Occupational Heat-Related Mortality in the United States, 2000-2010: Epidemiology and Policy Recommendations

by Diane M. Gubernot

B.A. in Biological Sciences, May 1990, Rutgers College, Rutgers University
M.P.H. in Environmental and Occupational Health, May 2006, The George Washington University

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Katherine L. Hunting
Professor Emeritus of Environmental and Occupational Health

The Milken Institute School of Public Health of The George Washington University certifies that Diane M. Gubernot has passed the Final Examination for the degree of Doctor of Public Health as of 31, October, 2014. This is the final and approved form of the dissertation.

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Diane M. Gubernot

Dissertation Research Committee:

Katherine L. Hunting, Professor Emeritus of Environmental and Occupational Health
Dissertation Director

G. Brooke Anderson, Department of Environmental & Radiological Health Sciences, College of Veterinary Medicine & Biomedical Science, Colorado State University
Committee Member

David Michaels, Professor (on leave) Environmental and Occupational Health; Assistant Secretary for Occupational Safety and Health, U.S. Department of Labor
Committee Member

Dedication

The author wishes to dedicate this dissertation to the men and women who have died as a result of performing their job duties in unsafe conditions and to Linda Amendt, my spouse, for her unconditional love, support, encouragement, and enthusiasm throughout my graduate studies.

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Abstract of Dissertation

Occupational Heat-Related Mortality in the United States, 2000-2010: Epidemiology and Policy Recommendations

Heat stress due to ambient outdoor temperatures is a workplace hazard that has not been well studied or characterized. The incidence of occupational heat-related illness is unknown. Heat-related morbidity and mortality have been well-studied at the population level, however it cannot be determined if these findings extend systematically to workers exposed to high heat conditions. Remarkably, there is no U.S. federal standard to protect workers from the peril of elevated environmental temperatures and few states have protective regulations. This dissertation research will add to the limited knowledge base of occupational heat-related illnesses, by characterizing worker fatalities due to environmental heat stress. Three independent, but related, research strategies were designed, executed, and completed to evaluate the current research, as well as knowledge gaps, and to thoroughly describe these fatalities based on available information.

This work was initiated with a thorough literature review to summarize research findings that characterize U.S. occupational heat-related morbidity and mortality and identify gaps in the existing research literature. This review of science, health, and medical databases found that few studies examine ambient heat stress or characterize the incidence of occupational heat-related illnesses and outcomes. Significantly more research examining the heterogeneity of worker and environmental risk factors to heat exposure is needed to identify unsafe working conditions and implement practical, evidence-based heat-stress policies and interventions.

The subsequent study describes the epidemiological characteristics of heat-related deaths among workers in the U.S. from 2000 to 2010. Fatality data were obtained at the Bureau of Labor Statistics from the confidential on-site Census of Fatal Occupational Injuries database. Fatality rates and risk ratios with 95% confidence intervals were calculated by year, sex, age group, ethnicity, race, state, and industry. Between 2000 and 2010, 359 occupational heat-related deaths were identified in the U.S., for a yearly average fatality rate of 0.22 per 1 million workers. Highest rates were found among Hispanics, men, the agriculture and construction industries, the states of Mississippi and Arkansas, and very small establishments. This study provides the first comprehensive national profile of heat-related deaths in the U.S. workplace. Prevention efforts should be directed at small businesses, states, industries and individuals who may be at increased risk of heat stress.

Lastly, to further characterize these fatalities, research was performed to: 1) determine the ranges of heat index and temperature at which workers fatally succumb to environmental heat; 2) identify risk factors that may influence heat-related deaths; and 3) translate these findings to policy recommendations. The Census of Fatal Occupational Injuries and the National Climate Data Center were used to identify worker heat-related deaths in the U.S., 2000- 2010, and to assign a maximum daily temperature and heat index to each case. Demographic, meteorological, and geographical variables were analyzed to evaluate any differences in fatal heat exposure. The National Weather Service temperature alert tools, the Excessive Heat Event warning and the heat index category chart, were utilized to assess community threshold suitability for workers subjected to exertional heat stress. Of the 327 cases that qualified for the analysis, there were no differences found in mean temperatures and heat indexes between the sexes, races, age groups, ethnic groups, and industries. Southern workers died at significantly higher temperatures than workers in the North. This study supports the use of heat index and temperature as a guide when evaluating environmental conditions for workers.

Population-level heat index threshold alerts are unsuitable for preventing exertional heat stress and new warning systems should be developed. Since heat-related health hazards at work can be anticipated before they manifest, preventive measures can be implemented before illness occurs. With no federal regulatory standards to protect workers from environmental heat exposure, and with climate change as a driver for adaptation and prevention of heat disorders, it is increasing sensible and imperative for the Occupational Safety and Health Administration to take action. National leadership is needed to promulgate regulations, develop new heat alert tools using the heat index as a metric, and promote state-specific occupational heat stress prevention policies.

Table of Contents

List of Figures

List of Tables

List of Acronyms/Nomenclature

1. ACGIH American Conference of Governmental Industrial Hygienists
2. BLS Bureau of Labor Statistics
3. CDC Centers for Disease Control and Prevention
4. CFOI Census of Fatal Occupational Injuries database
5. CI Confidence Interval
6. EHE Excessive Heat Event
7. HI Heat Index
8. HRI Heat-Related Illness
9. IPCC Intergovernmental Panel on Climate Change
10. ISO International Organization for Standardization
11. NCDC National Climatic Data Center
12. NIOSH National Institute of Occupational Safety and Health
13. NOAA National Oceanic and Atmospheric Administration
14. NWS National Weather Service
15. OSHA Occupational Safety and Health Administration
16. PPE Personal protective equipment
17. r correlation coefficient
18. Rh Relative Humidity
19. SD Standard Deviation
20. T_{MAX} Daily maximum temperature recorded
21. WBGT Wet Bulb Globe Temperature

Chapter 1: Introduction

In the United States (U.S.), employees are entitled to a safe and healthful workplace. However, despite standards promulgated and enforced by the Occupational Safety and Health Administration (OSHA), every year millions of workers are injured and thousands die while performing their job duties (Thomsen, et al., 2007; BLS, 2011).

Exposure to environmental heat is a significant, but overlooked, workplace hazard that has not been well-characterized or studied. Despite the evidence that heat stress is an occupational hazard, there are no U.S. federal government standards to protect workers, and few states have implemented heat safety regulations. Additionally, recommendations from various agencies and occupational organizations provide fundamentally complex, multifaceted approaches for exposure assessment and control.

All heat-related deaths are preventable (English et al., 2009), however more knowledge is needed to determine the risk factors – individual and environmental – that make sub-populations vulnerable to heat stress. Baseline data analyses of the recent past are needed to assess current heat threats and ongoing changes in our warming climate.

Numerous heat-wave studies have been conducted and published to assess health effects, vulnerabilities, risk factors, and mortality in the general population. Research on occupational heat exposure is considerably more limited than population level studies and it has been argued that occupational exposure to climate change effects has received very little attention (Kjellstrom et al., 2009 a and b; Lin and Chan, 2009; Hyatt et al., 2010; Holmer, 2010; Hollowell, 2010). Published empirical data for occupational heat-related morbidity and mortality are sparse and fragmented.

Estimates for heat-related morbidity and mortality in the general population are subject to undercounts as heat may trigger an existing health condition and heat exposure may not be considered as part of the diagnosis (Hajat et al., 2010; Kilbourne, 1999; Semenza et al., 1999). More recent studies of heat illness morbidity include primary and secondary diagnoses to more accurately capture the incidence of heat-related emergency department visits and hospitalizations (eg., Knowlton et al., 2009; Basu et al., 2012; Gronlund et al., 2014). For example, hyperthermia or heat exhaustion may not be listed as the primary diagnosis, but it may be included as a secondary diagnosis in a patient's record. The primary diagnosis may be a pre-existing illness triggered by heat exposure, or it may be a direct consequence of heat exposure (e.g., dehydration).

For population level mortality studies, using cause of death as a sole indicator would exclude deaths for which heat illness was a contributing factor and underestimate the number of deaths caused by exposure to heat (EPA, 2014). A 2006 Center for Disease Control and Prevention (CDC) report on heat-related deaths in the U.S. 1999-2003 acknowledges heat-related illnesses can exacerbate existing medical conditions and death from heat exposure can be preceded by various symptoms, and therefore heat-related deaths can be difficult to identify when illness onset or death is not witnessed by a clinician (CDC, 2006). This report disclosed that previous analyses of the risk factors associated with heat-related deaths have been based on the underlying cause entered on the death certificate and have not included decedents for whom hyperthermia was listed as a contributing factor. The authors re-analyzed their 1999-2003 data by including hyperthermia as a contributing factor; this increased the number of heat-related deaths by

54% and the authors confirmed that the number of heat-related deaths was previously underestimated (CDC, 2006).

Although occupational surveillance data for heat-related deaths are also subject to undercount due to pre-existing conditions as described above, the social setting of the workplace allows for the sudden onset of symptoms and the encompassing circumstances, to be witnessed by others. This may alleviate some of the underreporting of heat stress as a primary or contributing factor in a worker's death. The BLS Census of Fatal Occupational Injuries (CFOI) uses an average of four different types of documents, including death certificates, OSHA fatality reports, police statements, coroner reports, and media reports, to identify and confirm the circumstances of the workers' deaths (Wiatrowski, 2014). Although some occupational heat-related deaths may not be recognized as such, particularly if onset of illness occurs outside of the workplace, the CFOI is considered the most comprehensive, accurate, and complete database of worker fatalities available (Layne, 2004, Marsh & Jackson, 2013, Wiatrowski, 2014).

Under-reporting of non-fatal heat-related illnesses in the occupational arena is further complicated by inadequate surveillance systems, as will be described in Chapter 2. The National Institutes of Occupational Safety and Health (CDC/NIOSH, 2013) reports that in 2010, the U.S. Bureau of Labor Statistics (BLS) reported 4190 illnesses from exposure to environmental heat resulted in one or more days of lost work; in the same year, 40 heat-related fatalities were reported – approximately recognized 100 lost workday cases for every recognized death. BLS does not report data on heat-related illness cases that do not result in lost workdays. In this document, *The NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*

(2013), the shortcomings of occupational heat-related surveillance are summarized, "Because of a lack of recognition of heat-related illness and the nature of reporting only illnesses involving days away from work, the actual number of occupational heat illnesses and deaths is not known. Additionally, estimates of the number of workers exposed to heat are not available."

In summary, difficulty in recognizing heat-related illnesses and deaths and flaws in occupational surveillance systems (particularly for non-fatal illnesses) both contribute to the potential under-recognition of heat-related morbidity and mortality among workers. This dissertation describes 359 heat-related deaths that occurred between 2000 and 2010. These deaths must be considered the tip of the iceberg and do not adequately represent the true impact of harmful heat exposure in the workplace.

The overall goal of this research is to heighten awareness of worker susceptibility to heat stress and inform occupational safety policies; the objectives of this dissertation are described below:

- Contribute to accumulated knowledge on occupational heat disorders
- Identify research gaps and generate hypotheses
- Increase awareness in the scientific, medical, public health, occupational health, and government arenas
- Provide meaningful input for federal and state policy assessment

This study was designed to quantify and describe nationally reportable occupational fatalities due to heat exposure for the last decade (2000-2010). Fatality data were obtained at the U. S. Bureau of Labor Statistics from the confidential on-site Census of Fatal Occupational Injuries database. The research aims were: 1) to provide the first comprehensive literature review and research gap analysis of the epidemiology of occupational heat-related illnesses; 2) to describe overall heat-related fatality rates in the U.S. by year, industry, and state; 3) to describe the demographic characteristics of the cases; 4) to determine the ranges of heat index and maximum daily temperature at which workers fatally succumb to the effects of environmental heat; 5) to identify other risk factors that may contribute to heat-related deaths, such as temporal and geographical variables; and 6) to use these data to determine groups at highest risk for targeted prevention efforts and to inform policy-makers. Specifically, the following research questions will be answered by the dissertation studies:

1. What were the magnitude and characteristics of heat-related occupational mortality in the U.S., 2000-2010?
2. What were the spatial and temporal patterns of occupational heat-related fatalities in the U.S., 2000-2010?
3. Which industries and establishment types had the highest rates of occupational heat-related fatalities in the U.S., 2000-2010?
4. What ambient temperature and heat index ranges are associated with occupational heat-related fatalities?
5. Among heat-related fatalities, does the distribution of heat index values vary by age groups, race, sex, industry sector, or geography?
6. Do the National Weather Service heat thresholds for excessive heat events provide suitable protection for workers?

7. Do the National Weather Service heat index caution categories provide suitable warnings for workers?
8. How can the findings be interpreted to recommend practical heat stress prevention policies for the workplace?

The ensuing chapters are independent, but related, research projects designed to collectively meet the aforementioned aims of this dissertation and address the research questions. Chapter 2 provides a comprehensive literature review and a research gap analysis of occupational heat-related morbidity and mortality. The next chapter describes the epidemiology of worker heat fatalities and includes descriptions of data sources and methods, as well as an interpretation of the data. Chapter 4 describes the heat index and maximum temperature values associated with worker heat fatalities and assesses the National Weather Service's heat alert thresholds and their heat index category chart as an alert tool for workers. This chapter also includes the methodological approach and discussion of the data analyses. Each chapter also includes the limitations of the study, recommendations for future research, and policy needs.

This project contributes to the understanding of the heat-health relationship, which is beneficial for developing public health responses, evaluating worker population vulnerabilities to increased temperatures, updating existing guidelines, informing policy makers, and for designing future occupational adaptive measures in response to climate change.

Chapter 2: The Epidemiology of Occupational Heat Exposure in the United States: A Review of the Literature and Assessment of Research Needs in a Changing Climate. (2012). *Internat J BioMeterol* doi: 10.1007/S00484-013-0752-x

Background

In the United States, employees by law are entitled to a safe and healthful workplace. However, despite standards promulgated and enforced by the Occupational Safety and Health Administration (OSHA), every year millions of workers are injured and 4000-6500 die from fatal work-related injuries (Thomsen et al., 2007; BLS, 2011). Occupational surveillance systems capture these data and are key for designing effective interventions to improve worker safety and health.

Each year, there are thousands of occupational heat-related illnesses and during the last decade, more than 300 civilian workers died on the job due to environmental heat exposure (BLS, 2011). These data may not include severe or fatal injuries or illnesses, such as falls or myocardial infarctions, for which heat was a contributory cause. With a warming climate and more frequent extreme weather events predicted, this hazard could become a prominent employee safety issue in the near future. Even small changes in average temperature can potentially translate into a substantial increase in the number of deaths and cases of severe illness (Kilbourne, 1992).

Severe weather elements have always been a threat to human health. However significant shifts in weather patterns are escalating and climate change is now recognized by the World Health Organization (WHO) as one of the leading global health threats of the 21st century (WHO, 2009). The anticipated effects and importance of global climate change vary from region to region. In the U.S., increases in average ambient temperatures are expected and episodic heat waves are projected to increase in frequency (Christensen et al., 2007).

Heat-related disorders can arise from stress due to increased air temperature, humidity, radiant heat, and metabolic heat from strenuous physical work (Weeks, 1991). When ambient temperatures are high, the body becomes dependent on evaporative cooling and is susceptible to anything that restricts evaporation, such as high humidity, clothing, and low air movement (Budd, 2008). As body temperature rises, cardiovascular strain increases as more blood is pumped through the skin and additional sweat is secreted, accelerating dehydration (Budd, 2008).

Simply stated, heat stress occurs when the individual has been overexposed or over-exercised for his/her age and physical well-being in the existing thermal environment (NOAA/NWS, 2005). Generally, the body should maintain a core temperature within + 1^{o}C of normal temperature, 37^{o}C (*i.e.*, 100.4^{o}F maximum) (ACGIH, 2009). Illnesses due to heat occur along a continuum and may initially manifest as heat cramps or heat exhaustion; if left untreated these conditions can progress to heat stroke, which may be fatal. However, humans are capable of adjusting to heat, a process referred to as acclimatization. Acclimatization largely occurs within the first 4-6 days of repeated or continuous daily exposure and is usually complete within two weeks; the benefits decay quickly and are mostly lost 3 to 4 weeks after heat exposure ceases (WHO, 1969). Heat waves are episodic, and although the population may adapt to gradual temperature increases, physiological adaptation to intermittent extreme heat events is considered unlikely (Patz et al., 2000).

Heat is the leading cause of weather-related deaths in the U.S. and, on average, claims more lives than lightening, tornadoes, hurricanes, and floods combined (NOAA, 2011). The National Oceanic and Atmospheric Administration (NOAA) reported over 20,000 deaths in the U.S. were attributed to extreme heat in the years 1936 to 1975 (NOAA/NWS, 2005). Due to recent heat waves in the U.S. and Europe, numerous studies have been published within the last decade on heat-related hospitalizations and deaths. These studies were performed on the general population to characterize the mortality risk, identify vulnerable sub-populations and risk factors (Semenza et al., 1996; Semenza, et al., 1999; Knowlton et al., 2009; Bouchama et al., 2007; Stafoggia et al., 2006; Rey et al., 2009; Basu and Malig, 2011; Josseran et al., 2009; Williams et al., 2012), and examine heat wave temporal and spatial metrics associated with mortality (Anderson and Bell, 2011; Basara et al., 2010;Gabriel and Endlicher, 2011; Hondula et al., 2012; Son et al., 2012) so to inform preventive measures for reducing morbidity and mortality during extreme heat events.

Research on occupational heat exposure, however, is more limited than population level studies and it has been argued that occupational exposure to climate change effects has received very little attention (Kjellstrom et al., 2009a; Kjellstrom et al., 2009b; Lin and Chan, 2009; Hyatt et al., 2010; Holmer, 2010; Hollowell, 2010; Schulte and Chun, 2009). Published empirical and epidemiological studies on occupational heat stress are sparse and fragmented. In 1986, the National Institute for Occupational Safety and Health (NIOSH) estimated 5 to 10 million workers in the U.S. are exposed for at least part of the year to hot work conditions that can seriously threaten their health (NIOSH, 1986); yet, the incidence of occupational heat-related illnesses

(HRI) in the U.S. is not known. Additionally, illnesses related to heat are not always recognized, and the criteria to define heat-related deaths may differ by state, and among physicians, medical examiners, and coroners (Donoghue et al., 1997). Even with a correct diagnosis of HRI, the case may not be reported as work-related.

Occupational Surveillance and Standards

Congress created OSHA with the Occupational Safety and Health Act (OSH Act) of 1970 to ensure safe and healthful conditions for working people. OSHA sets and enforces standards and conducts inspections of facilities to assess compliance. The Agency also provides training, outreach, education, and assistance (www.osha.gov/workers.html).

In addition to specific industrial standards, employers must also comply with the General Duty Clause of the OSH Act, which requires employers to keep their workplaces free of serious recognized hazards (www.osha.gov). This clause, in Title 29 U.S. Code 654, may be cited when no OSHA standard applies to the hazard, such as a fatality due to excessive environmental heat exposure.

Few states have implemented occupational heat exposure regulations. Only California (CA Regs, 2012) and Washington (WA Leg, 2012) have standards for outdoor heat exposure, while Minnesota has an indoor heat exposure standard (MN Rules, 2012). OSHA, with the support of California OSHA and NIOSH, launched a heat illness prevention campaign in the summer of 2011. The aim of this voluntary program is to educate both employers and employees on recognition and prevention of heat illness by targeting outdoor workers. The OSHA website provides information on risks, prevention, signs and symptoms, and first aid for heat illnesses (www.osha.gov/SLTC/heatstress/). The Mine Safety and Health Administration (MSHA) also has voluntary guidelines and recommendations for preventing thermal stress in workers (MSHA, 2012).

Occupational heat stress is not a novel issue. The military pioneered studies on heat illnesses and enforced guidelines at training facilities to reduce heat causalities in 1953 (Minard et al. 1957). Formal CDC epidemiological investigations of work-related heat illnesses date back to 1957 (Falk and Briss, 2011). NIOSH recommended a heat exposure standard to OSHA in 1972 and updated that recommendation in 1986 (NIOSH, 1972; NIOSH 1986). Despite the history and the evidence that heat stress is an occupational hazard, neither OSHA nor MSHA have promulgated standards for environmental heat exposure under the U.S. Code of Federal Regulations and uniform heat stress prevention policies do not exist.

Public health surveillance data are necessary to determine the magnitude of the problem of occupational injuries and illnesses, identify workers at greatest risk, and develop prevention priorities (Thomsen et al., 2007). The Bureau of Labor Statistics (BLS), part of the Department of Labor, issues annual reports on the number of workplace injuries, illnesses, and fatalities in the U.S. The BLS conducts the annual Survey of Occupational Injuries and Illnesses and also collects information on workplace fatalities via the Census of Fatal Occupational Injuries.

Surveillance of worker illnesses and injuries is not optimal and it is well-established that occupational illnesses and injuries are under-counted (Miller, 2008; Rosenman et al., 2006; AFL-CIO, 2011; Taiwo et al., 2010). Occupational illnesses in general are challenging to diagnose for several reasons: 1) the similarities in the clinical presentation and pathophysiology of illnesses resulting from occupational and non-occupational exposures; 2) the latency period between exposure and symptom onset; 3) the multifactorial etiology of many diseases; and 4) the lack of patients communicating work-related hazardous exposures (Taiwo et al., 2010). Further, there are many reasons why employees may not report illness or injury to employers, including: 1) fear of discipline, termination or being labeled as a problem employee; 2) economic incentives; and 3) foreign-born workers may fear being reported to the U.S. Citizenship and Immigration Services (AFL-CIO, 2011). All of these factors, including lack of physician and patient awareness, may explain the underreporting and under-diagnosis of heat disorders, particularly in the working population. Since heat exposure can contribute to accidents and cardiovascular or respiratory problems, estimates for worker HRI are even more problematic as it is difficult to recognize as a contributing factor to illness or death.

The American Conference of Government Industrial Hygienists, NIOSH, and the International Organization for Standardization have published guidelines aimed at preventing occupational heat stress (ACGIH, 2009; NIOSH, 1986; ISO, 1989). These documents are highly technical, using sophisticated calculations for individual metabolic heat load, including clothing and work type, as well as applying wet bulb globe temperature (WBGT) measurements to determine apparent temperature exposure. These structured guidelines are intended for industrial hygienists and occupational clinicians to use for employees in their particular work environment. Employers who lack such specialized positions and equipment may be left without any heat stress prevention program.

Public Health and Occupational Studies and Reports

Few population-level studies on HRI have captured and reported occupational cases. A study of nonfatal natural and environmental injuries treated in emergency departments in the U.S. from 2001 to 2004 reported that 78.3% (20,775) of these injuries were heat-related and heat was the most common cause for environmental injury across all age categories (Sanchez et al., 2010). People with heat-related injuries had a median age of 34, 73.7% were males, and 73% of the heat-related diagnoses were heat exhaustion; an estimated 40.3% of the cases were from occupational exposures.

Several studies have exclusively investigated heat illness related to exertion. Nelson et al. (2009) stated exertional heat-related disorders are a risk to all physically active individuals in warm or hot environments. Consequently workers are at high risk to heat stress given that most outdoor work requires some level of activity, and at times considerable exertion or endurance. These authors studied all exertional heat-related injuries treated in emergency departments in the U.S., 1997-2006. They found the number of these injuries increased significantly over a ten year time period, from 3192 injuries (95% CI = 1290 - 5093) in 1997 to 7452 injuries (95% CI = 4270 - 10636) in 2006 ($p = 0.002$).

Workers who perform strenuous work while exposed to high temperatures are especially vulnerable to HRI as the combined metabolic and environmental heat loads challenge the bodies' cooling mechanisms. Yet few epidemiological studies specifically examine this workplace health hazard.

Several work-related risk factors for heat stress have been noted in the literature. A worker's length of service in a particular job has been found to be a risk factor for injury. This finding seems to hold true for workers who succumb to heat exposure as they might not be acclimatized to the heat and the exertion required for the job. Maeda et al. (2006) studied risk factors for heat stroke among Japanese forestry workers and found that a short duration of forestry service was associated with onset of heat stroke. In a case-series of exertional heat stroke in the military, 50% of the cases occurred during the first six months of service (Epstein et al., 1999). Another military study noted 44% of 5246 HRI cases occurring in a 12 year period affected soldiers with less than one year of service (Carter et al., 2005).

The military has performed numerous studies on the health of soldiers and the effects of extreme heat, as heat exposure has historically been a military concern (Hollowell, 2010; Epstein et al., 1999; Carter et al., 2005; Dellinger et al., 1996; Gardner et al., 1996). In the aforementioned case series analysis of military heat stroke cases, Epstein et al. (1999) reported that 60% of cases occurred in overweight soldiers and that heat stroke occurs mainly within the first two hours of exercise. These findings are relevant to worker safety in other occupations as well since obesity is a growing health problem in the U.S. (CDC, 2010).

Most studies to-date focus primarily on outdoor occupations, however extreme heat also affects those workers who are employed in un-air-conditioned facilities such as some factories and warehouses. Furthermore, the use of personal protective equipment (PPE) by numerous occupations, including first responders, exacerbates the risk for heat stress. PPE can contribute to heat-related injuries in conditions that are not considered excessively hot, because the equipment/clothing can prevent heat loss from the body and lead to hyperthermia (Crockford, 1999). This added risk is evident in a Washington state study (Bonauto et al., 2010) that found the average HRI ambient temperature affecting firefighters was only 78.7^{o} F compared to 88.6^{o} F ($p<0.001$) for other occupations.

North Carolina, Florida, and Washington states have published reports characterizing heat-related illnesses and fatalities either targeting, or including, those identified as work-related:

- Mirabelli and Richardson (2005) identified heat-related fatalities from medical examiners' records in North Carolina from January 1977 to December 31, 2001 (n=161). Although the authors examined fatalities in the general population, they identified 25% of cases as occupational heat-related fatalities (n= 40) and noted 45% of these occurred among farm laborers.
- The Florida Department of Health (2011) performed a descriptive analysis of occupational heat-related illnesses treated in Florida hospitals and emergency departments. Using Workers' Compensation records, the authors identified 2198 cases from 2005-2009. They noted the highest rates were in rural counties and in the 25-29 year age group.
- Washington State (Bonauto et al., 2010) also performed a descriptive study of 483 Workers' Compensation claims for heat-related illness from 2000-2009. They found most claims were in the administration of conservation programs, roofing contractors, site preparation contractors, and fire protection industry sectors. The vast majority of cases occurred May-September (97%), the median age was 34 years old, and 80.3% of the cases were male.

Few industry-specific studies have examined the epidemiology of occupational heat exposure in the U.S. Using MSHA surveillance data, Donaghue (2004) studied heat illness in the mining industry, 1983-2001, and found 538 heat-related illnesses; there were no fatal cases. Luginbuhl et al. (2008) identified 423 heat-related deaths which occurred among U.S. workers from 1992 through 2006, noting 102 of these fatalities occurred among workers employed in the agricultural, forestry, fishing, and hunting industries, with the crop production sector accounting for 68 of these deaths.

Fredricks et al. (2005) conducted a survey of roofing workers to better examine specific types of injuries and potential reasons for accidents. Corroborating OSHA's counsel that working in direct sunshine can add up to 15^{o}F to the temperature that the body perceives (OSHA, 2011), the roof workers in this survey study contended that an extra 10^{o}C (~15-20^{o}F) is generated while working on a roof with black asphalt shingles in direct sunshine. To compensate for this, schedules are temporally shifted, with work performed primarily in the early morning or evening. Although the authors studied types and frequencies of injuries in this industry, they did not present the data by month or study injuries associated with weather variables.

Several incident-specific reports of occupational HRI exist. Krake et al. (2003) reported on health hazards to park rangers from excessive heat at the Grand Canyon National Park and NIOSH investigated employee heat exposure on the tarmacs at Palm Beach International Airport (NIOSH, 2006). Both reports identified unhealthy heat exposures, however further exploration into industry- or occupation-wide HRI was not performed.

The effect of environmental heat on the responders to environmental disasters is noteworthy. Thousands of people, with varying degrees of training and fitness, may be deployed to respond to a major event. The responders can be exposed to numerous environmental threats, including ambient heat exposure. For example, during clean-up operations of the Deep Water Horizon Gulf Oil Spill of April 2010, over 739 incidents of illness due to heat were reported, some of which were very serious (OSHA, 2012). The NIOSH *Health Hazard Evaluation of Deepwater Horizon Response Workers* revealed that the conditions for heat stress were present, significant, and often the most pressing concern for the health and safety of the response workers; the required PPE intensified the health effects related to heat (Kings and Gibbons, 2010). The demand on health workers and emergency responders will increase in a changing climate with extreme weather events, yet public health policies to protect these essential workers from weather-related hazards are lacking (Hanna et al., 2011). See Appendix A, Table A for a list of occupational studies and a summary of findings.

In addition to direct health effects, other occupational research related to the potential effects of climate change examines the effects of increased heat exposure from the perspective of productivity and economics (Kjellstrom et al., 2009a; Kjellstrom et al., 2009b; Lin and Chan, 2009). Increased heat will decrease workers' abilities to perform and decrease productivity (Weeks, 1991; Lin and Chan, 2009; Chen et al., 2003; Ramsey, 1995). Since many low and middle income countries rely primarily on agriculture, this could have a devastating effect on both familial and national economies. Although this is very relevant for lower income economies, in countries such as the U.S., there still exists the competing situation between employee health, personal income, and business productivity (Hyatt et al., 2010). Notably, farm workers in many states are paid by the piece (amount harvested) and individuals may choose to not take employer-provided breaks if it will negatively influence their income.

Research Needs

Injuries exact a huge toll in U.S. workplaces, with 12-13 deaths and thousands of non-fatal injuries occurring on a typical day (BLS, 2011); the associated economic costs are estimated at $250 billion annually for occupational injuries, illnesses, and deaths (CDC/NIOSH, 1998; Adelakun, 1999). The costs to the nation are as high as some prominent diseases, yet the investment in occupational injury prevention is miniscule compared to resources dedicated to disease prevention research (CDC/NIOSH, 1998).

Shulte and Chun (2009) published a preliminary framework for climate change and occupational safety and health which identified seven categories of climate-related hazards that may affect workers' health, including increased ambient temperatures and extreme weather events. They discuss the need for occupational health research on weather variables to reduce uncertainties and promote meaningful planning. The authors expect such research may result in updated standards and controls, development of acclimatization and adaptation procedures, new research directions, development of early warning systems and surveillance, and increased attention to designing prevention programs.

Although HRI can occur in healthy persons, major risk factors include: dehydration; obesity; poor physical condition; previous diagnosis of HRI; the lack of acclimatization; febrile illness; deprivation, alcohol use, and disorders that affect sweating (Adelakun et al. 1999). Additional risk factors include wearing PPE, previous history of stroke, drug abuse, and use of certain medications, all of which can impair the body's thermoregulatory responses (Kilbourne, 1992; Adelakun et al., 1999). Individual characteristics can therefore play a profound role in the heat stress response.

To the authors' knowledge, there is no research that specifically examines the potential differences in the impact of rising ambient temperatures on workers as compared to the general population. Indeed, climate change vulnerability in the general population, including the above mentioned risk factors, and vulnerability in the occupational sector are not mutually exclusive. Sensitive sub-populations are also part of the U.S. working sector. However, it is not known if findings from population-level studies systematically extend to occupational health risks and outcomes. Occupational exposures to heat may be more hazardous than community exposures as the individual has less control over the work environment and activities. Budd (2008) suggests that HRI are more likely to develop when behavioral responses are not allowed to occur normally because of military discipline, business pressures, team effort, or personal motivation. Targeted research on the association of age, sex, existing illnesses, occupation, geographical location, and meteorological variables is needed so evidence-based interventions can be designed.

Aside from the direct effects of heat, the indirect effects include increased accident risk and adverse impacts on worker behavior (Park et al., 2009; Ramsey, 1995). The MSHA guideline, *Heat Stress in Mining* (MSHA, 2012), states that heat stress can also be expressed in the form of irritation, anger, or other emotions leading to rash acts by persons performing hazardous jobs. This document further reports the lowest accident rates have been related to miners working at temperatures less than 70^{o}F and the highest to temperatures exceeding 80^{o}F. Accordingly, this invisible and potentially unrecognized hazard may lead to adverse performance and cognitive effects which translate into greater overall occupational morbidity and mortality. Since most heat wave population studies exclude accidents from the analyses, community injuries during these extreme weather events are unstudied. Research on the characterization of occupational injuries occurring during high ambient temperatures would fill a significant gap in injury research.

The spatial patterns of occupational heat-related fatalities should be characterized to determine if acclimatization in the south has a protective effect on workers. This phenomenon seems to hold true for U.S. Army soldiers; recruits from northern states were found to be at greatest risk to HRI compared with recruits from southern states (incidence density ratio = 1.69; 95% CI: 1.42-1.9) (Maeda et al., 2006). However, many southern workers may experience an opposite effect due to poor housing conditions.

Many of those with the most hazardous jobs – migrant workers, immigrants, day workers, and/or those with lower socioeconomic status – are also most likely to have sub-standard housing that lacks air conditioning (Culp et al., 2011; Vallejos et al., 2011; Lowry et al., 2010). Thus, these individuals are at even greater risk of heat-related illnesses because they cannot cool their bodies adequately during the nighttime hours, which is critical for preventing HRI (Kalkstein and Davis, 1989). It is estimated that there are more than one million migrant workers in the U.S. (Kandel, 2008). These individuals travel to find seasonal work in agriculture and live transiently near their workplaces. Many workers have no education, low income, no health insurance, chronic health problems, and live in sub-standard housing, which are individually significant risk factors for heat-related morbidity and mortality (Culp et al., 2011; Vallejos et al., 2011; Lowry et al., 2010); these workers and their circumstances deserve further study.

Other heat phenomena such as the impact of high heat exposure earlier in the summer season when people are less acclimatized and the impact of urban heat islands on occupational heat stress warrants specific examination. Whether established community heat alert levels are appropriate and adequately communicated to workers also requires further analysis.

Economic analyses of implementing worker heat stress intervention programs for various industry sectors and establishment sizes should be considered. Washington State performed a cost-benefit impact analysis of heat illnesses prevention programs on small businesses and found the economic benefits outweighed the monetary costs due to reducing Workers' Compensation claim costs, indirect costs associated with illness/ injury, and productivity loss due to worker dehydration (WA, 2008).

In their climate change research needs outline, Portier et al. (2010) call for research focused on heat alert tools for specific geographic regions and vulnerable populations, as well as effective risk communication and prevention strategies. These tools can also be tailored specifically for workers. Heat-related illnesses are preventable if appropriate prevention measures are practiced by susceptible individuals. Although the advice for prevention and treatment is somewhat consistent, it is unclear if these recommendations are uniformly applicable to all workers. Different environmental circumstances and individual risk factors may indicate a need to prioritize preventive measures and treatments.

Hambling et al. (2011) stated, "Authorities need to be able to assess, anticipate, and monitor human health vulnerability to climate change in order to plan for, or implement actions to avoid these eventualities." Occupational health impacts of climate change, including increased heat exposure, have not been examined for most industries and therefore comprehensive, research-based actions cannot be taken to protect all indoor and outdoor workers in the U.S. exposed to this growing environmental hazard.

Conclusion

There is a clear need to focus on adaptation to climate change, and not just mitigation, as it is already impacting health world-wide. A policy response to protect workers from heat is a low-risk adaptation strategy as standards and improved guidelines are currently needed.

Despite calls for research on occupational heat stress, this arena of climate change research is not adequately regarded as a priority and remains poorly studied. Empirical and epidemiological studies on occupational heat exposure and illnesses are insufficient and not generalizable for appropriate hazard characterization. The incidence of occupational heat-related disorders in the U.S. is not known although millions of workers have some level of exposure to hot environments. This is at odds with the recommendations of the 2008 World Health Assembly (WHA, 2008) which delineated five climate change research priorities, including: 1) the scale and nature of health vulnerability; 2) health protection strategies, including cost-effectiveness; 3) decision support and other tools, such as surveillance and monitoring, for assessing vulnerability and health impacts; and 4) assessment of the likely financial costs and other resources for health protection. Occupational health research clearly falls under the auspices of these recommended priorities.

Heat-related health hazards at work can be anticipated before they manifest, and preventive measures can be implemented before illness occurs. Climate change is a driver for adaptation and prevention of heat disorders; workers are a research-neglected vulnerable sub-population. Consequently, intensified research and policy development for occupational heat stress risk factors and effective interventions are increasingly essential.

Chapter 3: Characterizing Occupational Heat-Related Mortality in the United States, 2000-2010: An Analysis using the Census of Fatal Occupational Injuries Database. (2014). *Am J Ind Med* (*In press*)

Background

As climate change effects gradually progress, the importance of understanding and preventing heat stress in the population becomes increasingly imperative. Within the last decade, numerous studies have associated extreme heat with mortality (Anderson and Bell, 2011; Hajat et al., 2006; Basu and Samet, 2002; Curriero et al., 2002) and identified sub-populations particularly vulnerable to heat (Semenza et al., 1996; Wainwright et al., 1999; Stafoggia et al., 2006; Rey et al., 2007; Gabriel and Endlicher, 2011). Environmental heat exposure is directly associated with an average of 618 fatalities/year in the U.S. (CDC, 2012a), making heat the leading cause of weather-related deaths, above lightening, tornadoes, hurricanes, and floods combined (NOAA/NWS, 2011). Further, these heat-fatality estimates likely exclude deaths for which heat was a discreet contributory cause (e.g., myocardial infarctions). High temperatures are also strongly associated with population-level increases in hospitalizations for cardiovascular, respiratory, and other illnesses, as well as excess emergency department visits (Semenza et al., 1999; Wainwright et al., 1999; Braga et al., 2002; Schwartz et al., 2004; Dolney and Sheridan, 2006; Knowlton et al., 2009; Semenza et al., 1999).

Less is known about occupational heat-related morbidity and mortality, since most previous studies have focused on population-level heat effects, despite added occupational factors that may translate into greater overall heat-related health risks in the workplace. Workers are sometimes required to perform exertional work tasks while exposed to high ambient temperatures, increasing vulnerability to heat-related health effects. Physical strain and increased metabolic heat load can trigger accidents through physical fatigue, impaired mental capacity, and misuse of personal protective equipment (PPE) (Rowlinson et al., 2013; Park et al., 2009; Ramsey, 1995); PPE restricts heat loss from the body and becomes problematic to employees working in the heat (Crockford, 1999).

Despite the potential of heat stress as an occupational hazard, there are no federal government standards to protect workers. The extent of heat-related injuries and illnesses (HRI) in U.S. workers is not known, although in 1986, the National Institute for Occupational Safety and Health (NIOSH) estimated 5 to 10 million employees are exposed yearly (NIOSH, 1986). The published works on occupational HRI are limited and generally focus on particular events, outcomes, states, or industries (Gubernot et al., 2013). For example, previous studies have investigated heat-related fatalities specifically in agricultural workers (Luginbuhl et al., 2008) and in the state of North Carolina (Mirabelli and Richardson, 2005), and heat-related morbidity in miners (Donoghue, 2004), responders to the Deep Water Horizon Gulf Oil Spill of April 2010 (King and Gibbons, 2011), the military (Carter et al., 2005; Gardener et al., 1996; Epstein et al., 1999), and workers in the states of Washington (Bonauto et al., 2010; Bonauto et al., 2007) and Florida (Florida DOH, 2011).

To our knowledge, no prior study has described the epidemiology of U.S. occupational heat-related fatalities over multiple years, including all industries and states. The study aims are 1) to describe overall rates by year, industry, and state; 2) to describe the demographic characteristics of the cases; and 3) to use these data to determine groups at highest risk for targeted prevention efforts. Although this article specifically focuses on fatal HRI occupational events, insights from these findings could be applied to broader heat illness prevention efforts.

Methods

Data Sources

Fatality data were obtained at the Bureau of Labor Statistics (BLS) from the confidential on-site Census of Fatal Occupational Injuries (CFOI) database. The database represents all identified worker fatalities including those outside the scope of the Occupational Safety and Health Administration's (OSHA) coverage, such as volunteers (BLS, 2002). Undocumented workers are included in CFOI as are military personnel stationed in the U.S. A heat-related death is identified in CFOI as an exposure to environmental heat with the BLS Occupational Injury and Illness Classification System event/exposure code 321 and the nature code of 072. Event and nature codes for environmental heat deaths reported 2000 through 2010 were queried and confirmed as related to environmental heat by reviewing the case narratives. The data reported in this paper are presented per BLS guidelines for confidentiality; however, all data are included in our analyses.

The Current Population Survey (CPS) provides denominator data for employed individuals and includes all employed civilian non-institutionalized workers $\geq$ 16 years of age. These CPS data are available on the BLS website for rate determination.

Institutional Review Board approval was not required for this research as the records are of deceased persons and there are no linkages to identifying information; data are displayed as summary statistics only. For the same reasons, informed consent was not required. A data confidentiality agreement was signed by the Bureau of Labor Statistics and the George Washington University.

Variable Definitions and Codes

The following CFOI variables were included in the analyses: sex; age; age group; race; ethnicity; month; time of day; day of week; county; state; establishment size; ownership type; employee status; industry; date of incident; and date of death.

Demographic Variables

Age was utilized as a continuous variable and also categorically as classified by BLS. We also dichotomized the age variable as younger (<55 years old) and older (≥ 55 years old). The age of death was used in the calculations; in nearly every case, age of death and age of incident (exposure) were the same. The BLS classification for sex, race, and Hispanic origin were also used.

Temporal and Geographical Variables

CFOI includes workers in all 50 states and the District of Columbia. The BLS classification for month, time of day, day of week, and state were used. The state variable refers to the state of exposure. We calculated the “time survived” variable which was dichotomized into “death on day of exposure” and “death after day of exposure”.

Establishment and Industry Variables

We utilized the BLS industry sector codes, establishment size, and ownership type classifications. The BLS utilizes the North American Industry Classification System (NAICS) to assign industry codes. Prior to 2003, the BLS applied the Standard Industrial

Classification Industry Group codes. The agency implemented changes in industrial classification to better measure economic activities and to include newer industries and sub-sectors (BLS, 2013). We accounted for and addressed the differences in these systems for appropriate industry classification in these analyses. We determined heat-related fatality rates for the BLS NAICS-aggregated industry sectors. Based on these preliminary data, we categorized industries by the three sectors with the highest rates: 1) Agriculture, Forestry, Fishing and Hunting - NAICS code 11; 2) Construction - NAICS code 23; 3) and Administrative and Support and Waste Management and Remediation Services - NAICS code 56, which we refer to as Support, Waste and Remediation Services. All other industries served as the referent group.

Statistical Analysis

Data were extracted, managed and analyzed using Microsoft Excel (Microsoft, Redmond, WA). Injury rates were calculated as number of deaths per 1,000,000 workers. The numerators indicate the number of deaths and denominator data are estimates from the CPS. Average annual incidence rates were calculated for each group. Risks were calculated using rate ratios with 95% confidence intervals (CI) as described by Rothman (Rothman and Greenland, 2008).

Deaths of volunteers, individuals < 16 years of age, and military personnel were included in the counts but removed from the rate analyses as they are not represented in the CPS denominator data.

Results

Yearly Occupational Heat-Related Mortality Rates

Our analysis of CFOI record data from 2000-2010, identified 359 worker deaths reported due to exposure to environmental heat in the U.S. There were 5 volunteers and 15 military personnel included in this total; no workers < 16 years old were identified.

The average annual heat-related fatality rate was 0.22 deaths per 1 million workers. For the study time period of 2000-2010, the highest rates were in 2005 (0.32) and 2006 (0.30), followed by 2002 and 2010 with rates of 0.29; the lowest rate was in 2004 (0.11). We dichotomized the study period into "earlier" (2000-2004) and "later" (2005-2010) and found a higher rate for the latter years (0.25 vs. 0.18) with a rate ratio (RR) of 1.4 (95% CI: 1.1, 1.7).

Demographic Characteristics

The distribution of demographic characteristics for the 359 fatalities is summarized in Table 3-1. Only 10 cases were female. Males had a significantly higher rate compared to females, with an RR of 32.0 (95% CI: 17.0, 60.0). When rates in the agriculture and construction industries were stratified by sex, males continued to have higher rates. However, in accordance with BLS publishing criteria, these data are not reported here.

The median age of deceased workers was 41 years old. There was no significant difference in HRI fatality rates among age groups with the exception of the ≥ 65-year stratum. This group had a slightly significant increased rate of 0.34 with an RR of 2.2

(95% CI: 1.1, 4.4). Age groups dichotomized as < 55 years and ≥ 55 years had nearly identical rates (Table 3-1).

Higher rates were associated with ethnicity and race. Blacks had an RR of 1.5 (95% CI: 1.1, 2.0) compared to whites. Notably, Hispanics compared to non-Hispanics had an RR of 3.2 (95% CI: 2.5, 4.0) and an average yearly fatality rate of 0.54 per 1 million workers (Table 3-1). When rates were stratified by ethnicity in the agriculture and construction industries, the same pattern was observed. Hispanics had an RR of 3.4 (95% CI: 2.0, 5.8) when compared to non-Hispanics in agriculture and an RR of 1.7 (95% CI: 1.1, 2.6) in construction (data not shown).

Mortality Rates by Industry and State

Table 3-2 displays the industries with the highest average annual rates of heat-related mortality: Agriculture (3.06 per 1 million workers), Construction (1.13), and Support, Waste and Remediation Services (0.56). All other industry sectors served as the referent group. In comparison to the referent group, agriculture had more than 35 times the risk of heat-related death and construction had 13 times the risk; these two industries accounted for 207 (58%) of the cases. Support, Waste and Remediation Services had an RR of 6.4 (95% CI: 4.4, 9.4).

Table 3-1. Occupational Heat-Related Fatalities in the U.S. 2000-2010, by Demographic Characteristics

Characteristic	Average # of workers per year[a]	Average HRI deaths per year[b]	Average rate per million workers per year[c]	Rate ratio (95%CI)[d]	Percent of total HRI deaths[e]
Total ……….	140,346,000	32.6	0.22	N/A	**100%**
Sex					
Female…………	65,482,000	0.9	0.01	1.0 (referent)	**2.8%**
Male ……………	74,864,000	31.7	0.40	**32.0 (17.0–60.0)**	**97.2%**
Age group					
16-19 years………	5,903,000	1.3	0.15	1.0 (referent)	**3.9%**
20-24 years………	13,437,000	2.4	0.12	0.8 (0.4 – 1.5) 1.2	**7.2%**
25-34 years………	30,769,000	6.2	0.19	(0.7 – 2.2)	**18.9%**
35-44 years………	34,209,000	8.9	0.26	1.7 (1.0 – 3.0)	**27.3%**
45-54 years………	32,515,000	8.5	0.25	1.6 (0.9 –2.8)	**25.9%**
55 -64 years………	18,142,000	3.7	0.21	1.4 (0.7 – 2.5)	**11.4%**
≥ 65 years ………	5142,000	1.7	0.34	**2.2 (1.1 – 4.4)**	**5.3%**
< 55 years……..	116,833,000	27.2	0.22	1.0 (referent)	**83.3%**
≥ 55 years………	23,284,000	5.5	0.23	1.0 (0.8 – 1.3)	**16.7%**
Race					
White ………….	116,019,000	24.1	0.20	1.0 (referent)	**73.8%**
Black ……………	15,254,000	4.7	0.29	**1.5 (1.1 -2.0)**	**13.6%**
Asian ……………	6,368,000	1.0	0.16	0.8 (0.4 – 1.4)	**3.1%**
Other ……………	N/A	1.8	N/A		**5.6%**
Not reported ……	N/A	1.0	N/A		**3.1%**
Ethnicity					
Non-Hispanic…….	**121,951,000**	**22.0**	**0.17**	**1.0 (referent)**	**67.4%**
Hispanic …………	**18,395,000**	**10.3**	**0.54**	3.2 (2.5 – 4.0)	**31.5%**
Not Reported…….	**N/A**	**N/A[f]**	**N/A**		

CI – Confidence Interval; **HRI**- Heat-related illness

[a] All numbers may not sum to total due to CPS rounding of estimates. Does not include military personnel and volunteers.

[b] Includes military personnel and volunteers

[c] Excludes military personnel and volunteers

[d] Bolded values are statistically significant

[e] May not total 100% due to rounding

[f] Below BLS publishing criteria

Table 3-2. Occupational Heat-Related Fatality Rates in the U.S., 2000-2010, by Industry

Industry	NAICS code[a]	Average Yearly workers	Average yearly HRI deaths	Average rate per million workers/year	Rate ratio (95% CI)	Percent of all industry sector HRI deaths[b]
Agriculture, Forestry, Fishing, and Hunting	11	2,232,000	6.8	3.06	35.2 (26.3-47.0)	21.0%
Construction	23	10,503,000	12.0	1.13	13.0 (10.1-16.7)	36.8%
Support, Waste, and Remediation Services	56	5,846,000	3.3	0.56	6.4 (4.4 9.4)	10.0%
All other industries	--	121,775,000	10.5	0.09	1.0 (referent)	32.3%

CI – Confidential Interval; **HRI** - Heat-related illness
[a] North American Industrial Classification System
[b] Numbers may not sum to 100% due to rounding

Similarly, Table 3-3 shows average annual HRI fatality rate and risk ratios among the ten states with the highest rates. Mississippi had the highest rate of 1.05 per 1 million workers, followed by Arkansas (0.66), Nevada (0.63), West Virginia (0.60), and South Carolina (0.52). The risk in Mississippi was more than 6 times that of the 40-state reference group. Texas, which accounted for 43 deaths, had a rate of 0.33 (data not shown). California, with 45 deaths, had a rate of 0.24 which was only slightly higher than the U.S average death rate of 0.22 (data not shown). These two states account for almost 25% of the deaths from 2000-2010 while 40% of deaths were attributed to the ten

Table 3-3. Ten U.S. States with Highest Occupational Heat-Related Death Rates for 2000-2010

Rank by Rate	State	Average # of workers per year	Average HRI deaths per year[a]	Average rate per million workers per year[b]	Rate Ratio (95% CI)	Percent of all national HRI deaths that occurred in state[c]
1	Mississippi	1,212,000	1.3	1.05	6.4 (3.7-10.9)	3.9%
2	Arkansas	1,241,000	0.8	0.66	4.0 (2.1-7.8)	2.5%
3	Nevada	1,150,000	0.7	0.63	3.8 (1.9-7.7)	2.2%
4	West Virginia	757,000	0.5	0.60	3.6 (1.5 -8.8)	1.4%
5	South Carolina	1,913,000	1.1	0.52	3.1 (1.8-5.6)	3.3%
6	North Carolina	4,093,000	2.0	0.47	2.8 (1.8 -4.4)	6.1%
7	Arizona	2,687,000	1.2	0.41	2.5 (1.4-5.1)	3.6%
8	Oklahoma	1,632,000	0.6	0.40	2.4 (1.1 -5.1)	1.9%
9	Florida	8,118,000	3.7	0.37	2.2 (1.6-3.1)	11.4%
10	Missouri	2,755,000	1.0	0.36	2.2 (1.2-4.0)	3.1%
	All other 40 states + DC	114,442,000	19.7	0.17	1.0 (referent)	60.0%

a Includes military personnel and volunteers
[b] Excludes military personnel and volunteers
[c] May not equal 100% due to rounding

Temporal and Establishment Characteristics

The largest number of deaths occurred during July (34%) with the vast majority of the cases occurring in the summer months of June-August (86%). The majority of the workers (65%) fell ill in the afternoon hours between 12 noon and 6:00 pm. Approximately 90% of the cases occurred during the normal work week of Monday-Friday. Most workers died on the day of exposure (71%).

Private industry accounted for 321 deaths (89%) and 21 deaths occurred in the federal government, primarily U.S.-based military personnel. Of the 244 cases that reported establishment size, the largest proportions of cases were in very small establishments of less than 10 employees (43%) and very large establishments of greater than 100 employees (27.5%). We cannot determine the risk of small establishments as BLS denominator data for establishment sizes differ from CFOI size categories.

Discussion

Our study, the largest nationally representative epidemiological study on occupational HRI fatalities, demonstrates the importance of these preventable deaths. There is clearly a need to develop more effective HRI prevention programs to reduce worker heat-related morbidity and mortality. The findings identified the contribution of various factors to occupational HRI fatalities which include sex, race, ethnicity, industry sector, and state.

There was no distinguishable year-to-year trend in fatalities from 2000 to 2010. However, dichotomizing the study time resulted in a slightly, but statistically significant, higher rate in the latter half of the decade. This suggests that the yearly rates reflected fluctuating weather patterns.

Working men die of heat-related illness far more than women. Compared to females, men had 32 times the risk of a work-related HRI death. When the high risk industries were stratified by sex, men continued to have significantly higher rates. Population studies also find males account for the majority of deaths. The Centers for Disease Control and Prevention found that of the 7415 heat-related deaths reported 1999-2010, the majority (68%) were male (CDC, 2012). Heat wave vulnerability studies on demographic subgroups are inconclusive and inconsistencies have been reported with regard to sex (Semenza et al., 1999; Stafoggia et al., 2006; Whitman et al., 1997; Ellis et al., 1975). Our study and other occupational research finds a much higher rate among working men and this observation deserves further study.

Although we hypothesized that increased age would be associated with higher HRI fatality rates, the difference in rates among the age groups was not substantial. Increased age is an established risk factor for heat-related deaths and population level heat-related morbidity and mortality studies have shown this to be a significant variable (Semenza et al., 1999; Knowlton et al., 2009; Basu et al., 2005). When we dichotomized the age groups < 55 years and ≥ 55 years, the rates were nearly identical (Table 3-1). Our data show that only the ≥ 65 years age group had an elevated risk of a heat-related death. This smaller-than expected increase in the heat-related death rate among the oldest workers might be explained by older persons not being equally represented in the high risk occupations and duties within these high risk industries. This warrants further investigation.

Race had a small, but significant, effect on fatality rates. The slightly increased rate among black workers seen in this analysis has also been found in other occupational heat-related studies (Mirabelli and Richardson 2005; Florida DOH, 2011). Ethnicity was more strongly associated with higher rates: Hispanics were 3.2 times more likely to die of work-related heat exposure than non-Hispanics. Although Hispanics account for 13.6% of the general workforce, they represent an estimated 20.1% of agriculture and 23.4% of construction workers. The higher risk for Hispanics is partially explained by their over-representation in these high risk industries. However, when ethnicity was stratified for the agriculture and construction industries, the higher rates persisted. As previously reported, these workers may have added risks due to language and cultural barriers; migrant worker or day laborer status; hazards of poverty; poor housing and healthcare; and inadequate training (Culp et al., 2011; Kahn, 2004; Kandel, 2008; Mirabelli et al., 2010; Vallejos, 2011; Lowry et al., 2010; Fleischer et al., 2013; Liebman and Augustave, 2010).

As expected, agriculture and construction had the highest rates for HRI deaths. Some farm and construction workers are paid by the job, and individuals may avoid taking a break as it will negatively influence their income. Heat-related studies in the U.S. construction industry are particularly lacking, however, heat stress and the need for preventive measures in the farming industry have been previously discussed (Park et al., 2009; Luginbuhl et al., 2008; Mirabelli et al., 2010; Vallejos, 2011; Lowry et al., 2010; Fleischer et al., 2013; Liebman and Augustave, 2010; Kjellstrom et al., 2009; Stoeckin-Marois et al., 2013).

Our study identified 15 military personnel who expired due to environmental heat while on the job or training at a U.S. facility. The military has performed numerous studies on the health of soldiers and the effects of extreme heat, as heat exposure has historically been a military concern. Heat illness research and implementation of preventive measures are key practices of the U.S. military and discussed elsewhere (Carter et al., 2005; Gardener et al., 1996; Epstein et al., 1999; Hollowell, 2010; Yaglou and Minard, 1957; AETC, 2000).

Although Texas and California accounted for 88 (24.5%) of the fatalities, they were not among the states with the highest death rates. California, which did not have a significantly high rate (0.24), has evaluated a comprehensive heat prevention campaign (initiated in 2010) targeted at agricultural workers and has an enforceable regulation for prevention of heat illness in outdoor workers (Cal/OSHA, 2013, CA Code of Regulations, 2012). In fact, California and Washington states are in the forefront for implementing workplace safety policies to prevent heat-related illnesses (Jackson and Rosenberg, 2010). States with higher HRI death rates, such as Mississippi and Arkansas, should consider immediate implementation of such policies or prevention programs targeting their high risk industries and workers.

With 71% of the cases dying on the day of exposure, the survival time variable suggests that the HRI cases were acute and possibly not recognized and treated in a timely manner. Prevention programs should focus on early recognition and treatment of HRI signs and symptoms.

Length of service, which has been shown to be associated with workplace injuries, was not analyzed in this study due to lack of data. Newer employees and those not acclimatized to working in hot conditions are most likely at high risk of HRI as seen in other studies (Carter et al., 2005; Epstein et al., 1999; Maeda et al., 2006). HRI training and acclimatization programs for new employees should be encouraged for all industries employing outdoors workers.

Many of the intervention and monitoring practices recommended in the available heat stress prevention guidances, such as the American Conference of Governmental Industrial Hygienists guideline (ACGIH, 2009), are not practical for all work places. The guidelines are appropriate for large, stable operations, with established procedures, medical surveillance, Wet Bulb Globe Temperature equipment and an industrial hygienist responsible for monitoring conditions. For worksites that are small and non-stationary, or where employees work independently or in remote areas, the use of complex guidelines may not be feasible. As noted by Yorio and Wachter (2013), small businesses may not have the resources to develop and implement effective safety measures. Small establishments that are decentralized may also lack the organizational structure to support safe practices.

These reasons may explain why the highest percentage of heat-related deaths occurred in establishments of < 10 employees. Yet, these small establishments are exempt from OSH Act's injury and incident reporting requirement as well as programmed OSHA inspections (29 CFR 1904.1). This study, as well as previous research, has shown that work-place fatalities can be disproportionally high among small businesses (Weil and Wolfrod, 2013; Taylor et al., 2002). Clearly these establishments should be targets for well-designed interventions to communicate, educate, and address workplace health and safety. Additionally, small businesses merit particular attention from occupational health policy makers for a strategic plan for risk communication and possibly a legislative approach on the particular health and safety needs of these establishments (MacEachen et al., 2010).

OSHA, with the support of NIOSH, launched a heat illness prevention campaign in the summer of 2011. The aim of this endeavor is to educate both employers and employees on recognition and prevention of occupational heat illness. The OSHA website provides information on risks, prevention, signs and symptoms, and first aid (https://www.osha.gov/SLTC/heatstress/index.html).

Limitations

Our data and analyses include several potential limitations which are inherent to occupational surveillance studies. Surveillance of worker illnesses and injuries is not optimal and it is well-established that occupational illnesses and injuries are under-counted (Miller, 2008; AFL-CIO, 2011; Rosenman et al., 2006). Further, there are many reasons why employees may not report illness or injury to employers, including: 1) fear of discipline or termination; 2) economic incentives; 3) fear of being labeled as accident-prone or a problem employee; and 4) foreign-born workers may fear being reported to the U.S. Citizenship and Immigration Services (AFL-CIO, 2011). Although these issues apply to workers reporting on-the-job illnesses and injuries, a fatality may not be classified as work-related if it occurs after an individual has completed his or her shift or leaves the job site.

The outcome - occupational heat-related fatality - is subject to disease misclassification because heat-related illnesses are not always recognized by patients, physicians or medical examiners. Definitions and procedures used by medical examiners and coroners are not standardized (Donoghue et al., 1997; Sun, 2010). Deaths, such as cardiovascular fatalities, where heat was a contributory cause may not be recorded as heat-related, as CFOI data represent only those deaths for which heat exposure is specifically included on the death certificate or other official documentation. Heat-related occupational fatalities are expected to be underreported for purposes of this study and the number of heat-related fatalities presented should be considered the minimum estimate of deaths. Nevertheless, as determined by Layne (2004), CFOI provides the most comprehensive and complete count of fatal work injuries available.

CPS denominator estimates may have some level of sampling error that can unknowingly impact our calculated fatality rates. The rates are based on employment only and do not take into account differences in the number of hours worked (BLS/CFOI, 2006).

The results of this study are based on 359 cases and yearly average rates from an 11-year time frame. Failure to achieve significance in variable associations might reflect insufficient sample size or other study limitations rather than absence of an actual relationship (Gordis, 2009). Additionally, the rates for the states are based on this 11-year timeframe and therefore any decreases in deaths due to implementation of heat stress programs are not captured in these data.

We analyzed industry sector only. Further analysis of occupation will provide additional characterization of HRI fatalities in the workplace. Lastly, consideration of employees' personal risk factors and predisposition to heat illnesses, as well as interactions between risk factors, was beyond the scope of this study.

Conclusions

Improving our understanding of at-risk workers is essential to avert preventable heat-related deaths and illnesses. This study is a first step in characterizing these workplace fatalities. Occupational exposures to heat may be more hazardous than routine community exposures as the individual has less control over the work environment.

Heat-related morbidity in the workplace is difficult to ascertain due to limitations in occupational surveillance systems. However, fatal and non-fatal occupational heat-related illnesses most likely have similar epidemiologic patterns and risk factors. Further research on personal risk factors, PPE use, and other potential occupational or environmental risk factors contributing to heat-related morbidity and mortality in the workplace is needed.

Although severe weather elements have always been a threat to human health, significant shifts in weather patterns are escalating and climate change is now recognized by the World Health Organization as one of the leading global health threats of the 21st century (WHO, 2009). Research on occupation health impacts of weather extremes is relevant not only for the present, but also to contribute to preparedness for, and adaptation to, the projected effects of climate change.

Chapter 4: Occupational Heat-Related Fatalities in the United States Characterized by Heat Index and Maximum Daily Temperatures, 2000-2010

Background

High ambient temperatures can increase morbidity and mortality among vulnerable populations. Heat illnesses due to excessive environmental heat exposure encompass a spectrum of disorders ranging from heat cramps to heat stroke, and heat can exacerbate a wide range of medical conditions (CDC/NIOSH, 2013). Heat-related disorders can arise from stress due to increased air temperature, humidity, radiant heat, and metabolic heat from strenuous physical work (Budd 2008). Studies related to heat often focus on population-level health effects of heat waves, while excessive heat as a health threat in other contexts is less frequently studied (Gubernot et al., 2013). In particular, outdoor environmental heat as an occupational hazard has not been well characterized or researched.

Population-specific factors determine whether a heat event poses a threat to a community (Semenza et al., 1996). For workers, these risk factors may include: type of work performed; location of work; individual worker risk factors (e.g., health status); sun exposure; degree of acclimatization; exertion required; access to water; use of personal protective equipment (PPE); timing of work (daytime extremes); work/rest cycles; exposure to additional hazards such as pollution and pesticides; and existence of employer prevention and training programs as well as the availability of on-the-job first aid (Adelakun et al., 1999; Epstein et al., 1999; Budd, 2008; NATA, 2014; OSHA, 2014). Consequently, a heat "event" for workers may not require extreme temperatures.

The Wet Bulb Globe Temperature (WBGT) measures temperature, humidity, sun exposure, and wind speed and is recommended by athletic associations (Armstrong et al., 2007; NATA, 2014); federal occupational agencies (OSHA,1999; CDC/NIOSH, 2013); and occupational standard organizations (ACGIH, 2009; Parsons, 1999). WBGT was also developed and is currently used by the U.S. military (Budd, 2008; AETC, 2000); it is considered the benchmark for workplace evaluation of heat stress and preventing occupational heat illnesses.

Measuring WBGT requires specialized, expensive instrumentation as well as experienced operators to obtain accurate, repeatable values; this is especially true for outdoor measurements which require time and precision to ensure that reliable data are obtained and interpreted (Lilegren et al., 2008). The NWS neither captures WBGT readings nor routinely collects the black globe measurements required to calculate WBGT. Therefore, without the sophisticated equipment on-site, businesses may have no means for assessing worker heat stress.

A simple approach to meteorological measurement is needed for estimating occupational heat exposure, especially for small businesses and remote worksites, which report a high proportion of heat-related fatalities (Gubernot et al,. 2014). Although OSHA's Technical Manual (OSHA, 1999) and the CDC/NIOSH recommendations (CDC/NIOSH, 2013) currently and historically use the WBGT as the method for determining worker heat stress, OSHA's heat campaign, initiated in 2011, uses the heat index (HI) and a slightly altered version of the NWS HI safety categories (OSHA, 2014). The OSHA smart-phone app provides the temperature, HI, and HI safety category for an individual's location. Although OSHA provides this information, there is no evidence that the categories are suitable for workers. The National Weather Service (NWS) bases its community temperature alerts on the heat index (NOAA/NWS, 2014), sometimes referred to as “apparent temperature”. It is based on Steadman’s apparent temperature formula (Steadman, 1979), which is calculated from temperature and humidity or dew point. The HI is used in most epidemiological studies of heat waves and population health (Kent et al., 2014; Golden et al., 2008; Semenza et al., 1999). Using the HI for measurement of heat exposure is considered suitable for policy and public health interventions (Anderson et al., 2013; Hacker and Smith, 2002). Using evidence-based HI safety categories for alerting workers to practice heat safety measures would possibly prevent a substantial number of occupational heat illnesses each year.

Worker injuries exact a huge toll in U.S. workplaces with associated economic costs estimated at $250 billion annually for occupational injuries, illnesses, and deaths (CDC, 2012b). Occupational prevention of heat illness entails resting in the shade, increasing fluid intake, providing heat illness education to workers, and ensuring first aid is available. The costs of implementing a heat illness prevention program would be beneficial as demonstrated by the Washington state cost-benefit impact analysis of heat illnesses prevention programs on small businesses. They found the economic benefits outweighed the monetary costs due to reducing Workers’ Compensation claim costs, indirect costs associated with illness/ injury, and productivity loss due to worker dehydration (WSDLI, 2008).

To our knowledge, no national-level study has focused on the relationship of meteorological variables and occupational heat-related fatalities in the United States. Our study analyzed the maximum daily temperature (T_{MAX}) and HI on the days and near the locations of occupational heat-related deaths reported to the Bureau of Labor Statistics' Census of Fatal Occupational Injuries (CFOI) from 2000 to 2010. The purpose of this research was to: 1) investigate the values of T_{MAX} and HI at which workers fatally succumb to the effects of outdoor environmental heat; 2) identify other risk factors that may contribute to heat-related deaths, such as workers' demographics; and 3) translate results to recommend heat stress preventive measures in the workplace.

Methods

Data Sources

We obtained fatality data for 2000-2010 from the Bureau of Labor Statistics' confidential on-site CFOI database. This database covers all identified worker fatalities in the 50 U.S. states and the District of Columbia, including those outside the scope of the Occupational Safety and Health Administration's (OSHA) coverage, such as volunteers. Undocumented workers are included in CFOI, as are military personnel stationed in the U.S.

A heat-related death is identified in CFOI as an exposure to environmental heat with an event/exposure code of 321 and nature code of 072 in the Bureau of Labor Statistic's Occupational Injury and Illness Classification System, 2007 version (www.bls.gov/iif/oiics_manual_2007.pdf). The event or exposure describes the manner in which the injury or illness was produced or inflicted by the source of injury or illness. Environmental injuries or illness in this major group (32*) include: heat exhaustion, heat stroke, freezing, frostbite, or hypothermia; exposure to environmental heat is assigned code 321. The nature of injury or illness identifies the principal physical characteristic(s) of the work related injury or illness. Effects of environmental conditions, major group 07*, classifies injuries or disorders that are a result of adverse environmental conditions. Nature code 072, Effects of heat and light, classifies injuries or disorders caused by the effects of heat and light. (http://www.bls.gov/iif/oiics_manual_2007.pdf).

Event and nature codes for environmental heat deaths reported 2000 through 2010 were queried and confirmed as related to environmental heat by reviewing the case narratives. The data reported in this paper are presented per BLS guidelines for confidentiality.

For weather data, we used National Climatic Data Center (NCDC) monitor-based measurements of maximum daily temperature and average daily dew point temperature. For the years 2005—2010, we accessed this data through the NCDC's Quality Controlled Local Climatological Data meteorological reports (NOAA/NCDC, 2014a), while for the years 2000—2004, we accessed the data through NCDC's Unedited Local Climatological Data (NOAA/NCDC, 2014b). These two sets of records contain the same data elements and are considered comparable (NCDC, personal communication, 2014). Both NCDC datasets are freely accessible to the public on NOAA's NCDC website.

Variable Definitions and Codes

<u>Case and Exposure Identification</u>

The Bureau of Labor Statistics restricts access to individual records of occupational deaths to protect confidentiality. Therefore, to create our dataset of heat-related occupational deaths, one of our authors (DG) performed parts of this study at the secure on-site research area of the Bureau of Labor Statistics. On-site, the primary author collected every record in the CFOI coded as 321 (heat-related death) and, for each recorded death, read the record narrative to confirm that the cause of death was exposure to outdoor ambient heat rather than secondary sources of heat (e.g., kitchen, furnaces). Each record included sex; age group; race; ethnicity; month; state; industry; and date of fatal heat exposure.

Maximum daily temperature (T_{MAX}) and dew point temperature of fatal exposure were assigned to each case by matching the date and county of exposure to NCDC weather records. If the county included a weather monitor, data from that monitor was used. If there was more than one station in the county, the most centralized station was utilized. In cases where the county did not include a weather monitor, the closest weather monitor to the county of exposure was used. The HI was calculated using the T_{MAX} and daily average dew point using Rothfusz's algorithm (Rothfusz, 1990; Anderson et al., 2013).

We used ANOVA and t-tests of differences in means to test whether fatal exposure conditions (T_{MAX} and HI) differed by a number of worker characteristics. We tested differences by sex, age category, race, ethnicity, industry, and geographical region, in all cases using data reported on the CFOI fatality record.

To investigate differences in fatal exposures by industry, we also used data from the CFOI records, but with some adjustment. Prior to 2003, the BLS applied the Standard Industrial Classification Industry Group codes. Since 2003, the BLS has used the North American Industry Classification System (NAICS) to assign industry codes. We therefore accounted for and addressed the differences in these systems for appropriate NAICS industry classification.

Geographic analysis

To investigate differences in fatal exposure conditions by location of death, we used the location of exposure recorded on each record to classify the death as occurring in the colder or warmer region of the U.S. We defined states with annual average temperatures of ≤ 52.4°F as "colder" and those greater than 52.4°F were considered "warmer". This threshold was based on the 2013 average U.S. annual temperature of 52.4°F (NOAA 2013). There were 21 warmer states with higher than average U.S. annual temperatures and 29 colder states with lower than average annual temperatures. This distinction resulted in a line bisecting the U.S. into northern and southern regions. We therefore refer to the colder region as the "North" and the warmer region as the "South".

To further examine geographical differences within a region, we performed additional analysis on six southern states previously identified as having high rates or frequencies of heat-related worker fatalities (Gubernot et al., 2014): Arizona (AZ), California (CA), Florida (FL), Mississippi (MS), North Carolina (NC), and Texas (TX). We used one-way ANOVA to test if averages of fatal exposure conditions differed significantly across these six states. This analysis aimed to clarify whether guidelines for unsafe outdoor heat might be universal, or if it is important to tailor guidelines to specific locations.

NOAA Heat Status

The NOAA's NWS has issued a Directive for Field Offices defining excessive heat events in the North and South (NOAA/NWS, 2011). For the South, an excessive heat event is defined as a day with HI ≥ 110°F, while for the North an excessive heat event is HI ≥ 105°F. We used these definitions to determine how many of the fatal heat exposures in our data occurred during days locally identified as excessive heat events.

In addition to these definitions of excessive heat events, NOAA's NWS has also created health-related heat danger categories using heat index cutoffs (NOAA/NWS, 2014). Their heat index chart divides heat index values into four heat alert categories: Caution (80°F-90°F); Extreme Caution (91°F-103°F); Danger (104°F-124°F); and Extreme Danger (>124°F). Heat index values of less than 80°F elicit no warning. We assigned the appropriate NOAA category for each heat-related occupational death.

Institutional Review Board

Institutional Review Board approval was not required for this research as the records are of deceased persons, and there are no linkages to identifying information. For the same reasons, informed consent was not required. A data confidentiality agreement was signed by the Bureau of Labor Statistics and the George Washington University.

Software

Data were extracted, managed and analyzed using Microsoft Excel (Microsoft, Redmond, WA) and QuikCalc (Graph Pad Software, San Diego, CA).

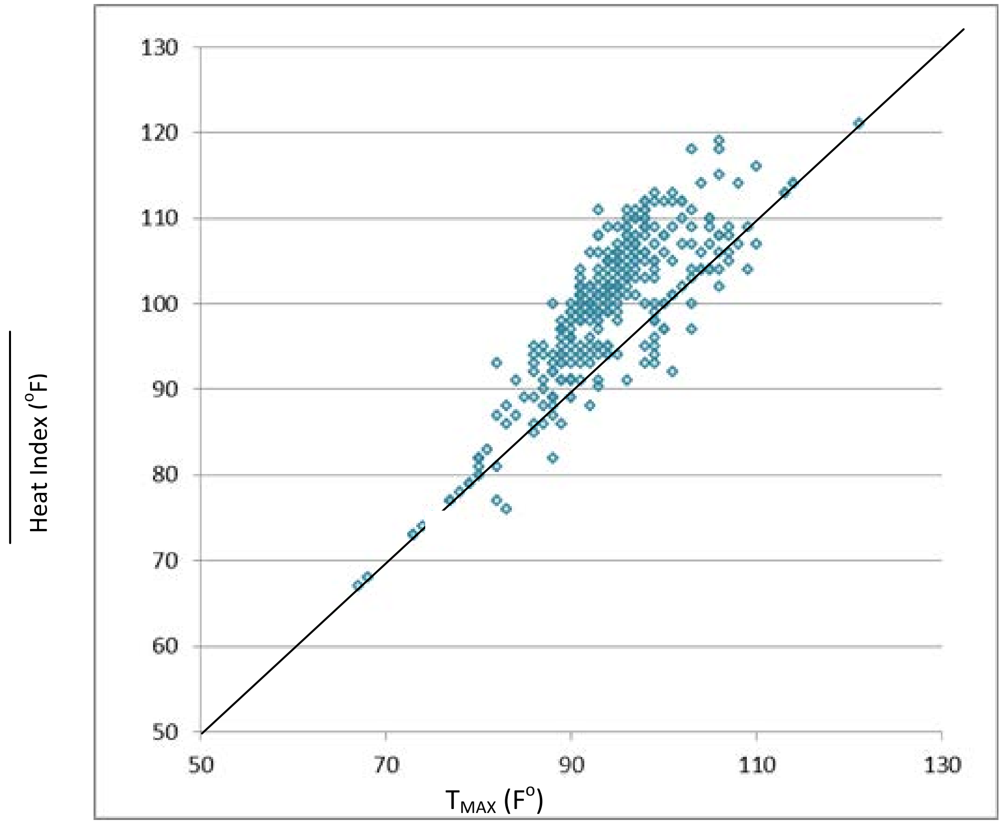
Results

Three hundred and fifty-nine (359) occupational heat-related deaths were identified in the CFOI for 2000-2010 and were previously described (Gubernot et al., 2014). After excluding cases for which narratives suggest a secondary or alternate source of heat and those with missing geographical information, 327 cases were included in this study.

Figure 4-1 shows temperatures and heat indexes at fatal exposure for each of the 327 cases. The average T_{MAX} at fatal exposure was 94.2^{o}F (sd: 7.5^{o}F), while average heat index was 100.0^{o}F (sd: 9.0^{o}F). Fatal exposure T_{MAX} and HI ranged from 67^{o} to 121^{o}F with most cases occurring between 85^{o}F and 107^{o}F for T_{MAX} and between 87^{o}F and 114^{o}F for the heat index (Figure 4-1). The two measures were strongly correlated (r=0.83) across the cases and, unsurprisingly, fatal heat indices tended to be higher than temperatures during more extreme heat, as indicated by the number of points on the left side of the figure above the reference line (which shows where values of the two measures would be equal: T_{MAX}=HI). However, there were some cases during extreme heat where T_{MAX} at fatal exposure exceeded the heat index; these cases were likely in very dry areas (e.g., Arizona). At lower heat (e.g., $T_{MAX} < 80^{o}$F), temperature and heat index at exposure were very similar, which follows from the heat index algorithm setting heat index equal to temperature at lower temperatures (Rothfusz, 1990; Anderson, et al., 2013).

We investigated whether fatal exposures differed by worker characteristics. Average fatal heat exposures were slightly lower for females (T_{MAX}: 94.0^{o}F; HI: 98.8^{o}F) than for males (T_{MAX}: 94.2^{o}F; HI: 100.0^{o}F). However, our data only included 10 female occupational heat deaths, and these differences were not statistically significant. There was also no evidence of differences in fatal exposures by age group, race, ethnicity, and industry.

Figure 4-1. Temperature (T_{MAX}) vs. Heat Index for N=327 U.S. Occupational Heat-Related Deaths, 2000-2010



Regionally, however, there were significant differences in fatal exposure temperatures. The North (n=61) had far fewer deaths than the South (n=266) and the average of T_{MAX} was significantly lower (90.7°F in the North and 95.0°F in the South) on the day of fatal exposure. Similarly, the northern mean HI of 95.0°F was significantly lower than the southern HI of 102.0°F, a difference of 7.0°F (95% CI: 4.4, 9.4°F), p <0.0001. The range in the South for T_{MAX}, 67°F to 121°F, is broader than the northern range (67°F to 102°F). The HI ranges are 67°F to 111°F and 67°F to 121°F for the North and South, respectively. To examine these ranges more closely, we calculated quartile values for HI for both North and South. The northern HI values (91°F, 95°F, 101°F and

111°F) and southern HI values (97°F, 102°F, 107°F and 119°F) demonstrate the difference in temperature distributions between these regions.

We further investigated geographical differences at the state level for the six southern states determined in a previous analysis to have either high rates or high numbers of occupational heat-related deaths (Arizona, California, Florida, Mississippi, North Carolina, and Texas) (Gubernot et al., 2014). These states represent both humid and non-humid conditions. Among these six states, the average T_{MAX} at fatal exposure differed significantly (Table 4-1) (F statistic from a one-way ANOVA: 11.19, p<0.001), while the mean heat indexes at fatal exposure were not significantly different across the states. There was an insufficient sample of northern cases to perform a similar inter-state analysis.

Table 4-1. Temperature and Heat Index Differences for Heat-Related Occupational Fatalities in Southern US States, 2000-2010

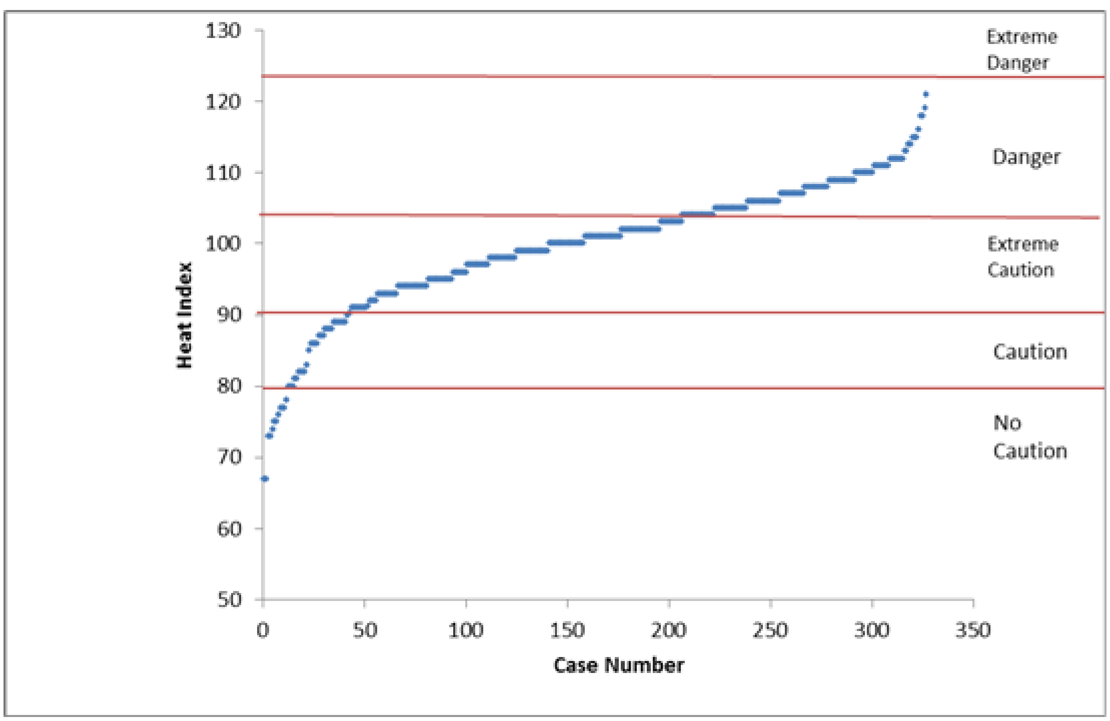
States	N	Mean T_{MAX}[1,2] (SD)	Mean Heat Index[1] (SD)
Florida	39	90.2 (7.5)	98.9 (8.5)
North Carolina	19	94.0 (7.5)	103.1 (8.6)
Mississippi	14	94.6 (7.7)	102.4 (8.6)
Texas	42	95.8 (7.2)	102.7 (8.6)
California	43	99.3 (7.6)	99.2 (8.6)
Arizona	11	106.6 (7.5)	104.8 (8.8)

1. Degrees Fahrenheit 2. One-Way ANOVA F=11.19, p<0.001

To determine if occupational heat-related deaths occurred mostly during excessive heat events (EHE), we used NOAA's definition for an EHE (≥105°F in the North and ≥110°F in the South), and found only 7 northern cases that occurred at this HI level; 88.5% of northern fatalities occurred on days not considered by NOAA to be EHEs. Similarly, only 35 of the southern heat-related occupational fatalities occurred on days meeting NOAA's southern EHE criteria (HI ≥110°F), while the majority of southern cases (87%) occurred outside of an EHE.

All of the cases are displayed in Figure 4-2 by NOAA Heat Index Categories (separated by horizontal lines). The majority of the cases fall in the "Extreme Caution" (121 cases) and "Danger" (163 cases) HI levels. However, 31 cases also occurred in the "Caution" category, and 12 cases occurred below this threshold (HI < 80°F, no caution).

Figure 4-2. Heat Index of N=327 U.S. Occupational Heat-Related Deaths, 2000-2010 with NOAA Heat Index Categories



Discussion

We examined variation in the association between mean maximum daily temperature and HI and the characteristics of worker fatalities and found significant differences between regions, states, and months. We also evaluated the exposure temperature of the fatalities using the NOAA HI chart as well as NOAA-defined excessive heat events.

There were no distinguishable differences between mean temperatures and heat index by sex. Few studies exist that examine the differences between the sexes for physiological reactions to heat exposure (CDC/NIOSH, 2013). However, very few (N=10) female occupational heat deaths were listed in the CFOI. Further research is needed to investigate this finding; a larger sample size may distinguish a variance.

We also found no differences in the average temperatures or HI of fatal heat exposure related to age. This was unexpected as age is a risk factor in population-based studies and older individuals can succumb at lower temperatures due to impaired thermoregulatory processes (Gamble et al., 2013; Larose et al., 2013). In the workplace, the lack of age difference in the exposure temperature for fatalities may be a function of the occupation or job tasks of older workers who might experience less physical exertion and heat exposure. There were also no significant differences in the temperatures of fatalities by race, ethnicity or industry. These findings suggest that a cross-industry policy may be appropriate to protect all workers from dangerous heat exposure.

The deaths in both the North and South occurring at less than 80^{o}F are curious, and are most likely due to exertion and/or wearing personal protective equipment. PPE can protect from solar radiation, but it also restricts evaporation and allows internal metabolic heat to accumulate in the body (ACGIH, 2009). Unfortunately, the CFOI narratives did not include information about the use of PPE. Additionally, those working in direct sunlight might have experienced a heat index of 15^{o}F higher than recorded (NOAA/NWS, 2014). Lastly, it is possible that these deaths could have occurred due to other sources of heat, but were not properly reported to OSHA and were thus incompletely recorded in CFOI.

Mean fatal exposure T_{MAX} differed significantly between six southern states with high numbers of heat-related occupational fatalities (Table 4-1), which suggests that a regional strategy may not be adequate using temperature alone as a metric of heat. Fatal exposure HIs were more similar among these states, indicating that heat index may be a better metric if creating a threshold based on the same metric of heat for many locations. Our analysis suggests that HI is able to somewhat dampen differences among state-level fatal exposures, since states with lower average T_{MAX} at fatal exposure tended to be more humid states (e.g., North Carolina, Florida), while states with higher average T_{MAX} tended to be drier (e.g., Arizona). The HI, which accounts for humidity, showed less state-to-state variation (Table 4-1). Although we were unable to demonstrate these differences in the North, policies using the heat index may also be most effective for heat stress prevention in the North given the potential for inter-state humidity and temperature differences.

The NWS generally initiates alert procedures when the HI is expected to exceed 105^{o}F-110^{o}F (depending on local climate) for at least 2 consecutive days (which NWS classifies as a heat wave). However, this study showed that the majority of worker deaths occurred outside of a NOAA-defined EHE. This may signify a difference between heat deaths in the general population and those that are occupational. With exertion increasing the metabolic heat load, occupational heat-related deaths occur at a range of temperatures, including those that are not considered excessively hot. Our results suggest that workers also face lethal heat-related danger on days too cool to be classified as EHEs under the NWS's definition.

The total heat load that a worker experiences is the sum of both environmental and physiological factors. Exertional heat stroke differs from classic heat stroke by individual characteristics (e.g., age), the type of activity in which individuals were involved (e.g., sedentary versus strenuous exertion), and the symptoms (e.g., sweating versus dry skin) (CDC/NIOSH, 2013). Current NOAA heat thresholds were most likely designed to prevent classic heat stroke/heat illness, yet exertional heat illness results in thousands of emergency room visits each year from those working or exercising in the heat (Nelson et al. 2011). A more appropriate categorical scale should be designed for occupational and recreational exposures with consideration of exertion and PPE use.

When deaths were compared to the NWS heat index classifications of health danger, there were no deaths in the HI >124^{o}F (Extreme Danger) heat index category, which may signify that worker training and behavior modification during such extreme heat are effectively limiting danger to workers (Morabito et al., 2006). Workers may be more likely to take breaks, stay hydrated, and shift work schedules to cooler hours when the heat is unusually high.

In 2011, OSHA initiated a Heat Campaign of nationwide education and outreach materials to help reduce the number of workers who are exposed to dangerous heat (www.osha.SLTC/heatillness/index.html). Although this campaign includes updated and comprehensive prevention measures and recommendations, it relies on employers' voluntary efforts. The outreach materials are based on heat index, which allows employers without WBGT apparatus to use a simplified system for evaluation of heat stress. OSHA is currently evaluating the heat campaign's materials via a survey on their website. However, the effectiveness of this initiative to reduce worker heat illness has not yet been evaluated; we recommend that an evaluation of the campaign's effect on the incidence of worker morbidity and mortality be performed.

The majority of the deaths in this study occurred due to heat exposure in HI categories "Danger" and "Extreme Caution". This may denote a need for OSHA and its state affiliates to further educate businesses, as well as the employees, to practice preventive measures for heat stress during these hot days. Workers are a vulnerable population with distinctive risk factors (e.g., exertion, PPE) that may exacerbate heat stress even at lower temperatures as evidenced by 25% of fatal heat exposures occurring in the lowest NOAA category (Caution) or below this threshold. Based on these findings, OSHA might consider updating its heat level chart to provide additional guidance for the low caution category of ≤ 91 degrees. We also recommend increasing awareness of the vulnerability of workers who wear PPE and/or are engaged in heavy exertional activities as lower temperatures could also prove to be deadly.

The most compelling action to protect employees would be an OSHA-promulgated federal standard. NIOSH has recommended such a heat standard based on its heat exposure research in 1972, 1986 and again in 2013. NIOSH contends, "The recommended standard is expected to prevent or greatly reduce the risk of adverse health effects to exposed workers". The findings of our study as well as previous research and surveillance findings demonstrate harmful heat exposure at work resulted in hundreds of deaths and tens of thousands of serious illnesses in the past decade (Gubernot et al, 2014;Luginbahl et al., 2008; CDC/NIOSH, 2013; BLS data, 2014). Therefore, we recommend that OSHA initiate a rulemaking process to consider a standard for heat exposure, similar to that of California, using HI instead of temperature alone. The California standard requires provision of water, access to shade (when the temperature exceeds 85 degrees Fahrenheit), and training. In addition, the standard includes high-heat procedures (when the temperature equals or exceeds 95 degrees Fahrenheit) which include effective communication to employees, observing employees for alertness and signs or symptoms of heat illness, reminding employees throughout the work shift to drink plenty of water, and close supervision of new employees (http://www.dir.ca.gov/title8/3395.html).

Limitations

There are several limitations to this study. Our data were obtained from the CFOI, which lacks some details of the fatalities, including worker health status, fitness, use of PPE, length of service and other individual and environmental risk factors. We also relied on the information recorded in the CFOI. Errors in reporting to OSHA and data errors recorded in the CFOI could affect the results of our analyses. However, the CFOI is considered to be the most comprehensive database that documents U.S. fatal occupational injuries (Layne, 2004).

The temperature assignment is subject to error as the temperature recorded from the weather station chosen may not be reflective of the actual temperature exposures of the cases. Further, our categorization of "North" and "South" regions for this study may not adequately represent the EHE threshold for each state. Further research could evaluate worker heat exposure based on local temperatures using relative (based on the area's temperature norms), rather than absolute temperature thresholds (Kent et al., 2014).

The heat index calculation may not precisely reflect the exposure of the individual on the day of fatal exposure. The records from the NCDC include only average dew point and this value was included in our HI equation with T_{MAX}. However, dew point does not fluctuate much in a 24 hour period since it is independent of temperature (unlike relative humidity) (Lawrence, 2005).

Comparisons across industries did not include worker occupations, which would provide increased specificity for risk evaluation. Additionally, worker exposure to full sun and time spent outdoors could not be evaluated for this study.

Further research is needed on the influence of PPE, personal risk factors, acclimatization, and specific occupations. Understanding the effect of these additional factors on worker heat-related morbidity and mortality is pertinent for the development of effective preventive measures.

Conclusion

This study supports the use of HI, which is a universally available and practical measurement of heat exposure, as an alternative to WBGT for policy and prevention measures. Extreme weather events cannot be prevented, but their consequences can be minimized by taking advantage of metrological forecasting for implementation of early warning systems that target vulnerable populations (Ebi and Schmier, 2005). Since occupational heat exposure is exacerbated by work-related factors, there is a critical need for U.S.-wide HI temperature thresholds designed for occupational alerts; general community alerts may not adequately protect workers. States and localities could further refine these thresholds based on local meteorological conditions.

Climate change is expected to increase average ambient temperatures globally, and episodic heat waves are projected to increase in frequency. A review by Shulte and Chun (2009) postulates that climate change is likely to increase the prevalence, distribution and severity of worker exposure to known hazards and result in increased occupational morbidity and mortality. This study provides a baseline minimum estimate of U.S. worker deaths due to heat and includes analyses of the T_{MAX} and HI temperatures at which the workers succumbed. Future trends can be assessed in the context of climate change as well as in the context of any prevention or adaptation strategies that may be implemented.

National policy is needed to educate and protect workers from the hazard of heat stress. Political will is also needed to integrate climate change adaptation into current occupational health policy to ensure interventions increase workers' capacity to withstand climate change while contemporaneously preventing morbidity and mortality in the workplace.

Chapter 5: Conclusions

At least 359 individuals died in the last decade in the U.S. as a result of heat exposure while performing their occupational duties; these are preventable deaths. This fact incited this dissertation research to examine the extent of current knowledge on occupational heat-related illness and perform a gap analysis of research and policy needs. A comprehensive rate-based study of all heat-related fatalities in the U.S. from 2000 to 2010 was also conducted to characterize these deaths and describe the demographics of the deceased individuals in order to identify the most vulnerable workers. Lastly, a temperature analysis was performed to determine the temperatures at which the various sub-populations of workers succumbed to the heat. These studies characterize the HRI fatalities based on available information and provide evidence for decision-makers to craft suitable policy and education measures to protect workers.

As described in Chapter 2, a comprehensive literature review described the existing U.S. research, knowledge, and scope of this public health problem. A gap analysis identified research needed to better understand this workplace hazard and prevent heat-related illnesses, injuries, and deaths through use of appropriate interventions.

The review found that existing literature is scant and fragmented. Published research includes a few industry-specific, event-specific, state-specific, and group-specific studies on occupational heat stress, heat illness, or heat fatalities. Thus, findings were limited in scope, but some studies did identify agriculture and some construction jobs as high risk. OSHA's surveillance system for occupational illnesses and injuries does not adequately capture HRI, therefore the true scope of the problem is unknown. Although the Intergovernmental Panel on Climate Change has called for adaptation research to prepare for and prevent morbidity and mortality due to climate change, very little work has been done in the occupational arena.

Although numerous population level studies of heat waves were conducted to identify vulnerable populations in communities, there is no evidence that these studies represent individuals in the workplace (Semenza et al. 1999; Semenza, et al. 1999; Knowlton et al., 2009; Bouchama et al., 2007; Stafoggia et al., 2006; Rey et al., 2009; Basu and Malig, 2011). Occupational exposures may be more hazardous as workers have less control over their work environment and are involved in activities requiring exertion (Budd, 2008). Many of the most hazardous jobs are performed by migrant workers, immigrants, and day workers with lower socioeconomic status. These workers may have sub-standard housing with no air conditioning and may be unable to cool their bodies in the evening, increasing the risk of day time HRI (Culp et al., 2011; Vallejos et al., 2011; Lowry et al., 2010).

Existing research is inadequate to characterize the incidence of occupational HRI. Furthermore, the effects of heat on the incidence of accidents and injuries have not been determined. There has been little or no research on spatial and temporal patterns of HRI, the effect of the Urban Heat Island on city workers, and evaluation of interventions. Research is also lacking on the synergistic effect of occupational exposures such as dust, pesticides and other occupational hazards in relation to elevated ambient temperatures; therefore, further research on these concerns is recommended in Chapter 2.

The gap analysis also determined the need for evaluation of interventions and existing training initiatives. Worker-specific warning systems need to be researched and evaluated as well as current risk communication practices, an observation that is also supported by the research in Chapter 4. Economic analyses should be performed as heat stress prevention programs could not only reduce illness and save lives, but also prove to be economically beneficial for businesses.

To address some of these research needs, a comprehensive analysis of the CFOI was subsequently performed to describe U. S. death rates by year, state, and industry and examine the demographic characteristics of the HRI fatalities. As described in Chapter 3, this is the first national epidemiological study to examine these occupational deaths.

The study identified 359 workers who died as a result of heat-related illness from 2000 to 2010. The average annual heat-related fatality rate was 0.22 deaths per 1 million workers. There were distinguishable differences year-to-year, but no apparent trends, suggesting the hypothesis that changes in the yearly rates reflect fluctuating weather patterns. When the decade was divided into earlier and later years, the latter half of the decade had a slightly higher rate, RR=1.4 (95% CI:1.1,1.7).

Of the 359 deaths, only 10 were female. The rate for males was significantly higher than females with a risk ratio of 32. Rates also varied with race and ethnicity. Blacks had a risk 1.5 times that of whites and Hispanics had a significant RR of 3.2 compared to non-Hispanics. These risk ratios all held true after controlling for industry, as described in the findings of Chapter 3.

Although older individuals have been shown to be at higher risk in community studies, this study found only a slight increase for older workers. The median age of deceased workers was 41 years old. There was no significant difference in HRI fatality rates among the age groups with the exception of the ≥ 65-year stratum which had an increased risk of 2.2 compared to the youngest workers.

It is notable that this is only a modestly higher death rate than the rest of the age groups. This contrasts with studies of the general population that found the frail, socially isolated, disabled, and/or elderly are at high risk from heat stroke and death rates for these vulnerable groups are markedly higher than younger people (Knowlton et al., 2009; Semenza et al., 1996; Hess et al., 2014). However, unlike in the general population where many older people are frail, older workers are subject to health selection factors – commonly referred to as the Healthy Worker Effect (HWE). The HWE is a term applied to the deficit of both morbidity and mortality ascribed to various employment-associated factors when workers and the general population are compared (Li & Sung, 1999). It is also very likely that older workers have different occupations and job tasks compared to younger workers. This is supported by other heat-related occupational studies (Luginbahl et al., 2008; FLA, 2011) and general population research on exertional heat-related illness visits to emergency departments (Lipmann et al., 2013; Nelson et al., 2011) in which younger age groups had higher rates or percentages of emergency department visits, attributed to their activities while exposed to environmental heat. For these reasons, older workers may not experience the same high risk as the elderly sub-population that is susceptible to classic heat stroke studied in general population heat wave research.

The industries with the highest rates of heat-related fatality were Agriculture and Construction. Agriculture had 35 times the risk of the referent group and Construction had 13 times the risk. These two industries accounted for 207 (58%) of the cases and employ the most migrant and day workers compared to other industries (Kendel, 2008; Lowry et al., 2010).

The states with the highest rates were Mississippi and Arkansas. These states can benefit from immediate implementation of worker heat stress education and prevention programs, as can others with average annual rates well above the all-state average. Of the case reports that included establishment size, the largest proportion (43%) occurred in small businesses of less than 10 employees. This is significant since these small businesses are exempt from the OSH Act's injury and incident reporting requirements as well as programmed OSHA inspections (29 CFR 1904.1).

In Chapter 4, maximum daily temperature and heat index values on the day of the deceased workers' exposure were determined using records from the National Climatic Data Center at NOAA. The overall maximum temperature and heat index ranges for all heat-related deaths included in the study was 67^{o}F to 121^{o}F. This is not only a broad range, it also includes workers who died at temperatures in the 67^{o}F to 80^{o}F range, below the threshold of the NOAA "Caution" category, elucidating in fact that individuals can succumb to heat at lower temperatures.

Deaths occurred in NOAA's Heat Index categories of "No Caution", "Caution", "Extreme Caution" and "Danger"; there were no fatalities at the "Extreme Danger" level. The majority of the cases fell in the "Extreme Caution" (121 cases) and "Danger" (163 cases) HI levels. However, 31 cases also occurred in the "Caution" category, and 12 cases occurred below this category (HI < 80^{o}F, no caution). Further, 87% of workers died on days outside of a NOAA-defined Excessive Heat Event- defined as using a threshold of 105^{o}F in the North and 110^{o}F in the South.

The study illustrated the need for a new heat warning system aimed at preventing exertional heat injuries. It is notable that the current heat index is based on classic heat stroke in the general population. As such, it does not adequately protect workers exerting themselves in the heat outdoors, possibly in direct sunlight, and potentially wearing personal protective equipment.

There were no differences in temperature and HI of exposure between demographic and industry groups; however regional analyses generated important findings. Temperatures on the day of exposure were significantly lower in northern states compared to southern states, indicating that regional or state-specific worker HRI prevention policies would be most effective.

The findings of these three research projects inform the following recommendations for federal policy makers:

1. *Initiate a rulemaking process to consider a federal, enforceable standard to protect workers from environmental heat exposure* The findings of our research as well as previous studies and surveillance findings demonstrate harmful heat exposure at work resulted in hundreds of deaths and tens of thousands of serious illnesses in the past decade (Luginbahl et al., 2008; NIOSH, 2013; BLS data, 2014). NIOSH has recommended a heat standard in 1972, 1986, and again in 2013 (NIOSH, 1972; NIOSH, 1986, NIOSH, 2013). Therefore, we recommend that OSHA initiate a rulemaking process to consider a standard for heat exposure.

2. *Re-analyze HI thresholds for heat alerts that are part of OSHA's Heat Campaign with consideration of worker PPE use.* OSHA's lowest caution category for HI heat alerts is ≤ 91^{o}F. Our temperature analysis in Chapter 4 found that 43 workers died at temperatures in this ≤ 91^{o}F category. OSHA should use these data, as well as data from other occupational and heat exertion research, to redefine the heat caution categories on its website and phone app. The research in Chapter 4 supports the use of HI, which is a universally available and practical measurement of heat exposure, as an alternative to WBGT for policy and prevention measures. The HI, which accounts for humidity, showed less state-to-state variation than temperature alone, making evident that HI is suitable for protective policies. Since occupational heat exposure is exacerbated by work-related factors, there is a critical need for a U.S. wide HI temperature threshold alerts designed for occupational conditions.

3. *Target small businesses and their employees with education on heat stress prevention, with focus on the agricultural and construction industries*. As found in Chapter 3, of the 359 heat-related fatalities, 43% were from small businesses (< 10 employees). Small establishments that are decentralized may also lack the organizational structure to support safe practices. This research, as well as previous studies, have shown that work-place fatalities can be disproportionally high among small businesses (Weil and Wolfrod, 2013; Taylor et al., 2002). With the highest rates of heat-related death in the agriculture and construction, small businesses in these industries should be targeted for interventions.

4. *Evaluate current risk communication for the prevention of heat stress.* As recommended in Chapter 4, OSHA's Heat Campaign should be evaluated for effectiveness. This should include determining employees' knowledge of heat prevention measures and how they are informed of potentially dangerous heat exposure.

5. *Encourage economic analyses of the impacts of implementing heat stress prevention programs for various industry sectors and establishment sizes.* Washington State performed a cost-benefit impact analysis of heat illnesses prevention programs on small businesses and found the economic benefits outweighed the monetary costs due to reducing Workers' Compensation claim costs, indirect costs associated with illness/ injury, and productivity loss due to worker dehydration (WA, 2008). Economic analyses within various industries and establishment sizes may serve as further incentive for adoption of heat prevention programs.

6. *Encourage further research to identify vulnerable worker sub-populations, the effect of heat on injuries and accidents, and the synergistic effect of heat with occupational exposures such as dust, pesticides and other occupational hazards.* These issues, noted in the gap analysis in Chapter 2, deserve attention to inform policy decisions and better protect workers.

These findings are described in the preceding chapters and publishable articles to disseminate the recommendations to occupational health practitioners and public health officials, with the intent of spurring additional research and policy discussions. The above recommendations would also serve as adaptation measures to prevent future HRI morbidity and mortality in our warming environment. Climate change is a driver for adaptation and prevention of heat disorders; workers are a research-neglected vulnerable sub-population. Consequently, intensified research and policy development for occupational heat stress risk factors and implementation of effective interventions are increasingly essential.

This dissertation research resulted in 3 publishable papers:

Gubernot D, Andersen GB, Hunting K. 2013 **The epidemiology of occupational heat-related morbidity and mortality in the United States: A review of the literature and assessment of research needs in a changing climate.** Internat J BioMeterol doi: 10.1007/S00484-013-0752-x

Gubernot DM, Anderson GB, Hunting KL. 2014. **Characterizing occupational heat-related mortality in the United States, 2000-2010: An analysis using the Census of Fatal Occupational Injuries database**. Am J Ind Med (*In press*)

Occupational Heat-Related Fatalities in the United States Characterized by Heat Index and Maximum Daily Temperatures, 2000-2010 (to be submitted)

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Appendix A

Table A. Occupational Heat Morbidity and Mortality Studies Performed in the U.S.

Study	Study Design/Population Characteristics	Main Findings
Florida Department of Health (2011)	Descriptive Case Series Occupational heat-related illnesses treated in Florida hospitals and emergency departments using Workers' Compensation records 2005-2009 N = 2198	• Age adjusted rate 3.7/100,000 • 3 deaths • Highest rates in rural counties • 87% male • Median age 36 years • Highest rate in 25-29 age group
King BS, Gibbons JD (2011)	Health Hazard Evaluation/Case Study All workers involved in the Deepwater Horizon Response 2130 total illnesses/injuries reported to the Unified Area Command N = 192 HRI	• At least 5 hospitalized for HRI • 169 had general symptoms associated with HRI • Temperatures often exceeded 90 and relative humidity was high
Bonauto D, Rauser E, Lim L (2010)	Descriptive Case Series Workers' Compensation claims for HRI 2000-2009 Washington State N= 483	• HRI incidence rate 3.1/100,000 • $3682 avg/ claim • 6 days - median time loss from work • Median age - 34 years old • 80.3% of the cases were male • Highest rates in the administration of conservation programs, roofing contractors, site preparation contractors, and fire protection industry sectors
Luginbuhl RC, Jackson LL, Castillo D, Loringer KA (2008)	Descriptive Case-Series U.S. workers 1992-2006 Census of Fatal Occupational Injuries All heat-related deaths N= 423	• 102 (24%) in agriculture/forestry • Crop workers highest rate • 54% in the 35-54 age group • 59% in July • 29% in California

National Institute of Occupational Safety and Health (NIOSH) (2006)	Health Hazard Evaluation (Case Study) Palm Beach International Airport, Florida Aug 28-31, 2004 23 acclimatized participants	• WBGT range 77.5°-83.9° • 8 cases showed signs of heat strain • 1 case core body temp exceeded 101.3 • 10 cases heart rate exceeded ACGIH criteria
Carter R 3rd, Cheuvront SN, Williams JO, et al (2005)	Descriptive Case Series Heat illnesses and deaths for US Army 1980-2002 Total Army Injury Health Outcomes Database N= 5246 HRI hospitalizations 37 HRI deaths	• 60% reduction in hospitalization rates but 5-fold increase in heat stroke hospitalization rates over the study period • Heat stroke cases were associated with dehydration (17%), rhabdomyolysis (25%), and acute renal failure (13%) • Higher rates of hospitalization of recruits from northern states (1.69 incidence density ratio) • Higher rates among women (1.18 IDR)
Mirabelli MC, Richardson DB (2005) *	Descriptive Case Series North Carolina residents 1977-2001 Medical examiners records- all heat-related deaths N = 161 total HR deaths; 40 worker deaths	For job related deaths: • 58% black, 100% male • 41 median age • 20% history of drug/alcohol abuse; 5% alcohol detected at time of death. • 45% were farm laborers
Donoghue AM (2004)	Descriptive Case Series US Mining Industry 1983-2001 MSHA accident, injury, illness and employment database N = 538 HRI cases	• No fatalities • 79.4% occurred June-Aug • Highest rates in stone mills, metal mills and underground metal mines
Krake A, Mccullough J, King B (2003)	Health Hazard Evaluation (Case Study) Grand Canyon Nat Park June 26- July 4, 2000 15 participants	• All exceeded at least one ACGIH criterion physiological measurement • 1 case core body temp exceed 100.5 • Did not follow prevention measures

Dellinger AM, Kachur PS, Sternberg E, Russell J (1996)	Case Study Army National Guard involved in flood relief in Illinois July 5-Aug 18, 1993 N= 214 injuries/23 (19.3%) HRI cases	• HRI most frequent injury diagnosis • HRI 16% of injury to males; 41.7% to females • Female to male RR 3.07 (95% CI, 1.09-8.68)
Gardner JW, Kark JA, Karnei K, et al (1996	Matched Population-based Case-control Study Male Marine Corp recruits in basic training Parris Island, NC 1988-1992 528 HRI cases/1725 controls 391 HRI cases/1467 controls had measurements for analyses	• Race, BMI and run-times were independent predictors of exertional heat illness • BMI > 22, OR 1.9 • Non-whites OR 1.7 • Longer run-times significantly increased risk OR 3.4 to 4.2

*The study population included all deaths; however the authors also characterized heat-related deaths for those that were determined to be work-related.