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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

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Abstract

In recent years, the United States has experienced record-breaking summer heat. Climate change models forecast increasing U.S. temperatures and more frequent heat waves in coming years. This scoping review summarizes research findings that characterize U.S. occupational heat-related morbidity and mortality and identifies gaps in the existing research literature. Exposure to environmental heat is a significant, but overlooked, workplace hazard that has not been well-characterized or studied. The working population is diverse; job function, age, fitness level, and risk factors to heat-related illnesses vary. This review found that few studies examine or characterize the incidence of occupational heat-related illnesses and outcomes. More research on the effects of occupational heat exposure is needed to identify and implement evidence-based policies and interventions. 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, crafting policy to characterize and prevent occupational heat stress for all workers is increasingly sensible, practical, and imperative.

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Keywords

occupational health; heat exposure; heat illnesses; worker safety; climate change

Introduction

In the United States, employees are legally entitled to a safe and healthy 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 work-related injuries (Thomsen et al. 2007; BLS 2011). Surveillance systems capture these data and are key for designing effective interventions to improve worker safety and health.

With a warming climate and more frequent extreme weather events predicted, exposure to ambient heat 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). Yet both the general populace and public health officials often underestimate the impact of high temperatures on human health (Kravchenko et al. 2013).

Severe weather has always threatened human health. However, 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 et al. 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).

Heat stress occurs when an individual has been overexposed or over-exercised for his/her age and physical well-being in the existing thermal environment (NOAA 2005). Generally, the body should maintain a core temperature within + 1°C of the normal 37°C core body temperature, (i.e., 100.4°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 physiologically 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 from 1936 to 1975 (NOAA 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. Several studies characterized general population mortality risk and identified 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). Others examined 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).

Although heat-related illnesses (HRI) can occur in healthy persons, major risk factors include: dehydration; obesity; poor physical condition; previous diagnosis of HRI; lack of acclimatization; febrile illness; deprivation, alcohol use, and disorders that affect sweating (Adelakun et al. 1999). Additional risk factors include wearing personal protective equipment (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 as well as environmental circumstances can therefore play a profound role in the heat stress response.

Research on occupational heat exposure 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 data on occupational heat stress are sparse and fragmented.

This scoping review aims to 1) determine the volume, nature, and characterization of the U.S. epidemiological research published on occupational heat-related morbidity and mortality; 2) describe and summarize the studies that exist; and 3) identify future research needed to better characterize this public health problem and ultimately inform policy-makers.

Methods

We conducted a broad scoping review (Arksey and O'Malley, 2005) to determine the size and nature of existing research in both the published and grey literature. The databases searched include: MEDLINE, PubMed, Web of Science, Cochrane Collaboration database, and web-based searches including public health and occupational organizations. Additional searches of bibliographies identified studies and reports not found in the electronic queries.

The following title words were used to search the databases: "worker", "job", "occupation", "epidemiology" and derivatives of these words with the terms "heat", "hot", "weather", "temperature", "summer", "environmental health", "heat wave", "morbidity", "mortality", and "fatalities". Given the scarcity of the research, this search was broad and was not limited by dates, study quality, or study type. Population-level studies on ambient heat exposure that incorporated occupational data were also included, as were occupational injury studies that included heat exposures. Research reports on heat-related exposures to indoor heat sources, such as kitchen and steel-working environments, were not included in the scope of this review. While this review focuses on studies conducted in the U.S., research performed elsewhere and non-occupational studies are described in this paper to provide context for characterizing this public health problem.

Public Health and Occupational Studies and Reports

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. Military databases also capture work-related health data.

Surveillance of U.S. 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) 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) if doctors do not inquire about work-related hazards, patients may not communicate such 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. Moreover, 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 HRI diagnosis, the case may not be reported as work-related.

Each year, thousands of occupational heat-related illnesses are documented and during the last decade, more than 350 civilian workers died on the job due to environmental heat exposure (BLS 2013). These data may not include severe or fatal injuries or illnesses, such as falls or myocardial infarctions, for which heat was a contributory cause. 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 HRI in the U.S. is not known and updated exposure estimates have not been published.

The American Conference of Government Industrial Hygienists (ACGIH), 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 use by industrial hygienists and occupational clinicians for employees in their particular work environments. Employers who lack such specialized positions and equipment may be left without any heat stress prevention program.

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, however these cases were not further characterized.

Several studies have exclusively investigated heat illness related to exertion. Nelson et al. (2011) 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. A study of all exertional heat-related injuries treated in emergency departments in the U.S., 1997–2006 (Nelson et al. 2011) found the number of these injuries increased significantly over a ten year time period, from 3192 (95% CI = 1290 – 5093) in 1997 to 7452 (95% CI = 4270 – 10636) in 2006 ($p = 0.002$). Occupational cases were included, however they were not specifically identified in this study.

Several work-related risk factors for heat stress have been noted in the literature. Just as with occupational injuries in general, a worker's length of service in a particular job appears inversely related to the occurrence of HRI. This might be explained by inadequate training, acclimatization, or physical fitness for the job. Maeda et al. (2006) found that a short duration of forestry service was associated with onset of heat stroke among Japanese forestry workers. In a case-series of exertional heat stroke in the Israeli military, 50% of the cases occurred during the first six months of service (Epstein et al. 1999). Therefore HRI training also plays a notable role in illness prevention as dehydration can negate the advantages conferred by physical fitness and heat acclimatization (Ekblom et al. 1970).

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 in Israeli soldiers occurred in overweight soldiers and that heat stroke occurs mainly within the first two hours of exercise. These findings are relevant to U.S. worker safety as well since obesity is a growing health problem in the U.S. (CDC 2010).

Only North Carolina, Florida, and Washington States have published reports characterizing heat-related illnesses and fatalities either targeting, or including, those identified as work-related. These reports and other U.S. studies on occupational heat-related morbidity and mortality that met this study's review criteria are summarized in Table 1.

Fredricks et al. (2005) conducted a survey of roofing workers to better examine specific types of injuries and potential causes. Unfortunately, they did not present the data by month or study injuries associated with weather variables. However, the surveyed roofers contended that an extra 10°C (~15–20°F) is generated while working on a roof with black asphalt shingles in direct sunshine – corroborating OSHA's counsel that working in direct sunshine can add up to 15°F to the temperature that the body perceives (OSHA 2011). To compensate for this, the roofers' schedules are temporally shifted, with work performed primarily in the early morning or evening.

Several incident-specific evaluation 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. The investigation disclosed that most of the 2000 visitor rescues performed by the rangers each year are due to HRI, yet the rangers did not always follow procedures to prevent HRI in themselves. All participants monitored during this one week study exceeded at least one ACGIH criterion for heat stress (e.g., heart rate, respiratory rate, core body temperature, etc.). NIOSH also investigated employee heat exposure on the tarmacs at Palm Beach International Airport (NIOSH 2006); most monitored employees similarly exceeded ACGIH criteria. Although both reports identified unhealthy heat exposures, 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 Deepwater 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 (King and Gibbins 2011).

The use of PPE 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 that found the average HRI ambient

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temperature affecting firefighters was only 78.7° F compared to 88.6° F ($p<0.001$) for other occupations (Bonauto et al. 2010).

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 et al. 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.

Occupational 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.

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.

Few states have implemented occupational heat exposure regulations. Only California (CA Code of Regulations 2012) and Washington (WA State Legislature 2012) have standards for outdoor heat exposure, while Minnesota has an indoor heat exposure standard (MN Administrative 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).

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 2012). 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 (NIOSH 1998).

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.

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) who 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).

To the authors' knowledge, no research has specifically examined 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 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 heat stress studies should evaluate: 1) the incidence of occupational HRI in the U.S.; 2) the effect of heat on accident and injury rates; 3) spatial and temporal patterns; 4) urban heat islands; 5) environmental and occupational factors; 6) vulnerable worker sub-groups; 7) existing interventions and training programs; 8) warning systems and risk communication; 9) economic analyses; and 10) translational research to bridge the science into the policy realm.

Incidence of Occupational HRI in the U.S

Determining the incidence of HRI and characterizing this hazard in the working population (e.g., age, sex, occupations/industries at risk) is a research priority. The scope and magnitude of the problem needs to be determined to inform public health officials, to provide improved risk communication, and to incite a change in policy.

Heat Effects on Incidence of Accidents and Injuries

There is limited evidence that the indirect effects of heat 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. Since most heat wave population studies exclude accidents from the analyses, the incidence of injuries during these extreme weather events is unstudied. Research to characterize the magnitude and types of occupational injuries occurring during high ambient temperatures would fill a significant gap in injury research.

Spatial and Temporal Patterns

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 (Carter 2005). However, many Southern workers may experience an opposite effect due to poor housing conditions.

The impact of high heat exposure earlier in the summer season when workers are less acclimatized warrants analysis as population-level studies find that heat waves in the early summer are associated with higher mortality rates (Anderson and Bell 2011).

Urban Heat Islands

Many factors cause the urban heat island effect, including urban thermal storage, increased anthropogenic heat flux, decreased terrestrial radiation loss, and increased radiation due to particulates and greenhouse gases (Basara et al 2010). Urban areas also lack green spaces for shade, and all of these factors result in elevated day and nighttime temperatures. The impact of urban heat islands has been demonstrated in population-level studies (Basara et al. 2010) and this phenomenon’s impact on occupational heat stress calls for specific examination.

Environmental and Occupational Exposures

Further HRI research is needed on the effects of heat exposure in combination with humidity, air pollution, allergens, air pressure, air speed and lack of cloud cover (Kravchenko et al. 2013). The synergistic effects of occupational exposures such as dust, pesticides, and other occupational hazards must be considered.

Analysis of the overall anticipated impacts of climate change on worker safety in the U.S. would also be instrumental. For example, the potential effect of increased heat, decreased cold, and increased severe weather on the overall working population warrants study in light of the variability of our changing climate.

Vulnerable Working Populations

Vulnerable sub-groups such as migrant workers, workers with poor housing, crop workers paid by amount harvested, first responders, volunteers, and those required to wear encumbering PPE also deserve particular study.

Evaluation of Interventions and Training Programs

The impact of employers' HRI prevention programs and employee training require further investigation. Evaluations of interventions are needed to inform decision-makers of measures proven effective.

Evaluation of Warning Systems and Risk Communication

Whether established community heat alert levels are appropriate and adequately communicated to workers should be researched, as well as the adequacy of the temperature thresholds that elicit a warning. Heat warning systems can be tailored specifically for workers. Risk communication is needed for the general populace, as well as those with individual risk factors and in high-risk occupations. Perceptions of risk to HRI should also be studied.

Economic Analyses

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 illness 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 (WSDLI 2008). Introduction of heat stress prevention programs may prove to be economically beneficial in different sectors and states and provide an incentive for businesses to establish such programs.

Translational Research

Translation converts scientific and technically complex research into common language and actionable concepts in the practice setting (Wandesman et al. 2008). The increasing body of occupational and heat exposure research will require synthesis and translation into the policy arena.

A policy response to protect workers from heat is a low-risk adaptation strategy as standards and improved guidelines are currently needed. 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.

Conclusion

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 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 (WHA 2008). Occupational health research clearly falls under the auspices of these recommended research priorities.

There is a clear need to focus on adaptation to climate change, and not just mitigation, as it is already impacting health world-wide. Targeted research on the association of age, sex, existing illnesses, occupation/industry, geographical location, environmental conditions, and other variables is needed so evidence-based interventions can be designed and implemented to protect this climate-vulnerable population.

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Table 1

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, Gibbins 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)

Study	Study Design/Population Characteristics	Main Findings
		• 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 Primary investigation conducted 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/illness 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 • 1.5 mile run-times of ≥ 12 mins, OR 3.4 • 3 mile run-times of ≥ 23 mins, OR 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.