Three categories – Level I "high fit," Level II "fit," and Level III "less fit" – were established for comprehensive "fire fitness" and directly relate to the summed variable scores of 7-8, 9-10, and $\geq$ 11, respectively.

Statistical Analyses

Data from injury surveillance and annual physicals were merged utilizing unique identifiers, thus enabling a direct comparison of those with and without the outcome of interest (i.e., injury). Quantitative research methods, notably log-binomial regression and time-to-event models were used to evaluate the relationship between fitness measures and injury. Several different analysis strategies were evaluated. Fitness was assessed via three different variables: (1) aerobic capacity (VO_2max) as a continuous variable, and (2) VO_2max categorized into three levels of aerobic fitness. The third fitness variable was the aforementioned three levels of comprehensive "fire fitness." Models were evaluated for ability of fitness level (either VO_2max or fire fitness category) to predict subsequent injury. These models were constructed for any injury sustained, physical exercise injuries, and sprains/strains.

Log-binomial models are a type of generalized linear model that account for the dichotomous distribution of outcome responses and results in risk ratio estimates (Hilbe, 2009). In this set of models, analyses were conducted to assess the potential independent relationship between an individual's best, worst and average physical fitness status over the time period with their risk for ever having an injury during that time. For time-to-event (i.e., first injury) testing, life table and Kaplan-Meier analyses were conducted to estimate cumulative incidence, allowing for censoring (i.e., no injury). Cox proportional hazard models were also assessed. The added strength of capturing time-series (or longitudinal) data for the population increases the ability to account for at-risk time and control for confounding effects both within and across individuals, in addition to evaluating for secular trends.

Two types of time-to-event analyses were modeled. The first utilized the more classic cohort approach of using an individual's baseline measures of fitness (i.e., the first clinic evaluation) as the independent variable with time measured until the subject suffered an injury or was censored. The second time-to-event analysis utilized repeated measures, in which each time point (observation) began with an individual's annual medical exam (which occurs approximately every 12 months) until the outcome (reported injury) or censoring (no reported injury). Thus each individual could contribute multiple time intervals to the analysis. In this model, the actual calendar dates for entry and exit could vary for each individual, and exposure variables would only be assumed constant throughout each time interval during which an injury might or might not occur. This method should account for the variable observation periods since some employees may be introduced later in the study period (e.g., new employees, etc.), while others may drop out (e.g., retirement, transfer). With the hypothesis that those who are deemed less fit are more susceptible to injury, this repeated measures approach enables a single individual to contribute time at risk to each of the fitness levels based on their most recent physical assessment.

Statistical analyses were conducted using Stata software, version 11.2 (College Station, TX).

RESULTS

Between 2005 and 2009, there were between 577 and 694 annual commissioned employees within this metropolitan fire service (totals represent employees at the end of calendar years). During that time, 799 employees were evaluated for at least one physical exam and followed for some time period in the injury surveillance database. On average, approximately 87 percent of the workforce population was accounted for in the clinic database with a mean age of 39.2 years. The number of individuals with at least one injury of any type was 357, whereas, 174 and 294 individuals specifically sustained at least one exercise or sprain/strain injury, respectively, with median length of follow-up times of 2.5, 3.2 and 2.8 years.

Log-binomial analyses assessed the relationship between summarized (e.g., mean, best, worst) independent variables and the ever/never occurrence of injury. The resulting risk-ratios were overwhelmingly null or non-significant, signifying no discernible associations. A potential explanation could be the individual level variability some measures possess, as discussed in earlier findings (Poplin et al., 2012b). However, when accounting for time-to-event (i.e., first injury), the amount of statistical power to recognize associations between measures of fitness and injury improved.

For time-to-event modeling, one less subject was included in the analyses for all injuries (n=718) compared to 719 subjects included in the analyses for physical exercise injuries, and sprains/strains. Upon review, this was due to a laceration that occurred during the first clinic visit, thus the subject had no follow-up time for the all injury analysis.

Accounting for individual level changes and subsequent at-risk time within fitness levels was made possible through the repeated measures analysis. Kaplan-Meier analyses showed a decreased injury incidence rate (IR) with increases in 10-year age categories, in addition to an increase in the median time to injury. There were no significant differences identified between genders, with only five percent of the study population female (typical for a fire service). Increases in percent body fat were related with increased IR, driven most notably by those in the highest tier (>36% body fat).

With the exception of exercise related injuries, the baseline cohort analyses indicated an increased IR with decreases in total grip strength. In addition, baseline cohort analyses suggested a non-significant increase in IR with increased flexibility. Neither push-up nor sit-ups were found to be useful predictive measures, given the propensity for individuals to terminate testing once 30 repetitions have been completed (the minimum number needed to reach the highest fitness tier).

An objective of this study was to determine if a more global measure of one’s fitness would be more predictive of injury versus a more common approach of using aerobic capacity as a proxy measure for overall fitness. Table 1 shows the general summary characteristics of the incidence of injury outcomes for aerobic capacity (VO_2max) and the comprehensive fitness measure (“Fire Fit”) which represents the ability to perform all work demands associated with the fire service.

For baseline measures of fitness only, there were no systematic differences in the incidence of injuries between levels of aerobic capacity or comprehensive fire fitness. However, when repeated measures of fitness were included in the analyses, log-rank tests indicated statistically significant increases in IR with a decline in VO_2max (Table 1) for each injury outcome assessed. In addition, those with lower VO_2max levels were likely to sustain any injury sooner, as indicated by a median time-to-injury of 2.24 years in Tier III compared to 4.07 years for Tier I (Figure 1).

Repeated measure analyses also indicated an increase in IR with decreases in overall fire fitness levels, from 17.8 injuries per 100 person-years in level I (best) fitness to 20.6 and 29.2 injuries per 100 person-years in levels II and III, respectively. Statistical significance was found only in relation to sprain and strain injuries, as IR increased from 9.1 to 23.2 injuries per 100 person-years (Table 1) as comprehensive fire fitness decreased (Fire Fit Level III).

Table 1. Comparison of models utilizing either baseline values or repeated measures with summary statistics* between VO_2max and ‘Fire Fit’ measures and various injury outcomes

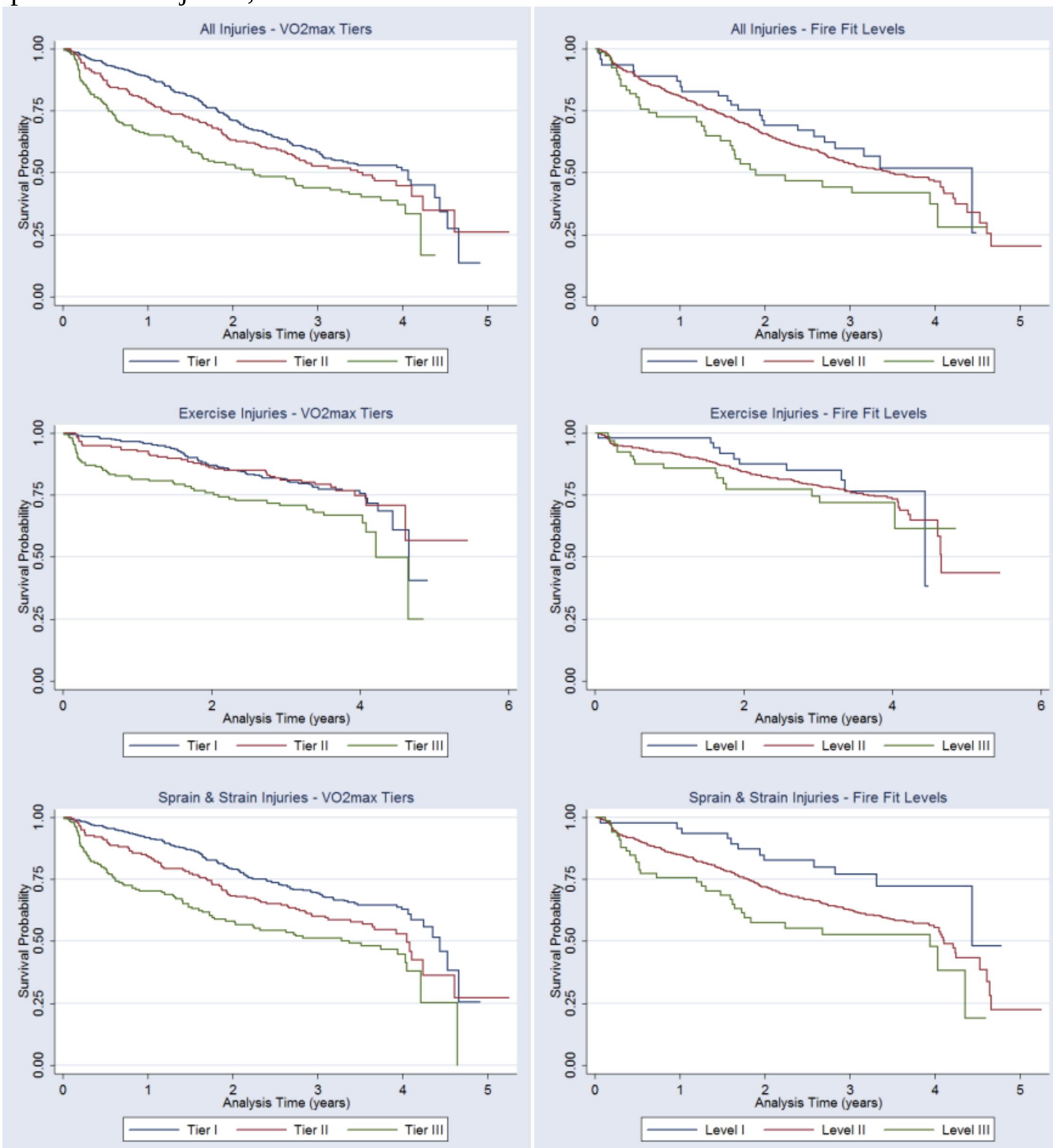
		Injury Type								
		All Injuries			**Physical Exercise**			**Sprains/Strains**		
Time-series Model Type		*IR*	*N*	*Years at risk*	*IR*	*N*	*Years at risk*	*IR*	*N*	*Years at risk*
VO_2max‡ Baseline	*Tier I*	21.7	253	613	8.4	254	763	15.8	254	676
	Tier II	17.9	225	558	7.2	225	652	14	225	593
	Tier III	23.8	222	484	10.2	222	577	18.9	222	513
VO_2max Repeated	*Tier I*	17.5	460	921	7.3	532	1116	12.2	482	996
	Tier II	21.1	287	442	7.2	332	541	17.2	312	483
	Tier III	29.9†	235	338	13.3†	263	407	25.1†	242	355
Fire Fit Baseline	*Level I*	23.9	44	109	8.3	44	144	18.5	44	124
	Level II	20.3	606	1455	8.3	607	1729	15.6	607	1557
	Level III	26.6	59	117	10.8	59	148	20.9	59	124
Fire Fit Repeated	*Level I*	17.8	79	124	6.9	96	145	9.1	83	132
	Level II	20.6	650	1458	8.4	675	1771	16	660	1569
	Level III	29.2	97	120	10.6	121	150	23.2†	108	134

*Incidence Rate (IR) per 100 person-years; Number of individuals at risk (N); Contributed time at risk (person-years)

‡ VO_2max tier value ranges: I > 48, II 43-48, III < 43 mL/kg/min

† Statistical significance ($p < 0.05$) between levels using log-rank test for equality of survival functions

Figure 1. VO_2max tier and Fire Fit level Kaplan-Meier curves for all, exercise, and sprain/strain injuries, 2005-2009



Cox-Proportional Hazard Modeling

Results from Cox proportional hazards models are presented in Table 2. These models are utilizing time to the injury as the dependent variable as a function of fitness. The hazard ratios for fitness are shown with respect to three modeling strategies: (1) VO_2max adjusted for age and gender, (2) VO_2max adjusted for all measures of fitness (i.e., VO_2max full model), and (3) the three-level, categorically-defined measure for comprehensive fire fitness. No statistically significant associations were found between fitness at baseline and subsequent injury over the following five years.

In contrast, utilizing the repeated measures method to model the multiple examination periods, allowed a fuller description of the relationships between fitness and injuries. With a hazard ratio of 0.959 for all injuries (repeated measures), a one mL/kg/min increase in VO_2max decreased the risk of injury 0.041 times. Converting this change in one unit increase of VO_2max to an equivalent measure of the amount of work needed to complete a given task in relation to the amount of energy expended during one minute of seated rest (metabolic equivalent of task or MET) would suggest that improving one's aerobic capacity by 1 MET (equal to 3.5 mL/kg/min) may reduce the risk for any injury by approximately 14%.

Table 2. Comparison of time-to-event models (baseline measures and repeated measures) for assessing the aerobic fitness and risk of injury, by type of injury

		Fitness Hazard Ratio (95% CI)	
Model	**Injury Outcome**	**VO_2max***	**VO_2max Full Model†**
Baseline Measures	All	1.00 (0.989 - 1.020) *(n=700)*	1.015 (0.998 - 1.033) *(n=645)*
	Physical Exercise	1.00 (0.983 - 1.027) *(n=701)*	1.013 (0.987 -1.039) *(n=646)*
	Sprains & Strains	0.994 (0.978 - 1.011) *(n=701)*	1.006 (0.987 - 1.026) *(n=646)*
Repeated Measures	All	0.959 (0.946 - 0.972) *(n=716)*	0.953 (0.939 - 0.968) *(n=710)*
	Physical Exercise	0.960 (0.941 - 0.979) *(n=718)*	0.953 (0.933 - 0.973) *(n=714)*
	Sprains & Strains	0.952 (0.937 - 0.967) *(n=718)*	0.947 (0.932 - 0.963) *(n=712)*

* Adjusted for gender and age
† Includes independent variables resting heart rate, grip strength, flexibility, percent body fat, sit-ups, push-up, age and gender

Table 3 assesses the relationship between the categorical levels (or tiers) of fitness for both aerobic (VO_2max) and comprehensive fire fitness variables for the repeated measures analyses. Since larger fire fitness categories signify a decrease in comprehensive fitness, the relationship between fitness and injury risk remains consistent. For each injury outcome, individuals with a lower fitness status had an increased injury hazard than those in the most fit category. For example, those with comprehensive fire fitness scores placed in Level III were 1.82 times as likely to have sustained any injury, as compared to individuals in the top (Level I) fire fitness category.

Similarly, individuals with a VO_2max between 43 and 48 mL/kg/min (Tier II) were 1.38 times more likely to sustain any injury, as compared to those in the top VO_2max tier (>48 mL/kg/min). The risk of injury increased with decreased fitness, as those with VO_2max less than 43 mL/kg/min (Tier III) were 2.2 times as likely to have any injury compared to the top VO_2max tier. The hazard ratios were also found to be greater when the event outcome was restricted to time to first reported sprain or strain.

Table 3. Hazard Ratios‡ for injuries by levels of two measures of fitness (VO_2max and Fire Fitness) in repeated measures modeling

		All Injuries	**Exercise Injuries**	**Sprains & Strains**
VO_2max Tier*		*(n=716)*	*(n=718)*	*(n=718)*
	I	*Ref*	*Ref*	*Ref*
	II	1.38 (1.06 - 1.78)†	1.20 (0.81 - 1.77)	1.61 (1.21 - 2.13)†
	III	2.22 (1.72 - 2.88)†	2.53 (1.76 - 3.64)†	2.63 (1.98 - 3.50)†
Fire Fit Level		*(n=718)*	*(n=719)*	*(n=719)*
	I	*Ref*	*Ref*	*Ref*
	II	1.26 (0.82 - 1.95)	1.28 (0.68 - 2.44)	1.97 (1.10 - 3.54)†
	III	1.82 (1.06 - 3.11)†	1.60 (0.72 - 3.53)	2.90 (1.48 - 5.66)†

‡ All models adjusted for gender and age
* VO_2max tier value ranges: I > 48, II 43-48, III < 43 mL/kg/min
† Statistically significant at $p < 0.05$

The largest association observed was the increased risk of sprain and strain injuries in relation to decline in comprehensive fire fitness. Individuals with comprehensive fitness scores placing them in the highest level, and thus least fit, were 2.9 times as likely to succumb to a sprain or strain, as compared to those in the most fit level (Table 3).

Effect Modification
Based on some of the preliminary modeling, there was a suggestion for decreased injuries with age. To assess the potential of effect modification of the relationship by age, a simple age-stratified analysis was completed for all injury outcomes, as well as sprains and strains. Age proved to be a significant modifier of VO_2max (interaction p-value < 0.05). Table 4 shows hazard ratios for all injuries for those less than age 30 years and 30 years and overall by the fitness scores. Table 5 presents similar information for strain and sprain injuries. For both outcome types (all injury and sprains/strains), the risk of injury among those with decreased VO_2max was compounded by being younger than 30 years of age, as compared to the risk of injury of those over the age of 30 years.

Table 4. Age stratified hazard ratios‡ for all injuries by fitness tiers or levels

		All Injuries	**Age < 30 years**	**Age 30+ years**
VO_2max Tier*		*(n=716)*	*(n=186)*	*(n=555)*
	I	*Ref*	*Ref*	*Ref*
	II	1.38 (1.06 - 1.78)†	2.28 (1.41 - 3.71)†	1.15 (0.85 - 1.57)
	III	2.22 (1.72 - 2.88)†	3.43 (2.10 - 5.58)†	1.86 (1.36 - 2.53)†
Fire Fit Level		*(n=718)*	*(n=187)*	*(n=556)*
	I	*Ref*	*Ref*	*Ref*
	II	1.26 (0.82 - 1.95)	1.67 (0.61 - 4.59)	1.13 (0.70 - 1.85)
	III	1.82 (1.06 - 3.11)†	2.99 (0.97 - 9.20)	1.42 (0.76 - 2.70)

‡ All models adjusted for gender and age within the strata
* VO_2max tier value ranges: I > 48, II 43-48, III < 43 mL/kg/min
† Statistically significant at $p < 0.05$

Table 5. Age stratified hazard ratios‡ for sprain/strain injuries by fitness tiers or levels

		Sprains & Strains	**Age < 30 years**	**Age 30+ years**
VO_2max Tier*		*(n=718)*	*(n=187)*	*(n=563)*
	I	*Ref*	*Ref*	*Ref*
	II	1.61 (1.21 - 2.13)†	2.27 (1.32 - 3.90)†	1.40 (1.00 - 1.95)†
	III	2.63 (1.98 - 3.50)†	4.48 (2.63 - 7.64)†	2.10 (1.49 - 2.96)†
Fire Fit Level		*(n=719)*	*(n=187)*	*(n=564)*
	I	*Ref*	*Ref*	*Ref*
	II	1.97 (1.10 - 3.54)†	2.65 (0.65 - 10.9)	1.74 (0.91 - 3.32)
	III	2.90 (1.48 - 5.66)†	5.04 (1.11 - 22.9)†	2.23 (1.03 - 4.83)†

‡ All models adjusted for gender and age within the strata
* VO_2max tier value ranges: I > 48, II 43-48, III < 43 mL/kg/min
† Statistically significant at $p < 0.05$

DISCUSSION

Injuries in the fire service are highly prevalent. The manner by which injuries evolve – resulting from an exchange of energy – has been described numerous ways. Illustrated by Peek-Asa's "causal model for injuries" (2003), the causal pathway that leads to injury is complex as the interplay between intrinsic and extrinsic risk factors often creates conditions suitable for injury to occur.

This study sought to better understand the association between levels of fitness and the incidence of injury by means of a retrospective occupational cohort. Findings can be summarized as one might hypothesize: lower fitness levels, as defined by either aerobic capacity or a comprehensive measure of fitness, are associated with increased risks in injury. Furthermore, these increased risks are modified by age, such that those there is an even larger effect between fitness level and subsequent injury in those under age 30.

Most occupational settings are obligated to only document and report injured and ill workers. Rarely does occupational health surveillance enable comparisons to the healthy or uninjured. As a result, occupational studies are often limited to a select sampling of the population and dependent on single time-point measures. This research, however, was afforded a significant advantage by conducting a comparison of physiologic and anthropomorphic characteristics between injured and uninjured over a five year period.

Aerobic capacity, as estimated by a submaximal treadmill test, is one of the more widespread measures used throughout the fire service as a fitness standard. Assuming that the relationship between aerobic capacity (VO_2max) and injury is valid, an extension of the primary research question was to determine if a more comprehensive assessment of fitness would predict injury differently, by accounting for other intrinsic fitness measures, particularly muscular strength, muscular endurance, flexibility, and body composition. To understand how fitness related to injury occurrence, it helps to appreciate the biomechanics (and forces) involved in the injury process. Theoretically, the more fit person will have a greater resistance (resilience) to those forces. However, other factors (e.g., situational factors) influences one's susceptibility leading up to the injury as well as the time of injury, itself.

Willems et al (2005a, b) suggest that the true causal relationships between risk factors and injury are largely unexplained, mostly due to minimal prospective study designs and lack of consensus in influential intrinsic risk factors with regard to specific injury types (Beynnon et al 2002). Intrinsic risk factors, such as central motor control (i.e., balance), skeletal abnormalities, alignment of joints, ligamentous laxity, etc. each influence local anatomy and biomechanical limitations (Lavender et al, 2007a, b; Conrad et al, 2008; Clemes, 2010; Chaffin, 2009; Crill and Hostler, 2005; Crosisier, 2004; Fields et al, 2011; Kaufman et al, 2000; Mehta and Agnew, 2010; O'Niel et al, 2011; Hamonko et al, 2011;

Hewett and Myer, 2011). The data assessed for this study did not permit evaluation for these types of intrinsic factors.

A number of studies have assessed the relationship between various measures of fitness and the performance of a given task. However, few studies have focused on assessing the association between fitness, performance and injury risk.

After instituting a new fitness program among United States Air Force (USAF) service members to increase fitness and participation in fitness related activities, mean relative VO_2max increased significantly (6.04 and 3.24 $mL \cdot kg^{-1} \cdot min^{-1}$ among men and women, respectively) over three years of the program (Giovannetti et al, 2012). The number of injuries also increased during that time, which was likely a result of increased participation in exercise activities with no embedded injury prevention program.

During an 8-week basic military training regimen, musculoskeletal injuries were assessed in relation to baseline body composition (BMI), aerobic fitness (3000 meter run), health assessment measures and age (Heir and Eide, 1996). Significant associations between injury and age over 23 years, increased BMI, slow run times, and dysfunction of back or lower limbs were observed at a univariate level. Multivariate logistic regressions showed no relationship between injury and aerobic fitness; however, increased BMI, minor back and lower limb dysfunctions, and mental dysfunctions were predictive factors.

A study of manual material handlers indicated no difference in likelihood to report an injury between exercisers and non-exercisers (McSweeney, 1997). However, authors noted that increased or regular exercise was likely to reduce absenteeism occurrence and duration.

In another study among male material handler employees at three separate facilities, no association was observed between injury occurrence and absolute aerobic capacity; however, a significant increase in injury risk was related to decreased relative VO_2max, in addition to increased percent body fat (Craig et al, 1998). Following a baseline treadmill test for VO_2max, participants of the Aerobic Center Longitudinal Study were assessed for physical activity over a 12-month period (Hootman et al, 2001). Increased risk of musculoskeletal injury was associated with increases in cardiorespiratory fitness (via treadmill test), as well as increases in the amount of reported weekly physical activity. Stratified analyses by physical activity type suggested that the association with cardiorespiratory fitness was potentially driven by unmeasured intensity levels of exercise. Summarizing these studies help elucidate the potential range of methodological approaches and comparability of results between research directed toward understanding the relationship between fitness and injury outcomes.

The type of injury may also be influenced by age (Chau et al, 2009; Croisier, 2004; Hollander and Bell, 2010; King et al, 2009; Kaufman et al, 2000; Kenny et al, 2008). Children and adolescents may have musculoskeletal systems that are not fully "developed", and therefore have more flexibility and laxity, compared to older populations that may also experience possible degenerative conditions. Furthermore, different age groups may be involved with different extrinsic or work situations. Gender differences involved in injury include muscle strength, aerobic capacity, body fat and hormonal activity (Chandry et al, 2010; Croisier, 2004; Feuerstein et al, 1997; Hollander and Bell, 2010).

Results from this retrospective cohort study indicate modification of injury risk based on age of the individual. In particular, younger employees (less than 30 years) with a "lower" VO_2max (defined for this purpose as those below the 50^{th} percentile), were at an increased risk of injury than their older, less fit counterparts. It is believed that this effect modification has less to do with any sort of biological condition related to age and instead is more associated with job rank (and presumably job duties and exposure to external conditions). Typically, younger personnel hold the rank of "firefighter" whereas promotion or career progression tends to lead into ranks of paramedic, engineer and captain. For most responses, firefighters are "first in" to an emergency scene and thus subject to greater hazards, known and unknown emergent threats, as well as the time-limiting stresses. One exception includes the risks paramedics are exposed to during calls involving advanced life support. Nevertheless, the hazard profile and exposure risk for the firefighter rank can be considered greater than that of their team counterparts (e.g., engineer, captain, chief, etc.).

Two important interpretations of the results were that individuals with decreased levels of fitness were at increased risk for injury, compared to their more fit counterparts. In addition, improving one's VO_2max by 1 MET was associated with a 14% reduction in the overall risk of injury. These findings are especially noteworthy considering that one-third of work-related injuries in this population were the result exercise activities (Poplin et al., 2012a), further indicating the need for fitness programs with improved structure and management relevant to the high physical demands of the job.

Strengths, limitations and future directions

There was clear benefit in the ability to conduct time-to-event analyses. The log-binomial model assumed constant follow-up time for all individuals, whereas Cox proportional hazard models allowed for different lengths of follow-up. In addition, Cox model coefficients are unbiased by censoring, unlike log-binomial (or logistic) models. Furthermore, the use of repeated measures modeling allowed the relationship between recent fitness levels and injuries to become more apparent. Still, much improvement can be made to more accurately define and assess at-risk time, both in terms of when an individual crosses the boundaries between levels of fitness, and their actual exposure time to various hazards and activities. The latter point is especially true if outcomes are based on operational job tasks (e.g. injuries during exercise).

While injury events occurring before the first observed clinic visit were removed to avoid left censoring bias (a product of data merging), there was no knowledge of previous injury history. In addition, analyses were restricted to the first specified injury event, therefore, recurrent injuries were not assessed. Future studies on recurrent injuries should enhance the understanding of injuries in this population, by differentiating the risks between repeated injuries (i.e., individuals that suffer the same injury type multiple times) and the repeatedly injured (individuals that suffer from multiple injury types). Questions will undoubtedly arise pertaining to the validity and reliability of measures used to determine fitness. Clinically, VO_2max is intuitively a valid measure. Muscles transfer chemical energy into mechanical energy. The efficiency by which muscles conduct this transfer are related to (1) aerobic capacity, (2) blood flow, (3) muscle capillarity, (4) mitochondrial content of muscles cells, and (5) muscle hypertrophy (Wilson, 2002). Because oxygen consumption is linearly related to heart rate and energy expenditure, when oxygen consumption is measured, there is an indirect measuring of an individual's maximal capacity to do work aerobically (ACSM, 2010).

However, there are considerable inter-individual differences in VO_2max. The four basic limiting factors of VO_2max are (1) pulmonary diffusing capacity; (2) maximal cardiac output; (3) oxygen carrying capacity of the blood; and (4) skeletal muscle characteristics. Aerobic capacity is primarily limited by the rate of oxygen delivery (i.e., heart, lungs, and blood), not the ability of the muscles to take up oxygen from the blood. It is estimated that 70-85% of the limitation in VO_2max is linked to maximal cardiac output (Cerretelli, 1987).

For this study population, VO_2max was estimated using a sub-maximal test protocol previously validated and used widely in the fire service (Gerkin, 1997). Two recent studies, however, have indicated the potential for sub-maximal tests to overestimate true aerobic capacity (Mier and Gibson, 2004; Tierney, 2010). If true, any overestimation of VO_2max should not influence the regression modeling, as the potential bias would be non-differential.

Of note, the distribution of VO_2max values is higher compared to the general population (Heyward, 2010). These differences are likely due to the use of an employed population and the active nature of the jobs. The cutoff values established for the fitness tiers in these analyses were based on the range of distributions within this active population. The overall fitness scores were developed to allow a wider evaluation of fitness than one focused exclusively on cardiorespiratory fitness. A challenge for all fire departments (and similar occupational settings) will be in determining the best measures for assessing each component of functional fitness that are (1) consistent and reliable, and (2) feasible for implementation, given limited resources or funding.

Conclusions

As injuries continue to be of relevant health concern in the fire service, the contribution of fitness to the likelihood of injury is significant. Given that injuries are often the result of a multitude of factors and the efficiency of every response activity in the fire service is dependent on health and fitness of those responders, comprehensive and multifaceted solutions need to be devised, applied and distributed in order to prevent further injury loss. The results and methodological approaches discussed in this study adds support for assessing individual level changes over time and not just at singular time points.
If the reliability or accuracy of submaximal estimates of VO_2max is of concern, the comprehensive measure of fire fitness would help attenuate some of the influence from inter-person variations of VO_2max. Despite any such uncertainties (Mier and Gibson, 2004; Tierney, 2011; Poplin et al, 2012b), decreases in both aerobic capacity and comprehensive "fire fitness" were significantly associated with the risk of injury outcomes, thus demonstrating some efficacy in monitoring for health risks.

The issue of fitness in the fire service is undoubtedly complex, and discussions surrounding fitness can often be lost due to concerns over establishing any type of physical standard that might put into questions one's ability to safely perform the physical work demands of the job. This can inherently be obstructive, if the intent is actually to protect the individual employee, their colleagues, and the community they unselfishly protect. The ultimate goal should be to establish and promote standard mechanisms by which fitness (and overall health and wellness) can be maintained, if not improved.

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APPENDIX D: APPROVAL OF HUMAN SUBJECTS

THE UNIVERSITY OF ARIZONA.

Human Subjects
Protection Program

1618 E. Helen Street
P.O. Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://www.irb.arizona.edu

May 8, 2009

Jeffrey Burgess, MD, MPH, MS
Department of Community, Environment and Policy
College of Public Health
PO Box 245210

RE: **PROJECT NO. 09-0246-02** Implementing Risk Management Strategies to Prevent Injuries among Firefighters

Dear Dr. Burgess:

We received your research proposal as cited above. The procedures to be followed in this study pose no more than minimal risk to participating subjects and have been reviewed by the Institutional Review Board (IRB) through an Expedited Review procedure as cited in the regulations issued by the U.S. Department of Health and Human Services [45 CFR Part 46.110(b)(1)] based on their inclusion under *research categories 5, 6 and 7*. Although full Committee review is not required, the committee will be informed of the approval of this project. This project is approved with an **expiration date of May 7, 2010**. Please make copies of the attached IRB stamped consent documents to consent your subjects.

The above noted project will be done in collaboration with Tucson and Phoenix Fire Departments. Both fire departments have provided letters of support.

The process evaluation survey questionnaire(s) being used in this study is being developed and will be submitted to the IRB for approval prior to its use.

The Institutional Review Board (IRB) of the University of Arizona has a current ***Federalwide Assurance*** of compliance, ***FWA00004218***, which is on file with the Department of Health and Human Services and covers this activity.

Approval is granted with the understanding that no further changes or additions will be made either to the procedures followed or the consent form(s) used (copies of which we have on file) without the knowledge and approval of the Institutional Review Board. Any research related physical or psychological harm to any subject must also be reported to the appropriate committee. Approval is also granted with the condition that all site authorization letters will be submitted to the IRB prior to data collection.

A university policy requires that all signed subject consent forms be kept in a permanent file in an area designated for that purpose by the Department Head or comparable authority. This will assure their accessibility in the event that university officials require the information and the principal investigator is unavailable for some reason.

Sincerely yours,

Elaine Jones

Elaine G. Jones, PhD, RN, FNAP
Chair, IRB2 Committee
UA Institutional Review Board

EGJ/rkd
Cc: Departmental/College Review Committee

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