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Assessing Heat-Related Mortality and Morbidity Risks in Rural Populations and Sub-Populations

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by

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ABSTRACT

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Heat stress is an environmental and occupational hazard exacerbated by climate change. Rural populations and sub-populations continue to experience disproportionate risks of heat-related impacts due to their low adaptive capacities in terms of infrastructure, information and other resources which are critical in dealing with heat. The study goals were to determine heat-related mortality risks in rural populations globally, explore the contribution of the outdoor work environment and other factors in association with occupational heat-related illnesses (HRI), and assess the risk of heat stress among crop workers using the Wet Bulb Globe Temperature (WBGT). Published peer-reviewed scientific literature on heat-related mortality in rural areas was used to assess heat-related risks among rural populations worldwide. Excess risks of both all-cause and cardiovascular mortalities were found although temperature had a stronger impact on cardiovascular deaths than for all-cause mortality. Also, using cross-sectional data from health screening clinics conducted during the summers of 2014, 2015, and 2016, a total of 425 patient encounters were analyzed using chi-square and logistic regression analyses to determine the role of the outdoor work environment and other factors associated with heat stress. As expected, the outdoor work environment was significantly associated with HRI. Out of the total of 67 HRI cases that were self-reported or diagnosed, 82% (55 cases) worked outdoors. There were nonsignificant elevations in HRI prevalence reported in males, workers below 40 years of

age, individuals who have worked in agriculture for ten years or less, and those trained on heat safety. Further, a comprehensive evaluation of heat stress among crop workers was conducted using the four thermal climate factors-- air temperature, humidity, wind speed and solar radiation-- as well as work load and clothing factors. It found both acclimatized and non-acclimatized workers at risk of HRI. Regression analysis revealed that HRI prevalence was strongly correlated with the daily maximum WBGT (R^2= 0.89; p= 0.03). Thus, effective heat safety precautions are needed, in addition to acclimatization, to protect vulnerable outdoor workers.

DEDICATION

I dedicate this work to my family, friends, and all who have contributed to its success.

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CHAPTER 1

INTRODUCTION

The fifth report of the Intergovernmental Panel on Climate Change has documented an increase of 0.3 – 0.6 °C in global mean surface temperature over the past century, mainly attributed to anthropogenic activities. In addition to the increasing global surface temperature and atmospheric carbon dioxide concentrations (CO_2), changing rainfall patterns, shrinking glacier volumes, increasing frequencies of flooding, hurricanes, droughts and other extreme weather conditions also provide evidence to support climate change (IPCC 2013; NOAA 2017). Climate change impacts are known to be severe among rural populations and sub-populations due to their reliance on natural resources and weather-dependent activities, along with a lack of access to information, decision making, and infrastructure. Moreover, most people who live or work in predominantly rural areas may be economically, socially, culturally, politically, institutionally, or otherwise marginalized, making them more vulnerable (Dasgupta et al. 2014; Gamble et al. 2016).

Increasing global temperatures also pose many challenges to occupational health and safety. Roelofs and Wegman (2014) referred to workers as the "climate canaries" similar to cases in chemical exposures, where their exposures are known to be greater in frequency, duration, and intensity compared to the general population. Workers, especially economically marginalized ones including Migrant and Seasonal Farmworkers (MSFWs), are usually ignored by climate researchers and federal agencies with no surveillance system to detect, monitor, report, or respond to severe cases of heat-related and other climate change effects (Frumkin et al. 2008; Portier et al. 2010). There is a need for workers to be given special attention because their exposures are compelled by their work and employer demands (Roelofs and Wegman 2014).

Heat stress remains one of the most frequently reported conditions among outdoor workers (Parsons 2014; Pogačar et al. 2018). Even in temperate regions of the world, including the United States, the risk of heat stress should not be underestimated, especially in situations where workers are not acclimatized to hot weather conditions (Adam-Poupart et al. 2013). According to the National Center for Farmworker Health, heat stress is commonly reported among the estimated three million farm workers in the United States (NCFH 2018). Yet, there is no heat stress standard in OSHA's current regulations (Arbury et al. 2014). Currently, California and Washington are the only states with heat stress standards that are currently operational for agricultural workers (California Division of Occupational Health and Safety 2006; Washington State Department of Labor and Industries 2008; Arcury et al. 2015). Agriculture, classified by the Food and Agriculture Organization (a United Nations agency) as a rural job with poor working conditions, remains dangerous in terms of preventable fatalities, injuries, and diseases (Wästerlund 2018). Migrant and seasonal farmworkers (MSFWs) are particularly vulnerable. The majority are immigrants with limited English proficiency who lack access to quality health care due to living in isolated rural communities. They live in poor housing facilities, and often lack access to air conditioning and fans (Villajero 2003; Arcury and Quandt 2007; Gamble et al. 2016).

To date, limited heat-related research has been conducted in rural areas. This can be attributed to a lack of meteorological data due to the paucity of weather monitoring stations (Hashizume et al. 2009; Lee et al. 2016). Additionally, small rural populations militate against epidemiologic studies with sufficient statistical power (Henderson et al. 2013; Ratcliffe et al. 2016; U.S. Census Bureau 2018). Thus, few studies have examined the temperature-mortality relationship in rural areas (Hashizume et al. 2009). To formulate comprehensive heat-health action plans, it is imperative that we assess heat-related health risks in rural populations and sub-populations known to have high heat exposures due to their work demands (Ebi et al. 2006; IPCC 2013; Gamble et al. 2016).

CHAPTER 2

REVIEW OF THE LITERATURE

Vulnerability to Heat-Related Effects

Heat, the leading cause of weather-related deaths in the United States, mostly affects vulnerable populations (Zanobetti et al. 2012; Sarofim et al. 2016; USEPA 2017). Vulnerability to heat stress and other weather-related impacts primarily depends on three main factors: exposure, sensitivity, and adaptive capacity (Gamble et al. 2016). In terms of heat stress, exposure can be defined as contact between the individual and hot environments (mostly high temperature and humidity). Sensitivity refers to the extent to which individuals or communities are affected by high temperatures and climate change. The third component, adaptive capacity, is defined as the way individuals, institutions, or communities can make adjustments to potential heat hazards, take advantage of opportunities, or recover from such threats in case they happen (Gamble et al. 2016). Conditions well-documented to determine the vulnerability of individuals and communities to heat stress include:

Occupation

Those who work outdoors or perform outdoor duties in hot environments for long hours are at high risk of heat stress, including farmworkers and construction workers. Also, the work load plays a significant role in contributing to heat stress. The more intense the job, the higher the risk of heat stress, especially when performed outdoors (Gamble et al. 2016; OSHA 2017; Wästerlund 2018).

Socioeconomic Status

Poor people are more likely to be exposed to extreme heat and other climate-related impacts (Harlan et al. 2006). Both poverty and education can determine how risk of heat stress is perceived by individuals, their response to heat warning systems, and general safety precautions available to them (Fothergill and Peek 2004).

Access to Infrastructure

Lack of transportation, utilities, medical facilities, communication, and other basic needs such as potable water can impede efforts to respond to heat stress and other weather-related emergencies (Gamble et al. 2016). Generally, communities that are predominantly rural have less infrastructure compared to those in urban areas (Hart et al. 2005). Minority groups including immigrants and low-income individuals tend to experience slow recoveries after weather-related disasters and other emergencies due to a lack of access to information, fewer government relief opportunities, and greater likelihood of experiencing some form of discrimination (Pastor et al. 2006).

Health Status, Age and Other Biological Traits

People with chronic illnesses, especially cardiovascular and respiratory diseases, are less able to deal with heat stress compared to healthy individuals (Semenza et al. 1996; Semenza et al. 1999; Ishigami et al. 2008). Children, pregnant women, people with disabilities, and the elderly, especially those above 60 years, are also vulnerable due to impaired ability to take actions to prevent or respond to heat-related impacts (Gamble et al. 2013).

Epidemiological Evidence

Most epidemiological studies on heat-related impacts have focused on the negative effects of high temperatures in urban settings (Henderson et al. 2013; Kovach et al. 2015). The adverse health effects of heat on non-rural or urban populations have been attributed to several factors, especially the urban heat island effect (UHI) and socioeconomic disparities (Kalnay and Cai 2003; Chan et al. 2012; Mohajerani et al. 2017). The UHI effect has become one of the greatest problems associated with urbanization and industrialization due to threats posed by increasing temperature. According to Oke (1997), annual ambient mean temperatures of some urban locations with high population densities can range between 1.8 to 5.4°F warmer than surrounding communities, with an evening temperature difference as high as 22°F.

Rural vs. Urban Studies

A study of 107 U.S. cities reported a 3% increase in the risk of heat-related mortality at higher temperatures. Curriero et al. (2002) evaluated the temperature-mortality risks in eleven U.S. cities and found increased mortality risks as temperatures increased, especially in northern cities. Examining heat- and cold-related mortality in twelve cities around the world, McMichael et al. (2008) found increasing rates with increasing temperatures in all but two cities, Chiang Mai in China and Cape Town in South Africa. Moreover, Gasparrini et al. (2015) analyzed a total of 74,225,200 deaths within a 27-year period (1985 to 2012) in 384 cities and concluded that heat was responsible for 0.42% of these deaths. Estrada and colleagues (2017) performed a cost-benefit analysis to assess the economic impacts of climate change for all the major urban areas in the world. Romero-Lankao et al. (2012) also examined the vulnerability factors that affect temperature-mortality relationships in non-rural areas.

Studies conducted in rural areas, although relatively fewer, have also reported that rural populations are vulnerable to heat-related mortality. Hajat and colleagues (2007) found an excess heat-related mortality of 3% in the most deprived rural regions of England and Wales while 2.2% excess mortality was recorded in urban locations with similar deprivations. In studying excess heat-related cardiovascular mortality in a rural region (Southern Bohemia) and an urban region (Prague) in Czech Republic from 1994-2009, Urban et al. (2014) found comparable excess mortality in both locations (Table 2.1).

Table 2.1: Mean Relative Excess Cardiovascular Mortalities (Adapted from Urban et al. 2014)

Diagnosis	% Excess mortality in rural region (95% CI)	% Excess mortality in urban region (95% CI)
Cardiovascular Disease	8.4 (4.9, 12.0)	10.8 (7.5, 14.1)
Ischemic Heart Disease	7.2 (2.2, 12.5)	7.0 (2.1, 12.2)
Cerebrovascular Disease	7.9 (1.3, 14.8)	10.0 (3.8, 16.6)
Chronic Ischemic Heart Disease	10.2 (3.5, 17.4)	10.9 (4.7, 17.4)
Atherosclerotic Vascular Disease	14.9 (5.0, 25.6)	19.4 (11.6, 27.7)

In China, Bai et al. (2014) assessed the relationship between daily mean temperature and mortality in three Tibetan counties (Chengguan, Jiangzi and Naidong) between 2008 and 2012. They found approximately 22.9% and 14.7% excess non-accidental heat-related deaths in Naidong and Jiangzi, which are predominantly rural regions. Chengguan, the urban district of the capital city of Tibet, recorded a lower excess mortality rate of 9.1%. The study also found stronger temperature effects of cardiovascular mortality than all-cause mortality (Bai et al. 2014). Both Naidong and Jiangzi recorded higher excess cardiovascular deaths (31.2% and 53.9%, respectively) while Chengguan recorded only 5.8%. Chen et al. (2016) also analyzed heat-related mortality associations in more urban and less urban counties in Jiangsu Province, from 2009-

2013 and found a higher overall mortality risk of 43% in less urban counties compared to 26% in more urban counties. A more recent study examining the impact of temperature on non-accidental mortality in Hubei also reported slightly higher heat mortality risk in rural areas than urban locations (Zhang et al. 2017).

In the United States, Berko et al. (2014) studied heat-related deaths and found similar mortality rates for rural and urban counties (2.6 and 3.1 deaths per million, respectively). Another study conducted in Georgia, North and South Carolina found that compared to Metropolitan Statistical Areas (MSAs), the heat-related mortality rate was 31% higher in rural areas (Lee et al. 2016). Kovach et al. (2015) also studied area-level risk factors for HRI in rural and urban locations across North Carolina and found that the highest HRI incidence (at least 41.6 emergency department visits per 100,000 person-years) occurred in predominantly rural locations in the southern Coastal Plain of North Carolina. In examining heat-related deaths and the level of urbanization across Ohio, Sheridan and Dolney (2003) concluded that rural and sub-urban counties had higher percentage increases in mortality compared to urban residents, but the difference was not statistically significant.

Occupational Epidemiology of Heat-Related Effects

Heat-related illnesses (HRI) and mortality remain major occupational threats, with global climate change expected to exacerbate heat stress especially in uncontrolled work environments (Lundgren et al. 2013; Wästerlund 2018). Heat stress can be defined as the buildup of heat generated by the muscles during work and in hot climates (USEPA 1993). It commonly occurs when the body is unable to sufficiently dissipate its excess heat generated by the surroundings (Wästerlund 2018). In the United States alone, an estimated 7,415 heat-related fatalities were recorded from 1999 to 2010 (CDC 2012; NOAA 2017). According to the Occupational Safety and Health Administration, there were 31 heat-related worker deaths and 4,120 heat-related worker illnesses reported in 2012 alone (OSHA 2014).

Workers in the agriculture, forestry, fishing, and hunting industries have been well-documented to be at high risk of heat stress. In an analysis of occupational health data from 2003 to 2008, the Centers for Disease Control and Prevention found a high rate of 0.3 fatalities per 100,000 full-time employees attributable to HRIs in this sector, which was more than ten times greater than that of all other industries (0.02 deaths per 100,000 fulltime employees) (CDC 2008). In 2015, the overall fatality rate reported for people working in the agriculture, forestry, fishing, and hunting sector was 22.8 per 100,000 employees, while the fatality rate for all other industries was 3.4 per 100,000 (MCN 2017). This has been attributed to a combination of factors: hazardous conditions, insufficient regulations, lack of access to quality health care, and poverty (MCN 2017). Most of these fatal cases have been known to involve younger workers who are not well acclimatized to the work environment (Gubernot et al. 2015). The inability of employers to modify the work environment to reduce heat exposures is a major contributor to heat-related morbidity and mortality in this industry (Wästerlund 2018).

Mechanisms of Heat Production and Dissipation

Heat is generated as a byproduct of the body’s metabolic processes including the transformation of energy in food into energy needed to perform work (Simon 1993; Wästerlund 2018). An approximate 75% of the energy in food is converted to heat energy, with the remaining used to perform work. Thus, the heavier the work load, the more heat is generated. The four mechanisms of heat transfer-- conduction, convection, radiation, and evaporation-- are well-documented in dissipating most of the body’s heat (Grubenhoff et al. 2007; Becker and

Stewart 2011; Wästerlund 2018). Radiation and evaporation account for most of the heat transfer in humans although convection becomes more relevant with increasing ambient temperatures due to heat dissipation by vasodilation (Simon 1993; Grubenhoff et al. 2007).

With radiation, the body gains or loses heat without direct contact. Heat dissipation via the skin occurs if the surrounding air temperature is lower than the skin temperature (Wästerlund 2018). As ambient heat increases, the body's ability to dissipate heat decreases due to radiation (Grubenhoff et al. 2007).

Convectional transfer of heat occurs when the body is exposed to wind (Wästerlund 2018). Circulatory dynamics, or the transfer of heat by extracellular fluids such as blood, is another way by which convection occurs (Grubenhoff et al. 2007; Wästerlund 2018). When core body temperature increases, the numerous blood vessels in the skin enlarge or open, enabling more blood flow to the skin's surface, thereby creating a larger surface area for heat exchange between the body and the environment (Wästerlund 2018).

Conduction is the direct transfer of heat from a warmer surface to a cooler surface (Howe and Boden 2007). Heat dissipation through conduction occurs when the body makes contact with objects that have lower temperature than the skin and can transport heat as well (Wästerlund 2018). The rate of conduction depends on the temperature gradient, the percentage of surface area in contact, and the conductive properties of the object in contact (Armstrong et al. 2007).

Evaporation is the most common and important mechanism of heat transfer in humans during hot weather conditions (Grubenhoff et al. 2007; Wästerlund 2018). Evaporation as a heat dissipation method becomes effective if the body sweats and the sweat evaporates to achieve a cooling effect. The presence of physical barriers such as heavy clothing or personal protective equipment (PPE) or other environmental factors including high humidity can result in loss of fluids without a cooling effect (Grubenhoff et al. 2007). Sweat glands are distributed throughout the body and an individual can lose approximately 600g of fluid per hour even when working in temperate conditions (Wästerlund 2018).

The heat balance equation, taking into consideration all the major heat transfer mechanisms, is summarized in Equation 1:

$$\text{(Equation 1)} \quad S = (M-W) \pm C \pm R \pm K - E$$

Where

S = change in body heat content or heat to be stored

(M−W) = total metabolism minus external work performed

C = convective heat exchange

R = radiative heat exchange

K = conductive heat exchange

E = evaporative heat loss

The body also uses a minimal amount of the heat generated to maintain a core body temperature between 36°C and 37.5°C. Body temperature regulation is a complex interplay of heat production, absorption, and dissipation regulated by the hypothalamus (Simon 1993; Grubenhoff et al. 2007). The anterior hypothalamus is known to function as an integrator and thermostat, with its preoptic nucleus acting as the center of thermal control. The efferent fibers in the autonomic nervous system are activated when there is a rise in core body temperature, resulting in cutaneous vasodilation, and increased rate of sweating (Simon 1993). The posterior hypothalamus, however, serves as a set point of the core body temperature and initiates the right physiological responses to protect health (NIOSH 2016). When the rate of heat production exceeds that of heat dissipation, the body temperature increases. This can result in hyperthermia and consequently heat-related illnesses (HRIs), especially in situations where the body's thermoregulatory mechanisms become overwhelmed by excessive metabolic heat production due to the work load, hot climates, and impaired heat production (Simon 1993).

HRI

Defined as a set of preventable conditions ranging from mild forms to potentially fatal heat stroke (Becker and Stewart 2011), HRI occurs in situations when the body's mechanisms to dissipate heat become impaired, and thus begin to store heat. Common signs and symptoms of HRI include dizziness, headache, confusion, nausea/vomiting, weakness, and diarrhea. Milder forms of HRI are normally associated with a core body temperature less than 40°C (104°F) with no central nervous system symptoms such as confusion (Howe and Boden 2007). These include heat edema, heat rash, heat cramps, heat syncope, and heat exhaustion (Becker and Stewart 2011). Heat stroke, on the other hand, is characterized by a core body temperature of at least 40°C with central nervous system (CNS) symptoms.

Heat edema is the mildest form of HRI that produces mild edema in the dependent areas of the hands, feet, and other extremities (Nichols 2014). It is associated with normal core body temperature (98.6°F) and normally occurs in individuals who sit for long periods of time or people not acclimatized to heat.

Heat rash, miliaria rubra or prickly heat, is also associated with normal core body temperatures. This mild form of HRI is characterized by a pruritic papulovesicular eruption over the clothed areas (Nichols 2014). This usually happens when the sweat glands become blocked, causing the skin to be continuously wet with unevaporated sweat which can lead to inflammatory reactions (Wästerlund 2018).

Heat cramps occur mostly when working in hot and humid environments (Becker and Stewart 2011). It is initiated by muscle fatigue, depletion of electrolytes, dehydration, and sodium losses, especially when people sweat a lot (Bartok et al. 2004; Casa et al. 2005). Also, workers are likely to suffer from heat cramps after drinking large volumes of water without replenishing their salts (Wästerlund 2018). This can lead to low plasma sodium concentrations (Bergeron 2012), which can trigger the mechanical deformation of motor nerve terminals causing the muscle cells to contract (Layzer 1994).

Heat syncope is caused primarily by a decrease in blood flow to the CNS as a result of peripheral vasodilation, volume depletion, and decreased vasomotor tone (Grubenhoff et al. 2007). This condition is common in non-acclimatized workers and is characterized by fainting and dizziness (Grubenhoff et al. 2007).

Heat exhaustion is characterized by hypotension and cardiovascular insufficiency due to dehydration when working in the heat (Grubenhoff et al. 2007; Nichols 2014). It signifies a moderate compromise of the body's thermoregulatory system. Common symptoms of heat exhaustion include nausea, vomiting, tachycardia, fatigue, headache, energy depletion, dry mucous membranes, and general irritability (Grubenhoff et al. 2007). In heat exhaustion, elevated core body temperatures do not rise beyond 40°C, and the mental status of the individual remains unaltered, distinguishing it from the most fatal heat stroke (Nichols 2014).

Heat stroke is a medical emergency (Grubenhoff et al. 2007; Nichols 2014). It is the most severe form of HRI diagnosed when the core body temperature exceeds 40°C, accompanied by CNS dysfunction and damage to the skeletal muscle and multiple organs (Grubenhoff et al. 2007; Nichols 2014). Heat stroke is common during heat waves (CDC 1995; Dematte et al. 1998). Headache, nausea, dizziness, and clumsiness are common early signs and symptoms, which can progress rapidly to apathy, confusion, and impaired consciousness. In instances where the core body temperature remains above 42°C for prolonged periods of time, heat stroke becomes more severe, which can cause rhabdomyolysis, renal failure, hypoglycemia, cardiac arrhythmias, or even death, if not well treated (Seto et al. 2005). Classic heat stroke and exertional heat stroke are the two types of heat stroke. The main distinction between classic and exertional heat stroke is that the latter is associated with profuse sweating as a result of working in the heat and occurs in healthy individuals (Grubenhoff et al. 2007).

HRI Risk Factors

Risk factors for HRI can be categorized broadly as internal or external. Internal risk factors for HRI include poor physical fitness, level of acclimatization, history of HRI, gender, young or old age, use of personal protective equipment or non-breathable clothing, lack of education, and alcohol intake (Nichols 2014). A study which reported total heat loss in 85 males, 20-70 years of age, confirmed a decreased rate of heat dissipation during physical activity in those above 40 years (Larose et al. 2013). Compared to males, females have been found to have lower sweating rates, and they often start sweating at higher inner core body temperatures. Thus females are at greater risk of suffering from HRIs. Some medical conditions such as diabetes, obesity, gastroenteritis, sickle cell trait, sweat gland dysfunction, and cystic fibrosis have been suggested to predispose individuals to HRI (Armstrong et al. 2007). For outdoor workers, acclimatization is key in determining how long the worker can be exposed to high temperatures without suffering from HRI. Acclimatization is a form of physiologic adaptation established in both laboratory and field work (WHO 1969). It enhances the body’s tolerance for heat stress, thus reducing the risk HRI and heat fatalities on the job (NIOSH 2016).

External risk factors include the outdoor work environment, a major contributor to HRI. Arcury et al. (2015) studied heat illness among 101 North Carolina Latino farmworkers and reported more than a third of this population suffered from heat illness due to the outdoor work environment. Moderate to heavy work load with long durations, coupled with inadequate rest, access to fluids, shade, and lack of an emergency action plan such as a heat alert program (HAP) are additional external risk factors for HRI (Armstrong et al. 2007).

Rural Populations and Sub-Populations

Rural inhabitants are generally characterized by higher proportions of the elderly and children, poor people, the unemployed, uninsured and underinsured residents. In addition, higher rates of chronic conditions, fewer healthcare facilities and providers, and economically fragile healthcare facilities with high closure rates all limit access to quality healthcare and overall quality of life (Hart et al. 2005).

According to the United Nations Department of Economic and Social Affairs Population Division (2013), almost half of the world's population reside in rural areas, with the majority living in less developed countries. Also, an estimated 70% of rural inhabitants are considered poor (International Fund for Agricultural Development 2010) and lack access to information, resources, infrastructure, and services (Dasgupta et al. 2014). Social determinants of health such as poverty, occupation, education, racial, and health disparities can interact with the three elements of vulnerability (i.e., exposure, sensitivity, and adaptive capacity) to exacerbate climate-related health outcomes including heat stress (Gamble et al. 2016). Rural populations and sub-populations may be disproportionately affected by these social determinants, which limit opportunities to attain healthy lifestyles. Access to healthcare services and conducive work environments are also limited in rural areas (Braveman et al. 2011), decreasing the ability to cope with heat-related effects (Gamble et al. 2016).

Defining Rural Areas

The definition of a rural area varies from place to place and remains a multifaceted concept suggesting many things to many people; it includes small towns, agricultural landscapes, isolation, and places with low population density (Hart et al. 2005; Coburn et al. 2007). It remains unclear even in policy-oriented and scholarly articles (IFAD 2010), and existing definitions depend on those of urban areas (Dasgupta et al. 2014). Thus, a rural area defined in a developed nation may differ from another in a less developed country in terms of population density, infrastructure, and resources.

In the United States, three common definitions are used by the federal government to define a rural area. The most common definition used by the U.S. Census Bureau is basically a delineation of geographical areas based on population density. Two types of urban areas have been defined: urbanized areas with at least 50,000 people and urban clusters with between 2,500 people to 50,000 people. Rural areas have fewer than 2,500 people (U.S. Census Bureau 2018). The Office of Management and Budget also defines MSAs as central counties with at least one urbanized area and surrounding counties economically tied to the central counties. Nonmetropolitan counties are defined as counties outside the metropolitan areas with two subdivisions: micropolitan statistical areas with an urban cluster of at least 10,000 people (but less than 50,000 people), and noncore counties. All counties that are not classified as MSAs are classified as rural (HRSA 2018). The third common definition by the Federal Office of Rural Health Policy utilizes both the Census Bureau and Office of Management and Budget definitions. This method assigns Rural-Urban Commuting Area (RUCA) codes to each census tract based on census data, allowing the identification of rural census tracts in counties classified as metropolitan. Less than 20% of the U.S. population reside in rural areas even though at least 75% of the landmass is classified as rural (Hart et al. 2005; Ratcliffe et al. 2016; HRSA 2018).

Migrant and Seasonal Farmworkers (MSFWs)

A migrant or migratory farmworker refers to an individual who is required to relocate from a permanent place of residence in search of rewarding employment in agriculture (MCN 2017). Seasonal farmworkers are employed in farmwork temporarily. They are not required to move from their permanent residence (MCN 2017). An estimated three to five million MSFWs including their dependents live in the United States (Larson and Plascensia 1993; Mehta 2000). The 2013-2014 National Agricultural Workers Survey, which is the most recent data, reported that the majority of agricultural workers are foreign born although most are legal residents in the United States (NCFH 2018). Also, 72% are males who could speak a little English. The average level of completed education was eighth grade (NCFH 2018). According to Gwyther and Jenkins (1998), MSFWs in the United States can be classified based on travel streams. Three main travel streams have been identified over the years: eastern, midwestern, and western travel streams. The eastern stream geographically extends from Florida to the northern Atlantic states. This is the most ethnically diverse group consisting of African-Americans, Haitians, Anglos, Jamaicans, and Latinos. The midwestern group occupies Texas, northern New Mexico and other parts of the southwest and midwest of the United States. The western stream, known to be the largest, covers California, Arizona, and other western states. The majority of MSFWs in both the Midwestern and the western groups are Latinos, with few Native Americans and Southeast Asians (Gwyther and Jenkins 1998).

MSFWs usually reside in migrant camps located in proximity to farms in rural communities, and in tents, vans, open fields, or even ditches (Hansen and Donohoe 2003; Wästerlund 2018). This mobile lifestyle, in combination with limited English proficiency and fear over citizenship status, makes assessing demographic information and health outcome data very challenging (MCN 2017). In addition, lack of access to quality health care due to living in isolated rural communities, living in poor housing facilities, and lack access to air conditioning and fans increases their vulnerability to HRI and other health conditions (Villajero 2003; Arcury and Quandt 2007; Gamble et al. 2016). Some challenges encountered specifically by MSFWs in accessing healthcare in the United States are outlined (Figure 2.1).

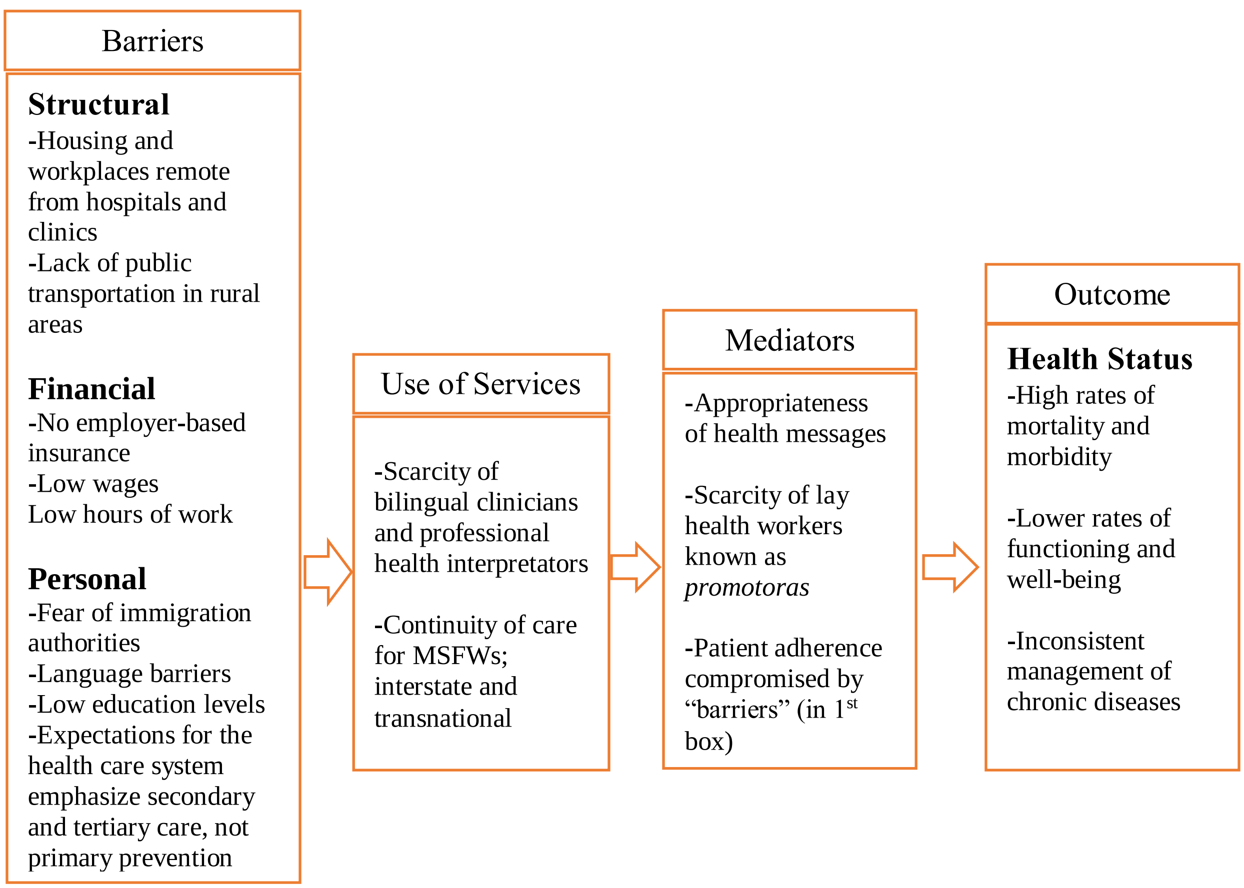

Figure 2.1: Model of Access to Care (Adapted from the Institute of Medicine 1993)

Methods for Assessing Heat Stress

Several indices have been invented over the years for assessing occupational heat stress. Some of these indices provide risk estimates based on environmental heat exposure and physical activity (Moran et al. 2003; Budd 2008). According to the National Institute for Occupational Safety and Health, for an index to have occupational use, the following basic criteria must be met:

1. Considers all important factors such as environmental, metabolic, clothing etc.
2. Practical, simple to use and generate accurate results
3. Simple and straightforward calculations
4. Methods and instruments should produce accurate results without necessarily interfering in job performance
5. Exposure limits must be supported by corresponding outcomes that reflect increased risk to workers' health and safety
6. Applicability for setting limits in a wide range of environmental and metabolic conditions (NIOSH 2016).

Commonly used heat stress indices include: Wet bulb globe temperature (WBGT) index, predicted heat strain (PHS), physiological measurements, heat index (HI), and air (dry bulb) temperature. The HI was not developed specifically for occupational use although it can be used for initial screening purposes in the absence of adequate climate data (Tustin et al. 2018).

Wet Bulb Globe Temperature (WBGT) index

WBGT was invented in the 1950s to control HRI and heat fatalities in United States military training camps. It is a widely used international standard particularly useful for monitoring and assessing the thermal conditions to which workers are exposed to determine the safety of the work environment (Yaglou and Minard 1957; Budd 2008; Parsons 2013). In addition, the WBGT index is simple, fast, and easy to use in various occupational settings for evaluating the heat stress to which an individual is subjected (ISO 1989). Currently known as the occupational gold standard for measuring and assessing environmental heat exposure in work places, this index constitutes the basis for Threshold Limit Values (TLVs) used in establishing work-rest cycles needed to protect workers from heat stress (ACGIH 2015).

WBGT considers all four thermal factors used in predicting heat stress-- air temperature, mean radiant temperature, air velocity and humidity-- although the instrument does not measure these factors directly. The WBGT instrument has three sensors: the dry bulb, natural wet-bulb, and globe thermometers. The dry bulb thermometer measures the air temperature and is normally shielded from direct sunlight with unrestricted air circulation. Both air temperature and humidity are measured using the natural wet-bulb thermometer, which is cylindrical in shape and covered with a wick of highly absorbent material, kept wet with distilled water throughout the measurement period. The globe thermometer is a 150 mm diameter black globe used to measure radiative heat exposure (Wästerlund 2018).

In outdoor environments, the instrument uses all three sensor data inputs weighing 70% of the wet bulb, 20% of the globe, and 10% of the dry bulb (Equation 2).

$$\text{(Equation 2)} \quad WBGT_{\mathbf{OUT}} = 0.7T_{nwb} + 0.2T_{g} + 0.1T_{db}$$

where T_{nwb} is the natural wet-bulb temperature, T_{g} is the globe temperature and T_{db} is the dry bulb temperature (Parsons 2013; OSHA 2017).

For indoor environments and outside buildings without solar radiation, the dry bulb temperature is not used since it is equal to the globe temperature without radiant heat (Equation 3).

$$\text{(Equation 3)} \quad WBGT_{\mathbf{IN}} = 0.7T_{nwb} + 0.3T_{g}$$

where T_{nwb} is the natural wet-bulb temperature and T_{db} is the dry bulb temperature.

The International Organization for Standardization (ISO) has developed WBGT reference values based on the metabolic rate of work (Table 2.2). These values are aimed at keeping the core body temperature below 38 °C in order to protect workers from HRI (Wästerlund 2018).

Table 2.2: WBGT Index Reference Values Based on Metabolic Rate of Work (Adapted from ISO, 1989)

Metabolic rate (M) (in w/m^2)	WBGT reference value (°C)	
	Acclimatized workers*	Non-acclimatized worker*
M ≤ 65	33	33
65 <M≤ 130	30	30
130 < M≤ 200	28	28
200 < M ≤ 260	25 (26)**	22 (23)**
M > 260	23 (25)**	18 (20) **

*Note.** Reference values remain same for metabolic rates ≤ 200 w/m^2
**Sensible air circulation

WBGT index is considered a valuable heat stress screening tool due to its widespread utilization in workplaces (Parsons 2014). The instrument is easy to use, durable, and relatively inexpensive, and the calculations are straightforward with few, easy to make measurements (NIOSH 2016). Limitations for this index include its inability to account for individual characteristics to assess evaporative cooling (Budd 2008). In addition, it is unable to accurately predict heat strain under conditions of high humidity and low air movements and does not consider the risk of dehydration due to excessive sweating (d'Ambrosio Alfano et al. 2014).

Predicted Heat Strain (PHS) Index

The PHS index is based on the heat balance equation (equation 1). It is regarded as the most advanced analytical method currently available for predicting the risk of heat stress for individuals working in the heat (Parsons 2013; Wästerlund 2018). Unlike the WBGT, PHS is able to predict both the core body temperatures and sweat rates of workers using models that also take into account the air temperature, wind speed, radiant heat, humidity, metabolic work rate, and clothing factors (Gao et al. 2018; Wästerlund 2018). These models predict heat exchange based on all four mechanisms of heat transfer: evaporation, radiation, convection, and conduction under the prevailing thermal and work conditions (Wästerlund 2018).

The PHS method determines both the required evaporation rate and the skin wettedness to keep the human body's heat balance (Wästerlund 2018). These values are then compared with the maximum evaporation and skin wettedness rates, which are partly dependent on the level of acclimatization of the individual. The maximum level of dehydration specified by the ISO standard is 5% of the body mass in situations where the person has full access to fluids (Wästerlund 2018). However, in the absence of fluids at the workplace, the maximum level of dehydration should be 3% of the body mass (Malchaire 2014).

The PHS model has some limitations. It is not a valid assessment in situations when protective clothing, with thermal insulation greater than 1.0, are worn in hot environments (Gao et al. 2018). Further limitations include its inability to assess the risk of heat stress in rapidly changing environments and for short-term heat exposures (Parsons 2013).

Physiological Measurements

Both the WBGT and PHS indices assume that workers are in good health and fit to perform the intended work (Wästerlund 2018). Thus, they cannot be used for unfit workers. In addition, when heat exposures are for short periods or in rapidly changing exposures, as well as in situations where protective clothing and equipment are worn, physiological measurements provide valid assessments of heat stress (Parsons 2013). The four main physiological indicators of thermal strain used for predicting individual responses are: core body temperature, mean skin temperature, heart rate, and body-mass loss. These measurements are necessary in evaluating the extent of heat strain experienced by each worker (Parsons 2013; Wästerlund 2018). However, they are invasive and may interrupt job performance, making this evaluation method less acceptable in workplaces.

Heat Index (HI)

The heat index combines air temperature and the relative humidity to quantify what the temperature feels like to the human body (Golden et al. 2008; Tustin et al. 2018). Also referred to as the apparent temperature, it was designed based on assumptions that the individual is wearing light clothing and walking in a shaded area (Steadman 1979). Thus, it was not solely invented for occupational purposes and does not take into consideration solar radiation effects, air velocity, work clothing, and strenuous activities. Nevertheless, in the absence of WBGT data, the heat index can serve as a useful tool to screen for potentially dangerous occupational environments (Tustin et al. 2018; Morris et al. 2019).

Air (dry bulb) Temperature

The daily air temperature (i.e., minimum, mean, or maximum) sometimes referred to as the dry bulb temperature, when shielded from radiation and moisture, can be used to define temperature extremes. The dry bulb temperature can be easily measured and can be useful in work situations where workers are required to wear vapor- and air-impermeable encapsulating clothing (NIOSH 2016). Thus, there is minimal solar radiation effect with limited evaporative cooling. A major weakness of this measure of heat exposure is that it does not take into account radiant heat (NIOSH 2016). Thus if conditions are above the comfort zone (i.e., > 23°C), it is not a good measure of heat exposure.

Managing HRI in Workers

Establishing specific WBGT guidelines and developing effective heat warning systems can be used to manage HRI in crop workers.

Establishing WBGT guidelines

This is necessary to protect workers from HRI during physical exertion in hot environments. WBGT guidelines should be specific to the region of interest, due to acclimatization or adaptation to a certain geographical location (Korey Stringer Institute 2017). Grundstein et al. (2015) grouped weather stations in different locations in the United States based on their extreme temperatures. Weather stations with WBGT values usually greater than 90.14°F have been placed in Category 3 or the hot region; those with WBGT values within 86.18°F and 89.96°F are placed in Category 2 or the moderate region; and then Category 1 or the mild region, are those with WBGT values below 86°F.

Category 3 covers states in the Southeast U.S., including Tennessee, as well as substantial parts of California, New Mexico, and Arizona. These geographical areas are usually warmer and thus have higher WBGT recordings. Table 2.3 shows the WBGT guidelines specific to our region for outdoor workers and soccer players in warm weather conditions.

Table 2.3: WBGT Guidelines for Region 3 (Adapted from the US SOCCER HEAT GUIDELINES, 2018)

WBGT recording (°F)	**Event Conditions**	**Alert level/Color indicator**	**Recommended Actions**
>92.0	Dangerous (Very High Risk)	Black	No work or training recommended
90.9-91.9	High Risk for HRI	Red	Take a break every 15 minutes up to a Maximum of 1 hour. Each break should be at least 4 minutes
87.1-90.1	Moderate Risk	Orange	10-minute break every 30 minutes up to a maximum of 2 hours
82.2-87.0	Low Risk	Yellow	12-minute break every 40 minutes
<82.1	No Risk	Green	10-minute break every 40 minutes

Developing Local Heat Alert and Warning Systems

HRI can be prevented or controlled by modifying the work load, environment, clothing and equipment, or by acclimatizing the worker to increased heat. NIOSH (2016) recommends the establishment of a documented Heat Alert Program (HAP) to protect the health of workers on days when the maximum temperature either exceeds 95 °F, or 90 °F and is at least 9 °F greater than the maximum readings on preceding days (i.e., a heat wave occurs). HAPs must utilize weather forecasts from credible meteorological stations. An effective HAP should also have two basic components:

1. A heat alert committee, usually formed in early spring, consisting of well-qualified, dedicated and competent health and safety professionals

2. Established guidelines to follow when there is a heat alert (NIOSH 2016).

The committee is responsible for planning and designing an appropriate training course for the target population and other vulnerable groups within the community. The course should emphasize primary prevention with the aim of early detection of HRI so that appropriate measures will be taken. The committee should also provide instructions for the supervisor to perform tasks that will reduce heat exposure. These include ensuring that infrastructure such as air conditioners, fans, and drinking fountains are functional, and also that employees know how to use them properly. Apart from establishing the criteria for declaring Heat Alerts, the committee should ascertain that the facilities needed to provide basic care are accessible in case of emergencies (Dukes-Dobos 1981).

Anticipating and developing an effective HAP or warning system is essential to address occupational heat stress in high-risk rural sub-populations such as MSFWs. A community partnership between East Tennessee State University and Rural Medical Service (RMS) has been built and sustained over the years to identify health needs and assist with provision of primary health care (Silver et al. 2014; Kelley et al. 2017). Cross-sectional epidemiologic data collected for almost a decade (i.e., 2010-2017) indicates that this population is at risk for HRI. Thus, it is within the vision of the community partnership to develop a heat warning system informed by current and future epidemiologic data as well as local WBGT measurements (Figure 2.2) to protect the farmworkers.

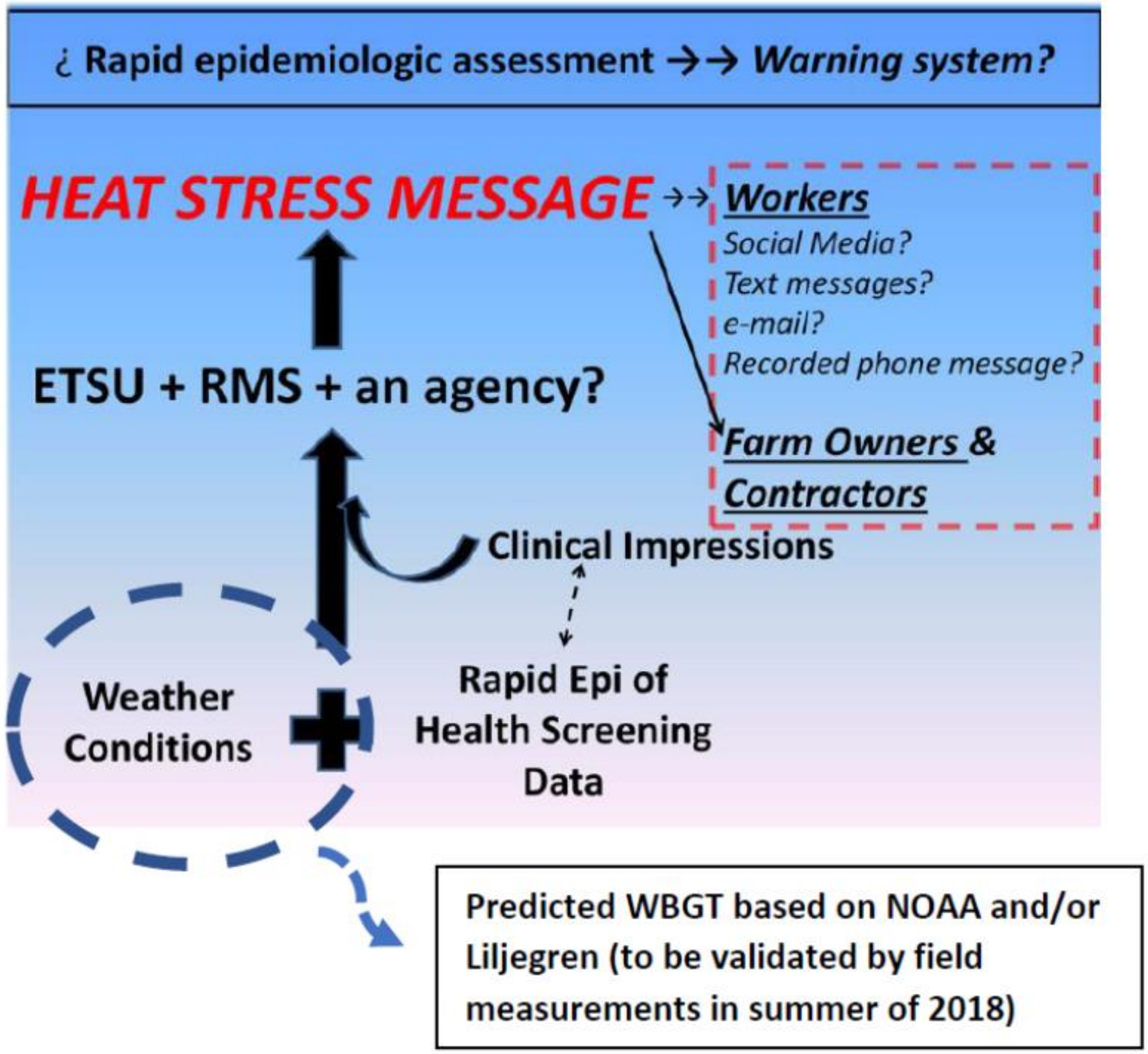

Figure 2.2: Long-range Vision for Developing a Heat Warning System Informed by Local WBGT, Epidemiologic and Clinical Data

CHAPTER 3

GOAL AND SPECIFIC AIMS

Heat stress remains an environmental and occupational hazard even in temperate regions. Heat-related mortality and morbidity have severe impacts on rural populations and sub-populations including those in developed countries. As rural communities differ in terms of characteristics, resources, and definitions, the impacts of heat stress in rural populations also vary. Even in developed countries such as the United States, marginalized groups including MSFWs, who work in agriculture and perform outdoor tasks, are known to be more vulnerable than the general population. Most researchers in this field have long held the idea that mainly urban residents are vulnerable to heat stress due to the "urban heat island" effect. However, more recent studies have disputed this claim, concluding that rural residents are equally vulnerable considering other predisposing factors apart from urban heat. A meta-analyses and review of the epidemiologic literature focusing on rural areas is necessary to set the pace, build the evidence, and, if possible, draw the attention of policy makers to consider rural populations and sub-populations in the policy-making process.

Moreover, with no current heat stress standard in place, outdoor workers in the category 3 zone (hot region) of the United States, known to have high heat exposures, need urgent attention. More so is the case of economically marginalized workers, including MSFWs whose work and employer demands, coupled with other socioeconomic factors such as poor housing and general lack of infrastructure, are known to be very vulnerable to heat stress.

This study aims to broaden existing knowledge of heat-related effects among rural populations and sub-populations using both secondary data from published peer-reviewed literature and primary data from summer health screenings conducted annually among crop workers in northeast Tennessee. The specific aims of the study are:

Aim 1: To assess heat-related mortality risks in rural populations by conducting meta-analysis and review of epidemiologic studies.

Hypothesis: Rural residents are vulnerable to heat-related mortality due to lack of infrastructure (i.e., low adaptive capacity) coupled with higher prevalence of chronic diseases (i.e., high sensitivity).

Aim 2: To examine the role of the outdoor work environment in association with HRI by comparing the prevalence of HRI in outdoor and indoor MSFWs in northeast Tennessee.

Hypothesis: Outdoor workers have higher heat exposure and will suffer from more HRI than those who work indoors.

Aim 3: To evaluate the risk of heat stress among crop workers in northeast Tennessee using the most common occupational heat stress standard, WBGT, and determine the correlation of daily maximum WBGT with the prevalence of heat stress signs and symptoms.

Hypothesis: Higher WBGT measures will correlate with higher prevalence of heat stress signs and symptoms identified in the health screening data.

CHAPTER 4

MATERIALS

Study Population

This research focused on two populations: The general rural population worldwide and MSFWs in rural northeast Tennessee.

Rural Populations Worldwide

Data on heat-related mortality in rural populations were generated using a comprehensive literature review technique to select studies that had already been conducted in predominantly rural communities worldwide. PubMed, Google Scholar, and Web of Science were the three search engines used in this study with specific keywords. In order to compare “apples to apples”, a series of exclusion criteria were applied. The six exclusion criteria applied were: 1. studies not published in English; 2. studies not performed on human populations (non-epidemiological studies); 3. studies reporting no effect estimates (i.e., relative risks [RRs] or % change in mortality) and those reporting effect estimates only for subpopulations, such as the elderly, but not for the entire population in the study area; 4. commentaries, review articles and editorials; 5. studies on morbidity; and 6. studies focusing on heat waves.

Only 14 studies were selected out of the total 476 studies generated by the literature search. However, these studies were further categorized based on the temperature metric used: eleven studies used daily mean temperature, two used daily maximum temperature and only one used weekly mean temperature. This analysis only included studies that used daily mean temperature. Studies using other temperature metrics were excluded.

MSFWs in Rural Northeast Tennessee

Data on MSFWs was collected during summer health screenings for 2014, 2015, and 2016 with a total sample size of 425 clinical encounters. A separate analysis was done for 2018 health screening data (n= 124). The cross-sectional data, collected at the close of work on or near farms, considers multiple health outcomes including HRI and other work-related conditions commonly identified in MSFWs. Some demographic characteristics of the study population are highlighted (Figure 4.1). The majority of crop workers were foreign born from Mexico (61%), while only 9% were born in the U.S.

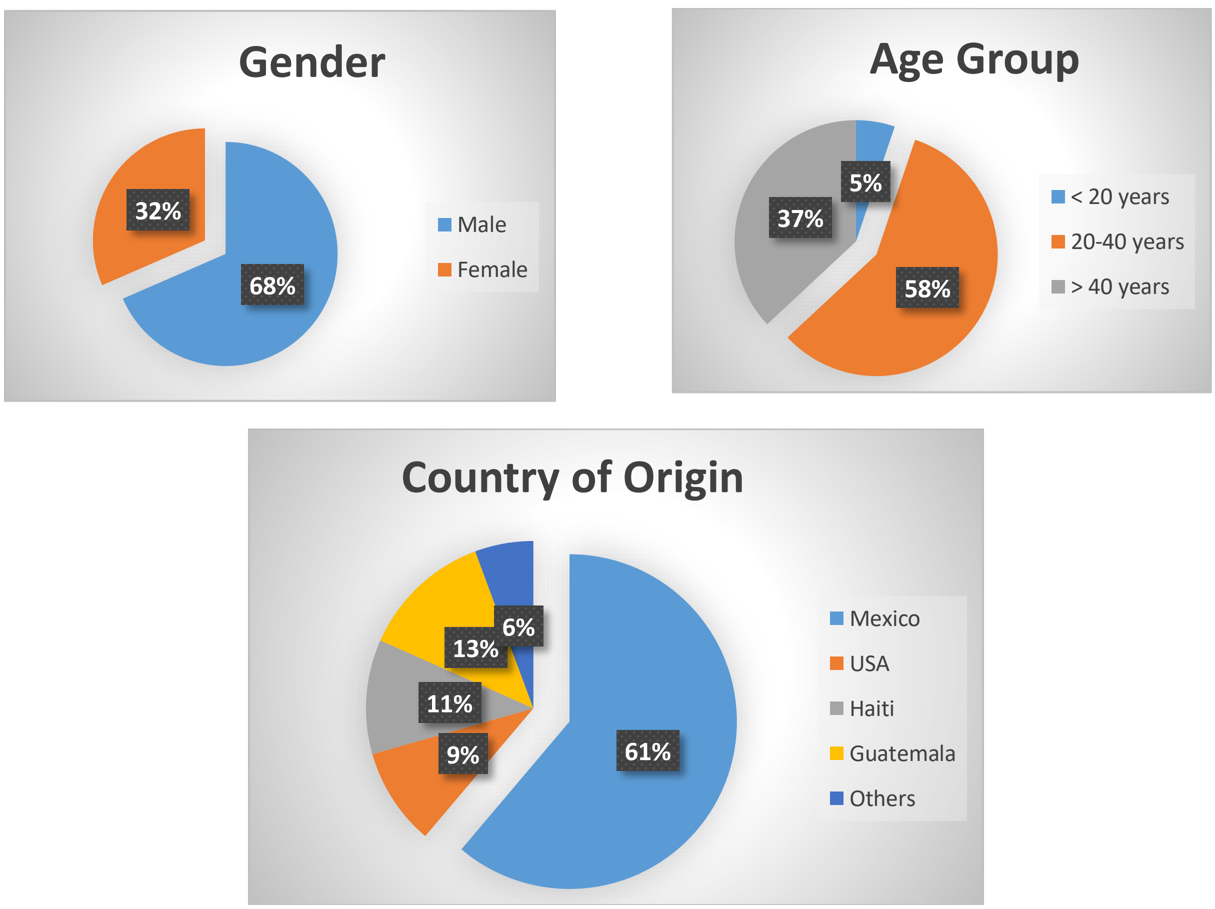

Figure 4.1: Demographic Characteristics of Crop Workers

Exposure Assessment

Three exposure metrics: daily mean temperature, daily heat index, and the daily maximum WBGT were used to assess heat-health outcomes.

Meta-Analysis

The meta-analyses of heat-related mortality studies used the daily mean temperature as the preferred metric instead of daily maximum and daily minimum temperatures because it is commonly used in heat-mortality studies. It also provides easily interpretable results, represents both day and night temperatures, and correlates more strongly with mortality than either the daily maximum or minimum temperatures.

Crop Workers

The daily heat index, combining the air temperature and the relative humidity (or dewpoint), was used in the initial HRI study among crop workers. The rationale for using the heat index instead of air temperature alone is that it is a better predictor of heat exposure, especially when work is performed outside the comfort zone (NIOSH 2016). However, it can only serve as an initial screening tool with the need for further assessment with the WBGT index (Morris et al. 2019; Tustin et al. 2018). Thus, we used the WBGT index in our final analysis of assessing the risk of HRI.

Health Outcome Assessment

Both HRI and heat-related mortality were the outcomes of interest.

Meta-Analysis

For heat-related mortality outcomes, some studies used in the meta-analysis were detailed in their methodology of identifying heat-related mortality (Hajat et al. 2007; Hashizume 2009; Urban and Kysely 2014; Bai et al. 2014; Chen et al. 2016; Zhang et al. 2017). Apart from one study that used codes from the International Classification of Disease, Ninth version, Clinical Modification (ICD-9-M) to define mortality cases (Hashizume 2009), the majority of studies used codes from the International Classification of Disease, Tenth Version (ICD-10) to define cases (Urban and Kysely 2014; Bai et al. 2014; Chen et al. 2016; Zhang et al. 2017). A study by Hajat and colleagues (2007) used ICD-9 codes for all deaths recorded in England and Wales between 1993 and 2000 and ICD-10 codes for deaths recoded from 2001-2003. The remaining studies, however, did not specify the type of coding used (Burkart et al. 2011; Diboulo et al. 2012; Lindeboom et al. 2012; Madrigano et al. 2015; Lee et al. 2016). All non-accidental deaths were examined (Bai et al. 2014; Chen et al. 2016; Zhang et al. 2017).

Crop Workers

We examined the following HRI symptoms that have been identified in the literature: skin rash, muscle cramps or spasms, dizziness or light-headedness, fainting, headache, heavy sweating, extreme weakness or fatigue, nausea, vomiting, or confusion were examined (Mirabelli et al. 2010; Arcury et al. 2015). Workers who reported two or more of these symptoms were classified as HRI cases. In addition, cases that were diagnosed explicitly by RMS physicians or nurses were also included. Most common diagnoses made in this study population included heat rash, heat exhaustion, and heat cramps. No fatal cases of heat stroke were diagnosed.

CHAPTER 5

ASSESSING HEAT-RELATED MORTALITY RISKS AMONG RURAL POPULATIONS: A SYSTEMATIC REVIEW AND META-ANALYSIS OF EPIDEMIOLOGICAL EVIDENCE

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Abstract

Most epidemiological studies of high temperature effects on mortality have focused on urban settings, while heat-related health risks in rural areas remain underexplored. To date there has been no meta-analysis of epidemiologic literature concerning heat-related mortality in rural settings. This study aims to systematically review the current literature for assessing heat-related mortality risk among rural populations. We conducted a comprehensive literature search using PubMed, Web of Science, and Google Scholar to identify articles published up to April 2018. Key selection criteria included study location, health endpoints, and study design. Fourteen studies conducted in rural areas in seven countries on four continents met the selection criteria, and eleven were included in the meta-analysis. Using the random effects model, the pooled estimates of relative risks (RRs) for all-cause and cardiovascular mortality were 1.030 (95% CI: 1.013, 1.048) and 1.111 (95% CI: 1.045, 1.181) per 1ºC increase in daily mean temperature, respectively. We found excess risks in rural settings not to be smaller than risks in urban settings. Our results suggest that rural populations, like urban populations, are also vulnerable to heat-

related mortality. Further evaluation of heat-related mortality among rural populations is warranted to develop public health interventions in rural communities.

Keywords: rural; mortality; heat-related; vulnerability; systematic review; meta-analysis

Introduction

Most epidemiological studies of the negative impacts of high temperature on human health have focused on urban settings [1-6]. However, heat-related health risks among rural populations remain underexplored. The adverse health impacts of high temperatures on urban populations have been attributed to several factors [7-9]. Of those, the urban heat island (UHI) effect, which can be defined as a phenomenon where surface temperatures in urban areas are higher than surrounding rural areas [10, 11], and heterogeneity in socioeconomic characteristics are noteworthy [9, 12].

Despite the fact that rural locations are often cooler than urban centers, rural areas may be distinctly disadvantaged in factors that increase population vulnerability to extreme weather, such as social isolation, access to health care and air conditioning and baseline health status, with some factors being markedly worse in less developed regions**.** To be able to formulate comprehensive heat-health action plans, it is imperative that we assess heat-related health risks in rural areas [14]; however, conducting risk assessments for rural settings can be challenging. Most rural areas, especially in underdeveloped countries, lack meteorological data due to a paucity of weather monitoring stations [15, 16]. Additionally, relatively small rural populations militate against epidemiologic studies with sufficient statistical power.

Moreover, the definition of rural areas remains vague and existing definitions depend on that of urban areas [17]. There is no single, universally preferred definition of rural, nor is there a single rural definition that can serve all policy purposes [18]. Thus, a rural area defined in a developed nation may differ from another in a less developed country in terms of metrics of population density, infrastructure and resources.

Even though fewer studies have examined the temperature-mortality relationship in rural areas, some studies in this category have reported that people in less urban areas may be more susceptible to heat [16, 19-21]. There is also emerging evidence regarding high rates of heat-related illness in rural areas [22]. Overall, vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity [23], making isolated rural populations with inadequate infrastructure likely to be more vulnerable to heat-related mortality. However, no study to date has systematically assessed the current global epidemiologic evidence related to rural vulnerability to summer heat in the peer-reviewed heat-related mortality literature.

The goal of this study was thus to conduct a systematic review of the epidemiologic literature of the association between high temperature and mortality in rural populations and generate the synthesis of results from different studies across the globe, using meta-analysis to examine rural vulnerability to heat-related mortality worldwide.

Materials and Methods

Search Strategy and Screening Criteria. We conducted a systematic literature review in April 2016 and revisited the literature in May 2017, and again in April 2018 to update our search. We used scientific peer-reviewed search engines PubMed, Web of Science and Google Scholar with no restriction on the geographical location or period of publication. Keywords used for this review were: **(Rural OR “non-urban”) AND (high temperature OR heat OR hot weather OR climate) AND (mortality OR deaths) AND (relative risk OR risk ratio OR**

effect measure OR change OR "RR"). There were no restrictions on publication date or location of studies.

We manually screened the abstracts of all studies selected initially located through the search and excluded the following:

1. studies not published in English;

2. studies not performed on human populations (non-epidemiological studies);

3. studies reporting no effect estimates (i.e., relative risks [RRs] or % change in mortality) those reporting effect estimates only for subpopulation, such as the elderly, but not for the entire population in the study area;

4. commentaries, review articles and editorials;

5. studies on morbidity; and

6. studies focusing on extreme temperature (heat waves), due to their inconsistent definitions [24, 25] and occurrence within short time periods [26].

Data Extraction. The effect estimate (RR or % change in mortality) reported in each study was extracted. When effect estimates for multiple lag periods were reported in a study, we selected the estimate for the shortest lag period, usually 0-1 day, due to the acute nature of high temperature effects [26]. Studies have reported that longer lag periods are likely to result in overestimation of the effects, especially when distributed lag non-linear models (DLNMs) are used [27, 28]. Due to differences in temperature metrics, studies that used mean daily temperatures were separated from those that used daily maximum temperatures. We normalized and converted all effect estimates and their 95% confidence intervals (CIs) into relative risks per Celsius degree (RRs per °C) increase in temperature for unification purposes, to be able to combine them into an overall RR estimate. The random effects model, which assumes that different studies were drawn from different populations with unique conditions that could impact on the treatment (i.e., temperature) effect, was preferred to the fixed effects model since each study was conducted in a different rural setting and under different conditions. Moreover, the random-effects model ensures that the different effect sizes in all studies are represented in the summary estimate [29].

We further stratified the selected studies into groups based on their level of development, per the United Nations' classification system [30]. According to the Development Policy and Analysis Division (DPAD) of the Department of Economic and Social Affairs in the United Nations Secretariat, all countries can be classified into one of these broad categories based on the prevailing economic conditions: developed economies, economies in transition, and developing economies. We then performed a sensitivity analysis to examine whether the level of development was a factor that affects the association between high temperature and mortality.

Both the Cochran's Q and the I^2 statistics can be used to determine statistical heterogeneity in the results. The Cochran's Q, calculated as the weighted sum of squared differences between individual study effects and the pooled or summarized effect across studies, is the traditional measure of heterogeneity, while the I^2 statistic explains percentage of variation across studies that is due to heterogeneity rather than chance [31, 32]. The relationship can be summarized by the equation: $I^2 = 100\% \text{ x } (Q\text{-}df)/Q$; where df is the degrees of freedom, defined as the number of studies used minus 1. For this study, we relied on the I^2 statistics, since it is more interpretable, provides more accurate estimates, and is more independent of the number of studies used in the analysis than the Cochran's Q [32]. All statistical analysis was performed using Comprehensive Meta-Analysis software (Version 3.0, Biostat, Englewood, NJ, USA).

Results

The literature search generated 479 studies. Figure 5.1 presents the selection and exclusion of studies. Among the 459 studies retained based on the first two exclusion criteria, 252 studies were excluded because they studied morbidity instead of mortality. Among the 207 remaining studies, 45 were excluded because they relied on climate variables other than temperature, and 36 were excluded because they focused on interventions and evaluations. The remaining 126 studies were also scrutinized: 46 on other causes of mortality not related to heat, 27 with no effect estimates, 18 on heat waves and eight duplicated studies were all excluded. Further, seven systematic reviews, commentaries and editorials and six studies conducted in non-rural settings were also excluded. As a result, 14 studies that examined the effects of high ambient temperature on mortality were identified. Table 5.1 presents the characteristics of these 14 studies. All studies were published in the last eleven years between 2006 and 2017. Two studies were conducted in North America (United States), two in Europe (England and Wales, Czech Republic), eight in Asia (China, Bangladesh, India), and two in Africa (Ghana, Burkina Faso). Among the 14 studies identified, eleven used daily mean for temperature metric, two used daily maximum and one used weekly mean (Table 5.1). In conducting the meta-analysis, we only included the eleven studies that used daily mean temperature since the remaining two temperature metric groups contained insufficient numbers of studies. The geographical locations of these eleven studies are shown in Figure 5.2.

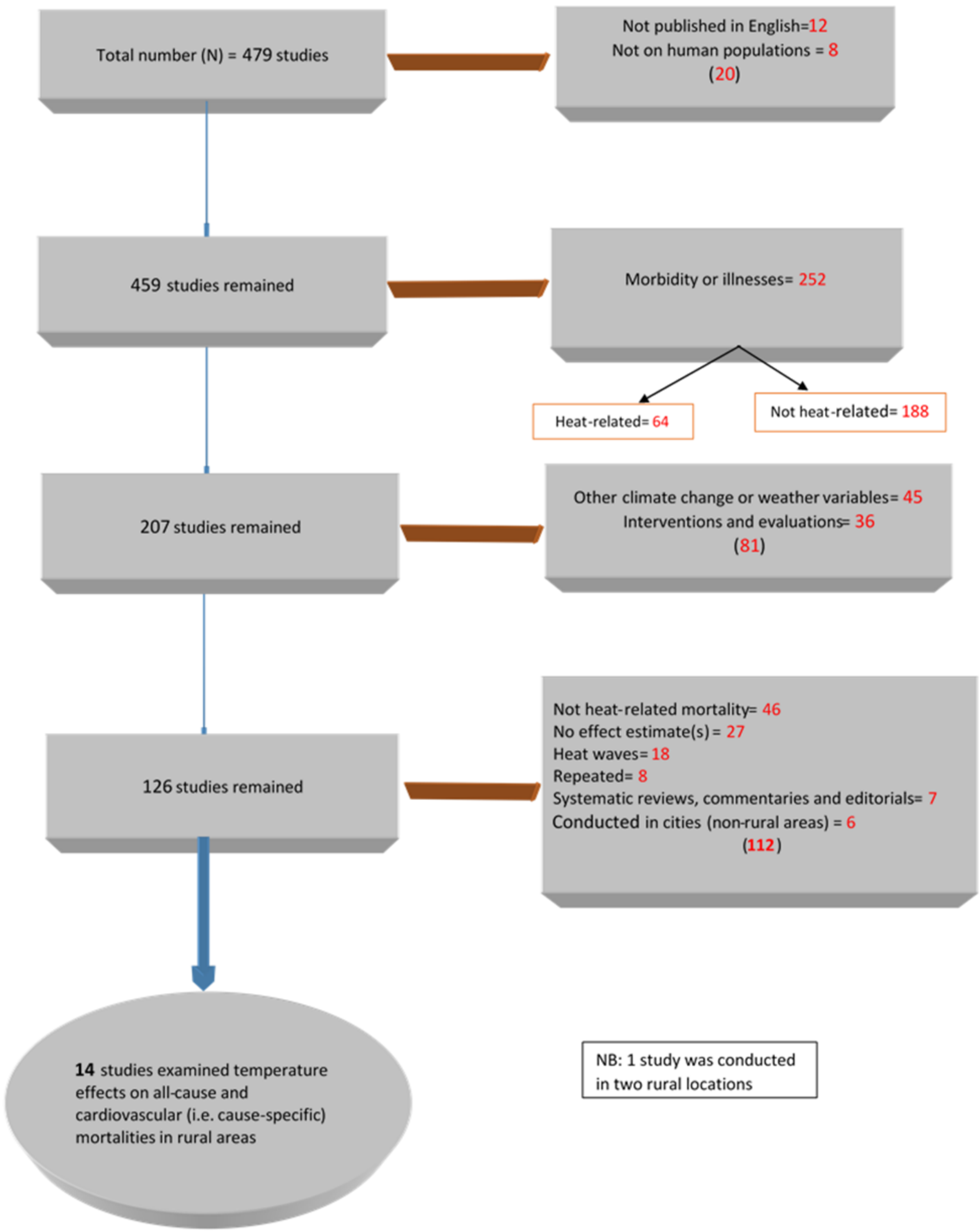
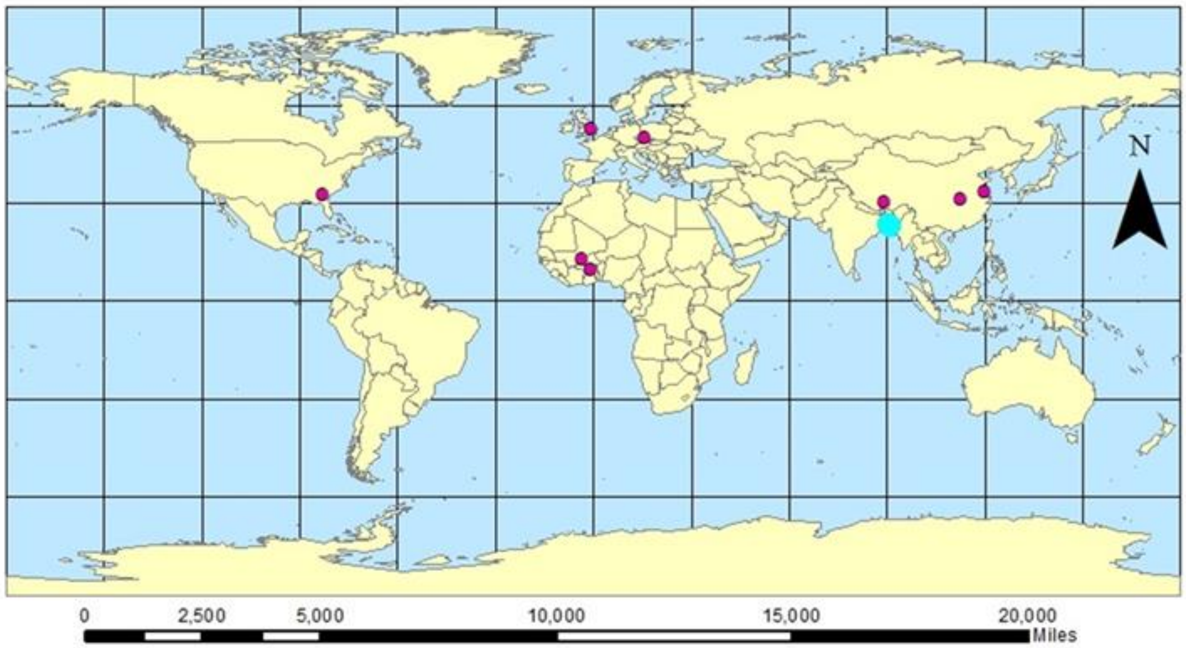


Figure 5.1. Flow Chart Illustrating Study Selection

Studies (Year published)	Study Period	Location	Effect Estimate [RR per °C (95% CI)]	Potential Confounding Factors	Temperature Threshold (°C)	Mortality Outcome (s)	Study Population	Lag Period (days)
Studies using daily mean temperature								
Hajat et al (2007) [33]	1993-2003	England & Wales	1.020 (1.010, 1.030)	Ozone, $PM_{2.5}$, seasonal varying factors, influenza epidemics	17-18	All-cause	N/A	0-1
Hashizume et al (2009) [15]	1994-2002	Matlab, Bangladesh	1.629 (1.232, 2.152)	Seasonality	30	Cardiovascular	220,000	0-1
Burkart et al (2011) [34]	2003-2007	Bangladesh	1.044 (0.990, 1.098)	Trend, season, day of the month and age	28.9	All-cause	~1,000,000	0-1
Diboulo et al (2012) [35]	1999-2009	Nouna, Burkina Faso	1.026 (1.001, 1.052)	Time trends and seasonality	30	All-cause	90,000	0-1
Lindeboom et al (2012) [36]	1983-2009	Matlab, Bangladesh	1.002 (1.001, 1.003)	Trend and seasonality	29	All-cause	225,002	0-1
Azongo et al (2012) [37]	1995-2010	Northern Ghana	1.018 (1.007, 1.029)	Time trends and seasonality	30.7	All-cause	N/A	0-1
Urban et al (2014) [38]	1994-2009	Czech Republic	1.085 (1.05, 1.12)	Winter days during six epidemics	23.5	Cardiovascular	3,400,000	N/A
Bai et al (2014) [39] Bai et al (2014) *	2008-2012 2008-2012	Naidong (Tibet), China Jiangzi (Tibet), China	1.047 (0.181, 1.144) 1.063 (0.167, 2.020) 1.037 (0.222, 1.121) 1.134 (0.206, 2.217)	Seasonality and long-term trend Seasonality and long-term trend	15.3 11.8	All-cause and cardiovascular All-cause and cardiovascular	N/A N/A	0-1 0-1
Chen et al (2016) [20]	2009-2013	Jiangsu Province, China	1.032 (1.028, 1.037)	Long-term trends and seasonality	24.1	All-cause	73,900,000	N/A
Lee et al (2016) [16]	2007-2011	Georgia, North & South Carolina, U.S.	1.021 (0.995, 1.047)	$PM_{2.5}$, age, race education, rural location	28.0	All-cause	N/A	N/A
Zhang et al (2017) [40]	2009-2012	Hubei, China	1.14 (1.02, 1.26)	Long-term and seasonal trends	27.7	All-cause	6,700,000	0-2
Studies using daily maximum temperature								
Ingole et al (2015) [41]	2003-2012	Vadu, India	1.36 (1.30, 1.42)	Day of the week, secular trends and other time-varying confounding factors	39.0	All-cause	131, 545	0
Madrigano et al (2015) [42]	1988-1999	New York, New Jersey, Connecticut, U.S.	1.007 (1.006, 1.008)	Ozone	21.1	All-cause	N/A	N/A
Studies using weekly mean temperature								
Alam et al (2012) [43]	1983-2009	Abhoynagar, Bangladesh	1.0 (no risk)	Rainfall	23.0	All-cause	34,774	0-3 weeks

Table 5.1. *Characteristics of Selected Studies That Examined Temperature Effects on All-cause and Cause-specific Mortality *Same study in 2 locations*



Green dot represents all 3 studies conducted in Bangladesh (i.e., same location)
Figure 5.2. Rural Locations Covered in This Study

Meta-analysis. We conducted two separate meta-analyses for studies examining the relationship between daily mean temperature and (1) all-cause mortality (Figure 5.3), and (2) cardiovascular mortality (Figure 5.4), respectively.

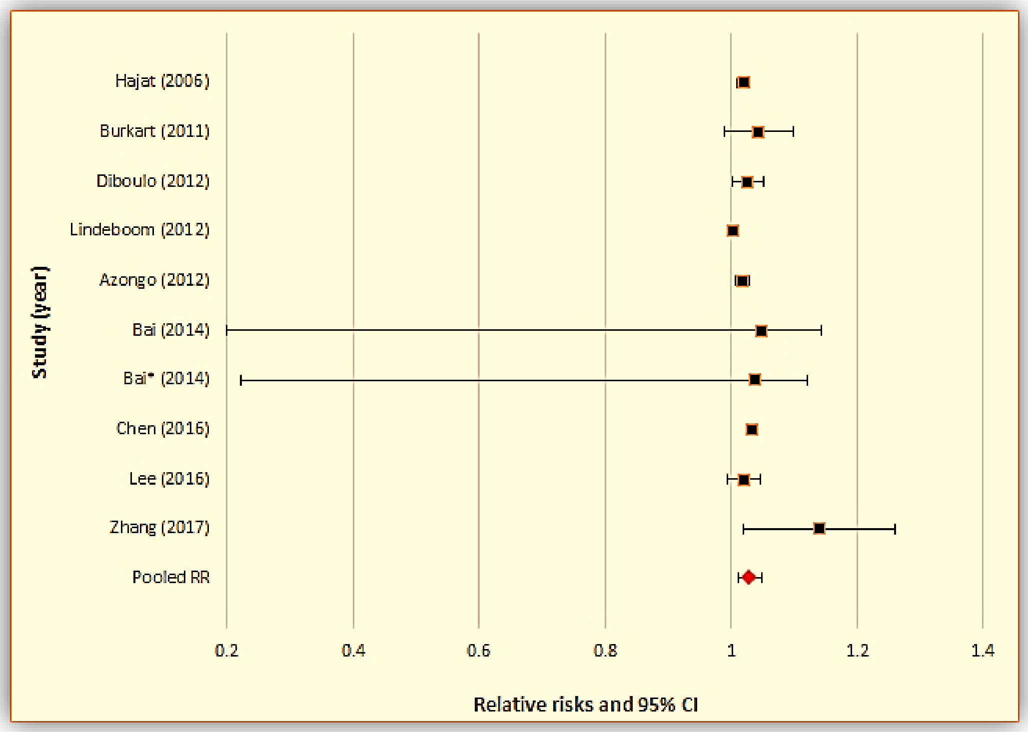


Figure 5.3. Meta-analysis Results for Studies Using Daily Mean Temperature for All-cause Mortality.

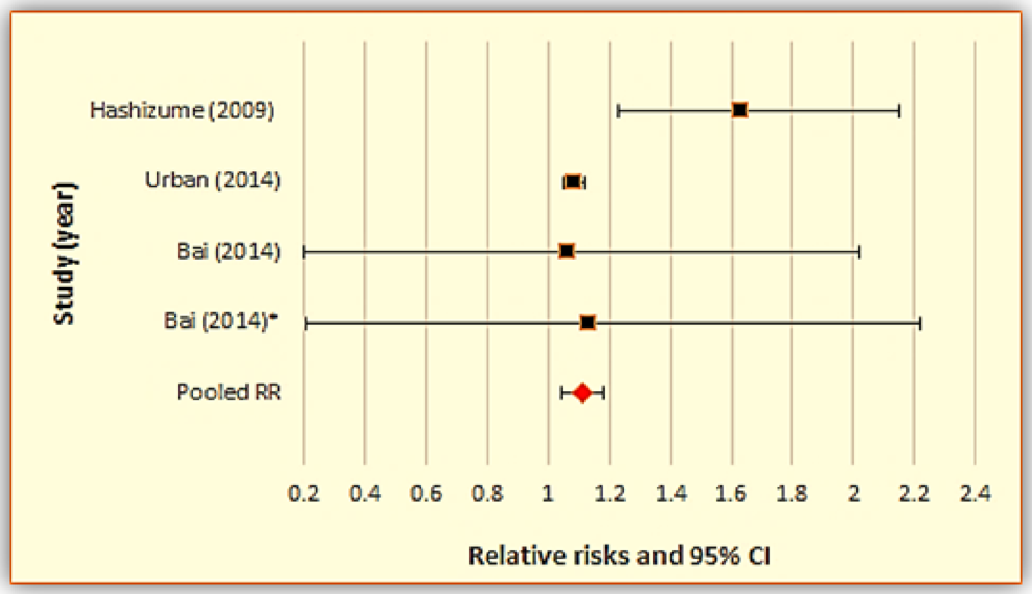


Figure 5.4. Meta-analysis Results for Studies Using Daily Mean Temperature for Cardiovascular Mortality.

Table 5.2. Effect Size Estimates of Studies Using Daily Mean Temperature for All-cause Mortality

Study (Year)	Location (Country)	Effect Size [95% Confidence Interval]			% Weight
Hajat (2007)	England & Wales	1.020	1.010	1.030	14.20
Burkart (2011)	Bangladesh	1.044	0.990	1.098	6.43
Diboulo (2012)	Nouna, Burkina Faso	1.026	1.001	1.052	11.72
Lindeboom (2012)	Matlab, Bangladesh	1.002	1.001	1.003	14.86
Azongo (2012)	Northern Ghana	1.018	1.007	1.029	14.06
Bai (2014)	Naidong, China	1.047	0.20	1.144	2.75
Bai* (2014)	Jiangzi, China	1.037	0.222	1.121	3.52
Chen (2016)	Jiangsu Province, China	1.032	1.028	1.037	14.35
Lee (2016)	Southeast U.S.	1.021	0.995	1.047	13.77
Zhang (2017)	Hubei, China	1.140	1.020	1.260	4.35
Pooled (I^2= 0.0%; p= 0.001)		1.030	1.013	1.048	100

Note: Weights are from random effects analysis.

Table 5.3. Effect Size Estimates of Studies Using Daily Mean Temperature for Cardiovascular Mortality

Study (Year)	Location	Effect Size [95% Confidence Interval]			% Weight
Hashizume (2009)	Matlab, Bangladesh	1.629	1.232	2.152	5.10
Urban (2014)	Czech Republic	1.085	1.05	1.12	32.28
Bai (2014)	Naidong, China	1.063	0.20	2.02	23.80
Bai (2014)*	Jiangzi, China	1.134	0.206	2.217	38.82
Pooled (I^2= 59.4%; p= 0.001)		1.111	1.045	1.181	100

Note. Weights are from random effects analysis.

The combined relative risks (RRs) for all-cause and cardiovascular mortality were, 1.030 (95% CI: 1.013, 1.048) and 1.111 (1.045, 1.181) per 1°C increase in mean daily temperature respectively. This means that in predominantly rural locations, every 1°C increase in mean daily temperature is associated with 3.0% excess mortality and 11.1% excess cardiovascular mortality. Also, the I^2 statistics for all-cause and cardiovascular mortality were 0.0% ($p< 0.01$) and 59.4% ($p< 0.01$), respectively, indicating no observed heterogeneity between the all-cause mortality studies and considerable heterogeneity among the cardiovascular mortality studies ($I^2> 50\%$).

Sensitivity Analysis. In addition to grouping studies based on their mortality outcomes (i.e., all-cause and cardiovascular mortality), we also stratified studies into two categories based on the level of economic development of the study nation: developed and developing countries using the United Nations' country classification [30]. None of the selected studies were in countries with transition economies based on the UN classification. The United States and United Kingdom fall into the developed country category and were separated from studies conducted in the remaining countries, all classified as developing countries. A sensitivity analysis was then performed within the developing and developed country groups (Figures 5.6 and 5.7). The results show that the excess mortality risk was higher among developing nations (3.6%) than developed nations (2.0%), although there were only two studies in the developed nation group (Tables 5.4 and 5.5).

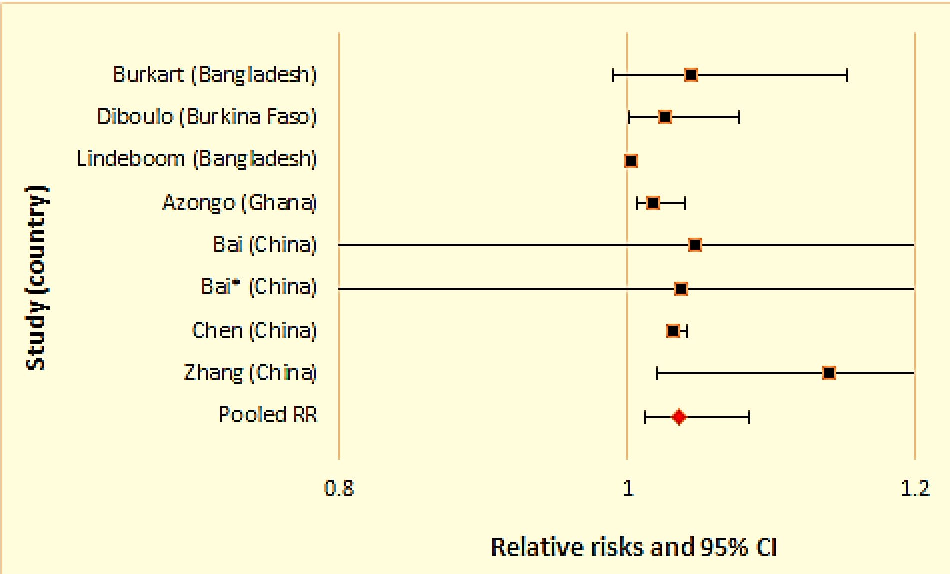


Figure 5.5. Sensitivity analysis for Studies Conducted in Developing Countries

Table 5.4. Effect Size Estimates of Studies in Developing Countries

Study (Country)	**Effect size [95% Confidence Interval]**			**% Weight**
Burkart (Bangladesh)	1.044	0.99	1.098	18.29
Diboulo (Burkina Faso)	1.026	1.001	1.052	4.79
Lindeboom (Bangladesh)	1.002	1.001	1.003	5.99
Azongo (Ghana)	1.018	1.007	1.029	10.08
Bai (China)	1.047	0.200	1.144	18.55
Bai* (China)	1.037	0.222	1.121	16.09
Chen (China)	1.032	1.028	1.037	18.99
Zhang (China)	1.14	1.020	1.260	7.23
Pooled (I^2= 0.0%; p= 0.004)	**1.036**	**1.012**	**1.061**	**100**

Note: Weights are from random effects analysis.

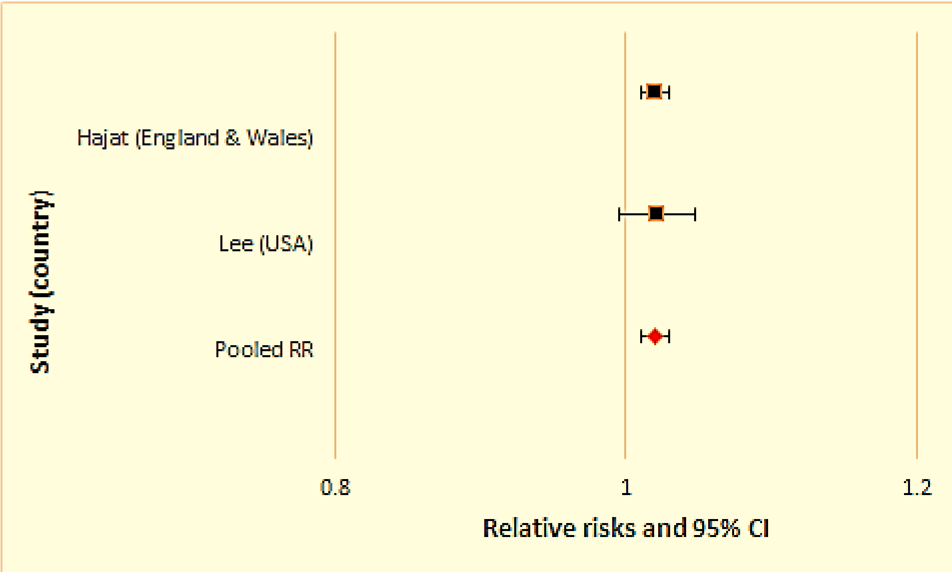


Figure 5.6. Sensitivity Analysis for Studies Conducted in Developed Countries

Table 5.5 Effect Size Estimates of Studies in Developed Countries

Study (Country)	**Effect size**	**[95% Confidence Interval]**		**% Weight**
Hajat (England & Wales)	1.020	1.010	1.030	87.1
Lee (USA)	1.021	0.995	1.047	12.9
Pooled (I^2=0.0%; p= 0.000)	**1.02**	**1.011**	**1.03**	**100**

Note. Weights are from random effects analysis.

Discussion

Global epidemiological studies of the association between high temperature and mortality have been primarily focused on urban areas, whereas fewer studies have examined nonurban areas to date. To the best of our knowledge, this is the first meta-analysis of heat-related mortality risks in rural locations worldwide. In this study, we focused on the endpoints of all-cause and cardiovascular mortality. We did not include studies of excess mortality during short-term heat waves, typically lasting a few days or weeks, owing to their inconsistent definitions, designs and methods [24, 25]. For the studies included in our meta-analysis, the duration of observations ranged from 4 to 27 years (median = 7 years).

The selected studies used consistent definitions and research designs in which daily mortality was regressed on daily mean temperature. Daily mean temperature is a very useful metric of heat exposure in assessing the temperature-mortality relationship [27, 44]. Apart from its ability to provide easily interpretable results, it best represents the temperature exposure throughout the whole day and night [45, 46]. A study of ambient temperature and mortality in Wuhan, China suggested that daily mean temperature was the best temperature metric for predicting temperature effects on cause-specific mortality [28]. Further support for use of this metric is that it has the lowest Akaike's information criterion for quasi-Poisson (Q-AIC) values, making it a better predictor than the maximum and minimum temperatures [39]; correlates more strongly with mortality than either T_{max} or T_{min} [15]; and shows coherent behavior with respect to mortality at both low and high temperatures [37]. Moreover, it is less prone to measurement error [37]. Interestingly, other studies [20, 47] reported similar results regardless of the temperature metric used.

In controlling for potential confounding factors, most studies selected adjusted for seasonality and time trends. Only a few adjusted for other environmental hazards, such as air pollutants, consistent with the observation of Madrigano [42] that not all studies adjust for ozone as a confounding factor when assessing temperature-mortality relationships. Exposure to ambient air pollutants, mainly particulate matter (PM) and ozone, have been linked to premature mortality [48], and thus may confound the temperature-mortality association [26, 49]. Ozone is a summer pollutant and climate change is projected to detrimentally affect ozone air quality and consequently increase mortality [50]. The observed correlations of PM concentrations with temperature are weaker than for ozone [51], yet PM has been found to peak in the summer in certain regions, such as the East Coast of the U.S. [26]. Therefore, PM also may be a confounder for the association between temperature and mortality in these regions. Noting that air pollutants and temperature have different biological effects, Guo [47] posited that their effects are likely to be independent of each other. In summary, the results for confounding or effect modification by air pollutants on the temperature-mortality relationship remain mixed [26].

Our results indicate evidence of heat vulnerability in rural areas. We estimated a 3% excess in all-cause mortality and an 11% excess in cardiovascular mortality to be associated with a 1°C increase in mean ambient temperature. In comparing the excess heat-related mortality risk with studies in the world's urban centers, we used the relative risks from a review [24] and illustrate the RRs in Figure A1 in Appendix 1. As shown in Figure A1, for all-cause mortality RRs per 1°C increase in large urban areas ranged from 1.00 to 1.17, with more than half of the estimates falling into the range of 1.01-1.03. Therefore, the excess risks in rural areas are similar to those in urban areas.

Our results suggest that rural residents may not be less vulnerable to heat than urban residents. Rural populations may benefit from the absence of extreme heat or "heat island" in rural environments, attributable to larger numbers of water bodies, trees, greenery fields and lower population density [36]. On the other hand, heat vulnerability is not only a product of heat exposure factors but more importantly, sensitivity and adaptive capacity [52]. Among rural inhabitants, marked differences exist in the components of heat vulnerability, such as lack of health care infrastructure and access to air conditioning, social isolation, informal settlements, and worse baseline health status. Moreover, certain occupational groups usually residing in rural areas such as agricultural workers, who spend a great deal of time exposed to extreme temperatures, may be a factor that contributes to increased susceptibility of rural populations to heat.

Lindeboom et al. [36] noted the possibility of gradual acclimatization as communities adapt to living in warmer climates. Generally, populations in regions within the tropical zone are better acclimatized and less sensitive to heat compared to those in the mid-latitude or temperate zones. This is apparent in higher temperature thresholds observed in tropical climates such as the Northern part of Ghana with a threshold above 30°C [37]. Other tropical places in Nouna, Burkina Faso [35] and Bangladesh [15, 34, 36] had similarly high temperature thresholds (see Table 1). Temperature thresholds for locations in the mid-latitudes were lower. In the southern part of the U.S., classified as the warmest region in the country [53], temperatures above 28°C increased mortality [16]. The thresholds were even much lower for Hubei [40], Jiangsu [20], and Tibet [39] provinces in China. Even though rural residents in tropical countries seem better acclimatized to warm climates [35], their low adaptive capacity due to limited resources to cope with heat [15, 36, 37, 39] increases their vulnerability. For instance, most houses in rural Matlab Bangladesh were described as "roofed and walled with corrugated iron sheets" [36], making residents more prone to heat effects. Issues of informal settlements [37], common in rural areas of developing countries, can lead to overcrowding, thus impeding adequate ventilation and increasing pressure on the limited rural health resources.

Some studies computed the heat vulnerability index by controlling for effect modifiers such as the average years of education, percentage of people ≥ 65 years old, number of air conditioning units per household, number of beds in health institutions per 1,000 people [20], rurality and deprivation [33]. Chen et al. [20] found a significant negative correlation between urbanicity and the heat vulnerability index in Jiangsu Province, China, while a study conducted in England and Wales found no correlation [33]. Previous studies have also found higher heat-related mortality risks in individuals with lower or no education [20, 39, 40], lower prevalence of air conditioning [1, 20], as well as dependence upon inadequate hospital infrastructure [20, 40]. A majority of these individuals reside in rural areas.

There were inconsistencies in the definitions of rural areas across studies. Some studies just mentioned “rural” with no definition. Within the United States, for example, the Census Bureau’s definition of “rural” varies state-to-state and overall is mainly described as simply “not urban”, which is quite subjective. Further, the character of “rural” regions may depend greatly upon a country’s level of economic development, per the United Nations’ classification system [30]. To explore this point, a separate sensitivity analysis was conducted for developed and developing countries as shown in Figures 5.5 and 5.6. Heat-related mortality risk was higher in developing countries as compared to developed countries (i.e., 3.6% and 2.0%, respectively), consistent with the lack of infrastructure in developing countries.

We acknowledge additional limitations of this study. Our comprehensive search of international epidemiological studies on the association between temperature and mortality only identified 14 studies, with the same temperature metric (daily mean) being used in eleven studies. The lack of meteorological data attributed to the paucity of weather stations in rural locations may have contributed to the limited number of studies we used for the meta-analyses. A further implication of widely spaced monitoring stations is that the exposure variable will not capture dynamic changes in temperature that occur in space, resulting in misclassification of exposure [16]. This misclassification is almost certain to be nondifferential (“random”) with respect to the outcome variable, mortality. Thus biased toward the null, relative risks derived from studies included in our meta-analysis may underestimate the true magnitude of heat’s effect on mortality.

With respect to the outcome variable, patterns of mortality in response to extreme heat are influenced by the underlying prevalence of temperature-sensitive diseases in a population. Epidemiologic studies of the impacts of extreme heat are most likely to find statistically significant increases in diseases that are already common. Although more common in urban areas, cardiovascular disease is a leading cause of death in rural areas world-wide [22]. Small increases above large, stable baseline rates – if caused by heat – are more likely to be detectable by statistical significance testing. None of the studies we reviewed differentiated among the various causes of death due to cardiovascular disease (i.e., stroke, MI, etc.), an area ripe for further investigation.

In addition, although respiratory mortality may be another potential outcome of interest, the current evidence concerning the association between heat and respiratory mortality is relatively weak. For instance, Hashizume et al. [15] found an increase in respiratory mortality only at low temperatures, unrelated to heat. In their study encompassing a 16-year period, Azongo et al. [37] inferred that respiratory deaths in children were only tangentially related to heat, and more directly related to periods of high precipitation (along with diarrhea and malaria).

Conclusions

This study assessed heat-related mortality risks among rural populations worldwide through a comprehensive review of epidemiologic literature and meta-analysis. Fourteen epidemiological studies of the association between high temperature and mortality among rural populations were identified. These studies were conducted in eight countries on four continents between 2006 and 2017. Among the 14 studies, eleven using daily mean metric for temperature were included in the random effects meta-analysis. The pooled estimates of relative risks (RRs) for all-cause and cardiovascular mortality were 1.030 (95% CI: 1.013, 1.048) and 1.111 (95% 2CI: 1.045, 1.181) per 1°C increase in daily mean temperature, respectively. We found considerable heterogeneity in studies for cardiovascular mortality (I^2 = 59.4%, p< 0.01), but not for all-cause mortality (I^2 = 0%, p< 0.01). The combined risk of excess heat-related mortality in rural populations appears to be not smaller than those reported in urban populations, suggesting that being a rural resident does not make one less vulnerable to heat. We also found higher excess mortality risks among developing nations than developed ones although this may not be statistically significant considering the limited number of studies used.

A key limitation of this study is the relatively small number of available studies focusing on rural populations worldwide. Lower population density and more dispersed weather stations are some of the factors that challenge quantitative studies of the relationship between temperature and mortality in rural areas [54]. Rural areas may also struggle with incomplete death registration, particularly in less developed regions [55]. However, further investigations of heat-related mortality in rural populations are certainly warranted. Future studies could also examine other causes of death, such as respiratory causes and HRI, all aimed at developing better public health interventions for heat risk management in rural areas.

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CHAPTER 6

HEAT-RELATED ILLNESS AMONG CROP WORKERS IN NORTHEAST TENNESSEE: THE ROLE OF THE OUTDOOR WORK ENVIRONMENT

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Abstract

Extreme temperatures are of increasing importance for the health and safety of outdoor workers. Heat-related illness (HRI) is of special concern in southeastern United States for crop workers whose heat exposures are known to be high in frequency, duration and intensity. This study aims at quantifying the prevalence of HRI among crop workers in Northeast Tennessee, and assessing the role of the outdoor work environment in HRI. Cross-sectional data were collected at 16 health screening events of a migrant health center held on or near tomato farms in northeast Tennessee during the summers of 2014, 2015 and 2016 (N= 425 encounters). HRI diagnosed by physicians and nurses, along with cases identified by having two or more HRI signs and symptoms, were counted and analyzed. Daily values of the heat index (HI) were estimated using high quality sources of weather data. Logistic regression analysis was completed to compare risk of HRI between outdoor and indoor workers. Associations between HRI prevalence and HI were assessed by curve-fitting using 0- and 1-day lag periods. The prevalence of HRI was 18.8% (55 cases) and 10.7% (12 cases) in outdoor and indoor crop workers, respectively. The odds that given one has HRI, they are 1.6 times more likely to work outdoors

[OR= 1.570 (95% CI: 0.762, 3.273)]. HRI prevalence had a stronger correlation with same day HI (lag 0) than with the previous workday's HI (lag 1). Scatter plots and regression coefficients for HRI prevalence and HI showed statistically significant correlations among outdoor workers but not for indoor workers. For outdoor workers, the trend line showed increasing rates of HRI above the occupational heat index threshold (85° F) while the trend line for indoor workers showed a slight increase in HRI rate above the threshold until 90°F, and then a decline in HRI rates likely due to modification of the work environment. The outdoor work environment is significantly associated with HRI. While indoor heat exposures can be reduced by modifying the work environment, such options cannot be applied to the outdoor work environment. Routine health screenings conducted by migrant health programs in the summer months afford opportunities for surveillance and potential interventions to reduce HRIs in outdoor crop workers.

Introduction

Agriculture, classified by the United Nations Food and Agriculture Organization as a rural job with poor working conditions, remains one of the most hazardous and stressful occupations.[1, 2] Due to the nature of farm work, workers encounter many physical, chemical, mechanical, ergonomic and weather or climate-related hazards.[3]

According to the National Center for Farmworker Health, heat stress is one of the commonly reported disorders among the estimated three million farm workers in the United States.[4] HRI is a serious health concern to agricultural workers who have a heat-related fatality risk 35 times higher than those in other industries.[5] Temporary workers, especially Migrant and Seasonal Farmworkers (MSFWs), remain vulnerable to heat effects due to the "use and dispose" nature of their jobs. OSHA issued eleven heat-related citations across American industry in 2013, with some cases involving temporary employees.[6, 7]

HRIs are preventable health conditions ranging from mild forms such as heat rash or cramps, to potentially fatal heat stroke.[8-10] The Centers for Disease Control and Prevention has identified two main contributors to heat stress in outdoor farmworkers: (1) internal metabolic heat generated by exertion or intense physical labor due to the nature of farm work, and (2) environmental heat due to the external conditions. Environmental conditions, including high heat index due to high temperature and humidity, as well as wearing heavy clothing, lack of appropriate rest regimens and not drinking adequate water can exacerbate metabolic heat.[11] The National Institute for Occupational Safety and Health (NIOSH) reported a total of 423 deaths attributable to occupational heat exposure in the United States from 1992 to 2006. Approximately one-quarter of these deaths were from farm-related activities. Another NIOSH analysis looked at 232 heat-related deaths recorded by the Census of Fatal Occupational Injuries from 2003 through 2009. An estimated 90% of these deaths occurred in summer, with more than half in southern states including Tennessee.[11, 12]

Economically disadvantaged workers, including MSFWs, are particularly vulnerable to heat stress. The majority are immigrants, with limited English proficiency, lacking access to quality health care due to living in isolated rural communities. They often live in poor housing facilities without air conditioning and fans.[13-15] Yet, few studies have examined HRI and the role of the outdoor work environment in MSFWs. Arcury and colleagues[16] examined heat exposure, HRI and behaviors in 101 Latino crop workers and found several exposure and task measures associated with experiencing HRI while working outdoors: working in work clothes and shoes, extremely hot weather conditions, and harvesting and topping tobacco in the previous three days.

Bethel and Harger[17] studied HRI in Oregon farmworkers and reported that almost 30% of these workers experienced at least two symptoms of HRI in the previous week. In another cross-sectional study of 300 Latino men, Mirabelli et al.[18] found that 40% of those working in extreme heat experienced symptoms of HRI at some point in their lifetime.

There are an estimated 166 migrant health programs affiliated with federally funded community health centers in the United States, providing primary care to the migrant farmworker population.[19] Although routine utilization may be as low as 20%[20], many of these programs conduct health screenings for agricultural workers during the hot summer months. Here, in the context of a decade-long campus-community partnership,[21, 22] we analyze several years of data routinely collected at summer health screenings of tomato workers, along with high quality weather data, with an eye toward assessing the risk of heat-related illness. Health outcome and exposure data were used to: 1) estimate the prevalence of HRI among MSFWs in northeast Tennessee; and 2) explore the role or contribution of the outdoor work environment to HRI.

Materials and Methods

Participants. Participants in this study are crop workers working on tomato farms located in Cocke, Greene and Hamblen counties in northeast Tennessee (Figure 1). A total of 425 clinical encounters with crop workers at summer health screenings comprise the data set. Most of these workers are from Mexico, had worked in agriculture for more than 10 years and receive primary medical care from Rural Medical Services (RMS), a community and migrant health center with primary care clinics in northeast Tennessee. The RMS Migrant Health Program provides health education and outreach to farmworkers including free health screening events at farms and farmworker housing areas.[23]

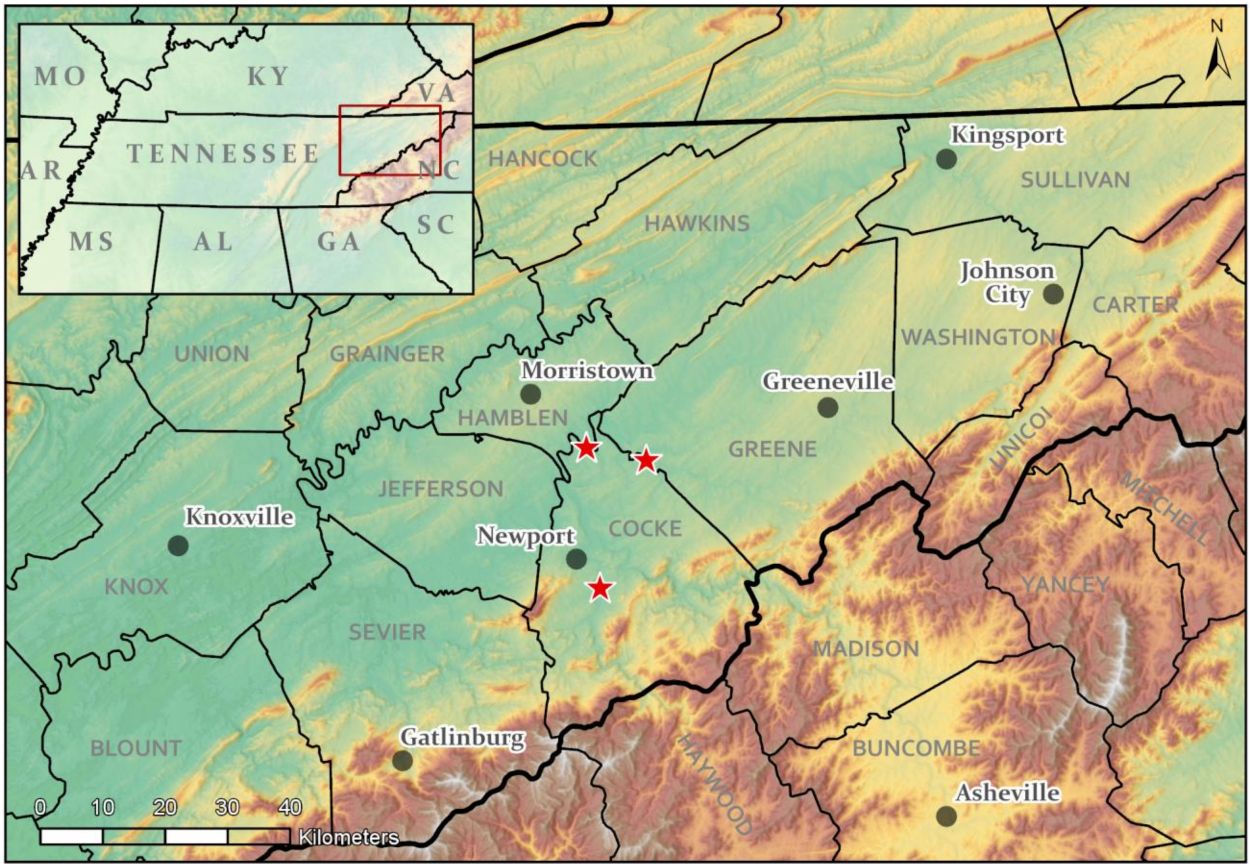

Figure 6.1. Map Showing Farm Locations in Northeast Tennessee

Survey Instrument and Measures. Occupational health questions, designed as a partnership activity, were incorporated into RMS's standard screening intake forms, administered by trained, bilingual social service and clinical professionals. The forms include questions on HRI, demographics, work history and current job tasks and conditions, along with clinical data and diagnoses made by clinicians, and lifestyle or behavioral factors that impact health. To examine symptoms of HRI, participants reported after their work shifts whether they were experiencing any of the following symptoms: skin rash, muscle cramps or spasms, dizziness or light-headedness, fainting, headache, heavy sweating, extreme weakness or fatigue, nausea, vomiting, or confusion.[16, 18] Two or more of these symptoms constituted our case definition HRI. Also included were cases in which an RMS physician or nurse made an explicit diagnosis of HRI.

Environmental Data. The Parameter-elevation Regressions on Independent Slopes Model (PRISM), regarded as a high-quality spatial data model in the United States, was used to obtain daily minimum, mean, and maximum temperatures and mean dew point values at our specific farm locations. This methodology was also informed by the paucity of weather stations near these locations.[24] The online tool for heat index calculation developed by the National Weather Service was used to estimate heat index values[25] ranging within 82-101°F.

Data Collection/Analysis. Data collected from the intake forms on 16 screening days in the summers of 2014, 2015, and 2016 was entered in Excel spreadsheets. Descriptive analysis was performed using both demographic and occupational characteristics of workers. The chi-square test was also used to assess significant associations within each predictor variable. The multivariate logistic regression with SAS 9.4 (SAS Cary, NC) utilized the model:

HRI (yes/no) = *Age group + Gender + Work environment (outdoor/indoor) + heat safety training + years worked in agriculture + heat index*

Odd ratios were generated for each predictor variable in association with the outcome variable (i.e., HRI). Curve-fitting using quadratic polynomials by The Scientific Python Development Environment (SPYDER 3.7) was done to assess the relationships between HRI prevalence in the outdoor and indoor work environments with heat index values (Appendix 3)

Results

Demographic and Occupational Characteristics. Some demographic and occupational characteristics of the study population are shown in Table 6.1 and Table 6.2, respectively.

Table 6.1: Demographic Characteristics of Crop Workers

Characteristics	Percent (n)
Gender	
Male	68.5% (291)
Female	31.5% (134)
Age	
<40 years	63.3% (269)
40 - 60 years	32.2% (137)
>60 years	4.5% (19)
Country of Origin	
Mexico	61.2% (260)
USA	9.4% (40)
Haiti	11.1% (47)
Guatemala	12.7% (54)
Others	5.6% (24)

Table 6.2: Occupational Characteristics of Crop Workers

Characteristics	Percent (n)
Work environment	
Outdoors	68.7% (292)
Picking tomatoes	281
Planting	11
Indoors	26.4% (112)
Packing tomatoes	107
Sorting tomatoes	5
N/A	4.9% (21)
Years worked in agriculture in the USA	
<1 year	10.4% (44)
1-5 years	24.7% (105)
6-10 years	18.8% (80)
>10 years	41.2% (175)
N/A	4.9% (21)
Have you received training on heat safety?	
Yes	46.1% (196)
No	45.9% (195)
N/A	8.0% (34)

N/A denotes missing values

HRI Descriptive Analysis. HRI prevalence by gender, age group and work environment heat safety training, years worked in agriculture and heat index using the chi-square test (Table

6.3) shows non-significant elevations in male crop workers compared to females, and in those between the ages 40 to 60 years compared to older and younger age strata. Workers above 60 years of age had the lowest prevalence, an observation consistent with self-pacing by experienced workers.[26, 27]

Only the work environment was significantly associated with HRI prevalence. The prevalence of HRIs in outdoor workers was higher, 18.8%, while that of indoor workers was 10.7%

Table 6.3: HRI Prevalence by Gender, Age Group, Work Environment, Heat Safety Training, Years Worked in Agriculture and Heat Index using Chi-Square Test

Characteristic	HRI (n)	No HRI (n)	% HRI Prevalence	Chi-Square	p-value
Gender				1.90	0.67
Male	57	234	19.6		
Female	23	111	17.2		
Age Group				0.21	0.57
<40 years	50	219	18.6		
40-60 years	28	109	20.4		
>60 years	2	17	10.5		
Work Environment				3.85	0.04*
Outdoor	55	237	18.8		
Indoor	12	100	10.7		
Heat Safety Training				3.79	0.08
Trained	40	156	20.4		
Not trained	27	168	13.8		
Years Worked in Agriculture				0.008	0.93
<10 years	41	218	15.8		
≥10 years	23	122	15.9		
Heat Index				2.17	0.14
<85 ºF (low)	22	162	11.9		
≥85 ºF (high)	45	196	18.7		

* denotes significant association

Logistic Regression Analysis. Odds ratios for the work environment, age group, gender, heat safety training and years worked in agriculture in association with HRI are shown (Table 6.4). Those with HRI have an approximately 60% increase in the odds of working outdoors compared to those without HRI, although this was not statistically significant.

Table 6.4: Odds ratio and 95% Confidence Intervals for logistic Regression

Parameter	**Odds Ratio Estimates**	**95% Confidence Limits**	
Outdoor vs. Indoor work environment	1.570	0.762	3.273
<40 years vs. 40-60 years	1.002	0.549	1.830
>60 years vs. 40-60 years	0.966	0.256	3.653
Male vs. female	1.214	0.647	2.275
<10 years vs ≥10 years in agriculture	0.992	0.519	1.895
Heat training vs. no heat training	1.525	0.830	2.805
High vs. low heat index	1.412	0.861	2.488

Heat Index and HRI Prevalence. Heat index values for same day (i.e., lag 0) and the previous work day (i.e., lag 1) were analyzed in association with HRI prevalence (Table 6.5; Appendix B). Results indicate that lag 0 had a stronger correlation, of borderline statistical significance, for HRI prevalence with daily heat index than did lag 1.

Table 6.5: Correlation and Regression Coefficients of HRI Prevalence with Daily Heat Index for Lags 0 and 1

Lag	**Regression Coefficient**	**Correlation Coefficient**	**p-value**
Lag 0	0.20	0.44	0.08
Lag 1	0.03	0.17	0.52

Figure 6.2 illustrates the relationship between the heat index and HRI prevalence. The regression equation can be interpreted as: HRI prevalence increases by 1.04% for each degree increase in heat index.

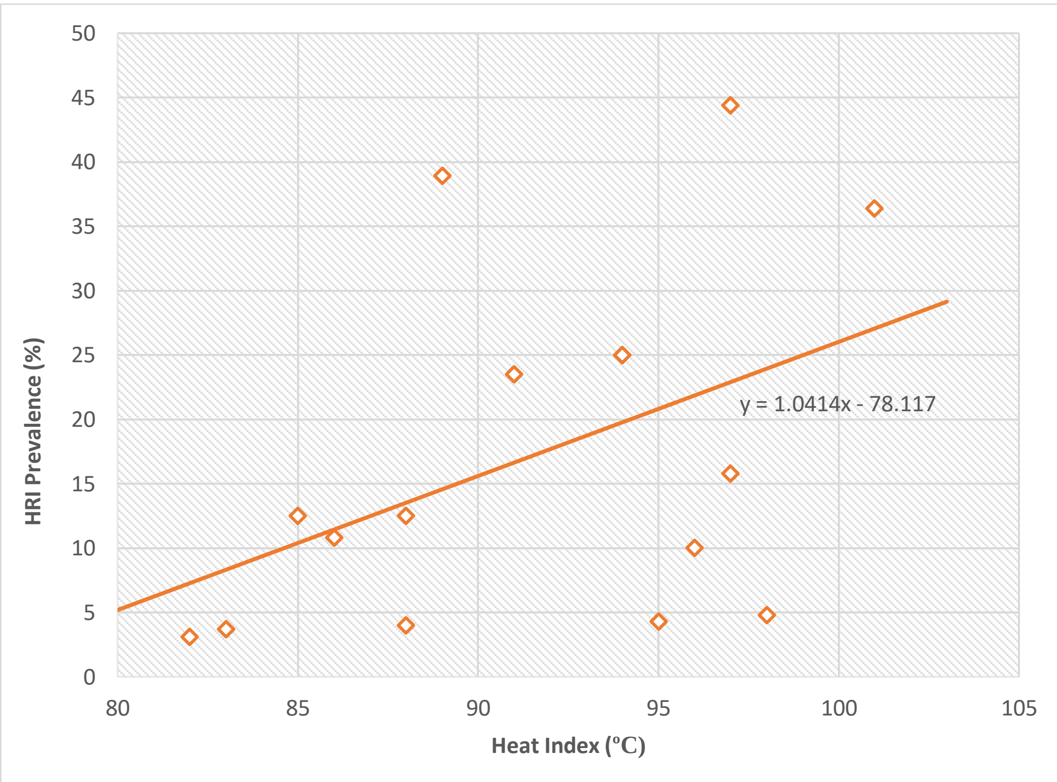

Figure 6.2: Plot of HRI prevalence and heat index

HRI Prevalence: Outdoor vs. Indoor Crop Workers. HRI prevalence was generally higher in outdoor crop workers than for those who work indoors (Appendix C). The associations between heat index values and HRI prevalence for outdoor and indoor crop workers are illustrated respectively using scatter plots and trend lines (Figures 6.3 and 6.4).

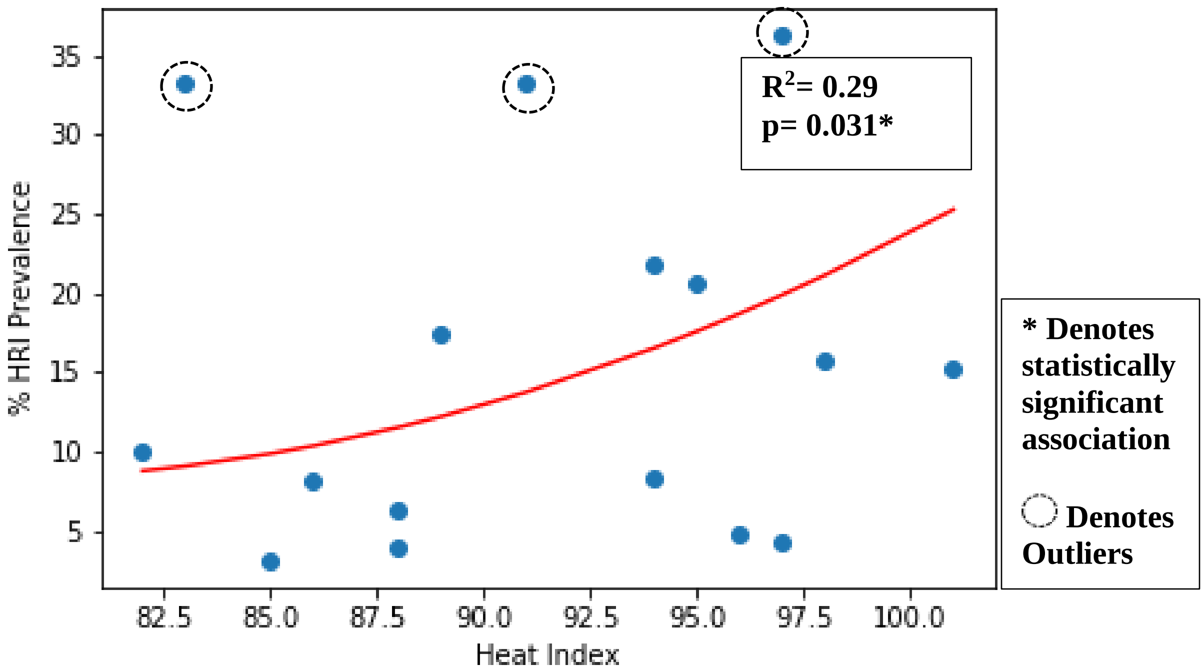

Figure 6.3: Scatter Plot and Trend line of HRI Prevalence and Heat Index for Outdoor Crop Workers

The trend line (Figure 6.3) shows an increase in HRI prevalence above the CDC's recommended heat index threshold (85°F) consistent with the uncontrolled nature of the outdoor work environment. Thus, the higher the heat index, the higher the prevalence of HRI.

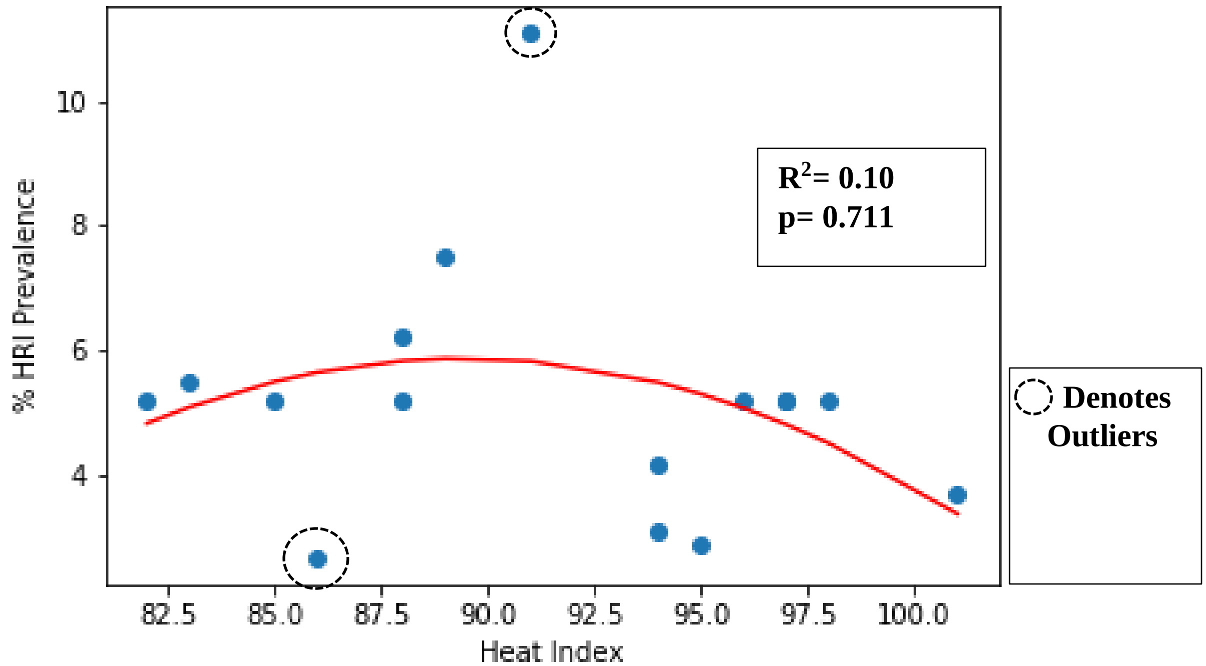

Figure 6.4: Scatter Plot and Trend line of HRI Prevalence and Heat Index for Indoor Crop Workers

The trend line for indoor workers (Figure 6.4) showed a slight increase above the threshold (85°F) until 90°F, then a steady decrease in HRI prevalence, although this trend was not statistically significant ($p = 0.711$).

The results indicate that the outdoor work environment was significantly associated with HRI prevalence, while this was not the case for the indoor work environment.

Discussion

To the best of our knowledge, this cross-sectional study is the first to explore HRI among crop workers in the fresh tomato industry, a crop valued in the United States at $1.86 billion.[28] Most crop workers were males (68%), foreign born (91%), and between the ages of 20 to 40 years (58%). Moreover, 69% work outdoors, and 41% have worked in agriculture for more than a decade. Fifty-five cases of HRI were identified in outdoor crop workers while twelve cases of

HRI were found in indoor workers. The odds that given one has HRI, they are 1.6 times more likely to work outdoors [OR= 1.570 (95% CI: 0.762, 3.273)].

Due to the acute nature of heat effects[29], we focused on symptoms experienced and reported within 24 hours of exposure to hot weather conditions (i.e., lag 0-1 day). Recall bias, a recognized limitation of cross-sectional studies, was thereby minimized. As expected, HRI prevalence reported on the same day of exposure (lag 0) had a stronger correlation than with the previous work day (lag 1). Scatter plots and regression coefficients of HRI prevalence showed statistically significant correlations with the outdoor work environment. Interestingly, HRI prevalence and HI were not significantly correlated for indoor workers. We speculate this may be attributable to employers and supervisors making large floor fans available in packing warehouses on some days when workers complain about heat. This is consistent with the fact that the indoor work environment can be modified, unlike the outdoor work environment.

This study shows that the outdoor work environment contributes significantly to HRI. Similarly, a study of 101 MSFWs conducted by Arcury and colleagues[16] found that the outdoor work environment was significantly associated with HRI, resulting in 36 HRI cases in outdoor workers compared with 14 HRI cases among those who work indoors. Consistent with our findings, gender and age were not significantly associated with HRI.[16]

Further, our study revealed that most work days exceeded the CDC's recommended occupational heat index threshold of 85° F.[30] This observation, coupled with limitations of using the heat index as a screening tool in workplaces, underscores the need for further screening and monitoring with the Wet Bulb Globe Temperature (WBGT) index.[31-36]

The study has some limitations. First, it is a cross-sectional study so we cannot draw causal inferences. Also, self-reported data may lead to recall bias. We attempted to address this issue by only evaluating exposure within 24 hours of the elicitation of health outcomes. Another key limitation of this study is the lack of direct field measurements on climatic factors. Due to the lack of standard WBGT measurements or other first-hand field data for 2014-2016, the years for which health outcome data were available, we relied instead on quality meteorological data at high spatial resolution.[37]

Data on metabolic heat generated based on specific job tasks, clothing, and other behaviors to reduce heat exposure would be useful for a more comprehensive assessment of HRI risks. Further, our sample was self-selected, consisting of only workers attending the screening events. Therefore, the results of this study cannot be generalized to other crop and agricultural workers in the United States.

Conclusions

In conclusion, the outdoor work environment is significantly associated with HRI. Outdoor crop workers are at higher risk of HRI than indoor workers, although indoor workers may not be fully exempted from risk of HRI**.** With existing challenges of assessing demographic and health outcome data in MSFWs nationwide, our strategic use of a sustained campus-community partnership for this study could be a model for other university-community partnerships with local migrant health centers in the United States. Health outcome data routinely collected at screenings for agricultural workers in the summer months may, in combination with high quality weather information, provide a basis for heat stress surveillance, and ultimately inform the development of interventions to manage the risk of HRI in vulnerable workers. Further studies using a widely acknowledged occupational heat stress standard, the WBGT index, in addition to other work-related risk factors are recommended.

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CHAPTER 7

ASSESSING THE RISK OF HEAT STRESS IN CROP WORKERS

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Abstract

Heat stress remains an occupational hazard even in temperate regions due to global warming. This poses significant health threats to agricultural and other outdoor workers. The purpose of this study is to evaluate the risk of heat stress in crop workers exposed to summer heat. The Wet Bulb Globe Temperature (WBGT) meter was used to collect data at constant intervals (i.e., 10 minutes) throughout six working days/shifts in the summer of 2018. Work load and clothing factors were used to determine the threshold limit value (TLV) and action limit (AL) for the study population. The prevalence of heat-related illness (HRI) among these workers was also evaluated for each work day/shift in correlation with the daily maximum WBGT. Both the TLV and AL were exceeded for most work hours revealing that crop workers were at risk of occupational heat-related illness. In addition, there was a strong significant correlation between daily maximum WBGT and HRI prevalence (R^2= 0.89; p= 0.03). Thus days with higher daily maximum WBGT had higher HRI prevalence. Crop workers remain at risk of HRI. Our study reveals that apart from acclimatization, other necessary measures need to be put in place to protect these workers. Further evaluation of work-rest cycles is recommended in crop workers.

Keywords: WBGT, heat stress, TLV, AL, ANOVA, attributable risk

Introduction

Global warming has significant impacts on the health of agricultural and outdoor workers in general [1, 2]. Particularly, agricultural workers have been known to be vulnerable to HRI and other climate-related outcomes due to heavy exertion and working outdoors [3]. Heat stress is a well-known occupational hazard [4-6]. Even in temperate regions, the risk of heat stress cannot be overlooked, especially when workers are not acclimatized to working in the summer heat [7, 8].

Over the years, many heat stress indices have been developed. Yet, there remains a paucity of practical field studies that quantify the relationship between these indices and heat-related illnesses in occupational settings [4]. The Wet Bulb Globe Temperature (WBGT), currently known as the occupational gold standard for measuring and assessing environmental heat exposure, is among the most widely used occupational heat stress indices in many regions across the world [5, 6, 9, 10]. Invented in the 1950s to control heat illnesses and fatalities in military training camps in the United States, it is currently used for setting national and international standards for assessing heat stress risks in occupational settings [11-13]. The WBGT index constitutes the basis for Threshold Limit Values (TLVs) used in establishing work-rest cycles needed to protect workers from heat stress [14].

Although WBGT incorporates all four thermal climatic factors-- air temperature, humidity, wind speed and solar radiation-- needed to assess occupational heat stress [4], a major inherent weakness is its inability to account for metabolic heat production through physical exertion (i.e. work load), and the effects of clothing worn by workers, as in situations where air-and vapor-impermeable protective clothing is worn [6, 11]. All the aforementioned factors are necessary for a comprehensive evaluation of occupational heat stress [9, 15]

Here, we assess the risk of heat stress among crop workers in northeast Tennessee, taking into consideration the work load and clothing factors.

Materials and Methods

WBGT Data Collection. Using the QUESTEMP°10 WBGT meter (model 924), data were collected at monitoring locations as close as possible to farm locations (Table 7.1). Data collection was completed every 10 minutes within work shifts for six different days in July and August of 2018 (Appendix D).

Table 7.1: Proxy Monitoring Locations for WBGT Data Collection

Date	**Specific Tasks of Workers Screened and Location**	**Elevation (ft.)**	**Monitoring Location**	**Elevation (ft.)**	**Hours Worked**	**Hours Monitored**
7/10/2018	Pickers – Location C	1083	Church across river from farm	1195	7am – 7pm	9:35am -- 5:35pm
7/17/2018	Pickers – Location B	1040	Private home across road from farm	1052	7am -- 2pm	10:05am – 6:05pm
7/24/2018	Pickers – Location D	1112	Public boat ramp downstream of farm	1120	9:30 am – 4pm	9:45am – 5:45pm
7/31/2018	Packers – Location D	1112	Semi-enclosed picnic pavilion	1175	11am – 6:30pm	9:35am – 5:35pm
8/7/2018	Pickers and Packers – Location C	1083	Church across river from farm	1195	8am – 2.30 pm 11am – 6.30 pm	9:35am – 5:35pm
8/14/2018	Pickers – Location D	1112	Public boat ramp downstream of farm	1120	7am -- 7pm	9:35am – 5:35pm

Determination of Threshold Limit Value and Action Limit. To determine the threshold limit value (TLV) and action limit (AL) for acclimatized and non-acclimatized crop workers respectively, the metabolic rate (i.e. work load) of 309.36 W (i.e., 266.18 kcal/hr) estimated in a past study in this population [16] was used. Workers in our study population typically wear work clothes (long sleeves and pants), thus our clothing adjustment factor (CAF) was 0, based on the recommendation of ACGIH [17]. We then used the ACGIH's standard graph (Figure 7.1) to determine the TLV and AL, temperatures at which there is a heat hazard present for an acclimatized worker (TLV) and non-acclimatized worker (AL), respectively.

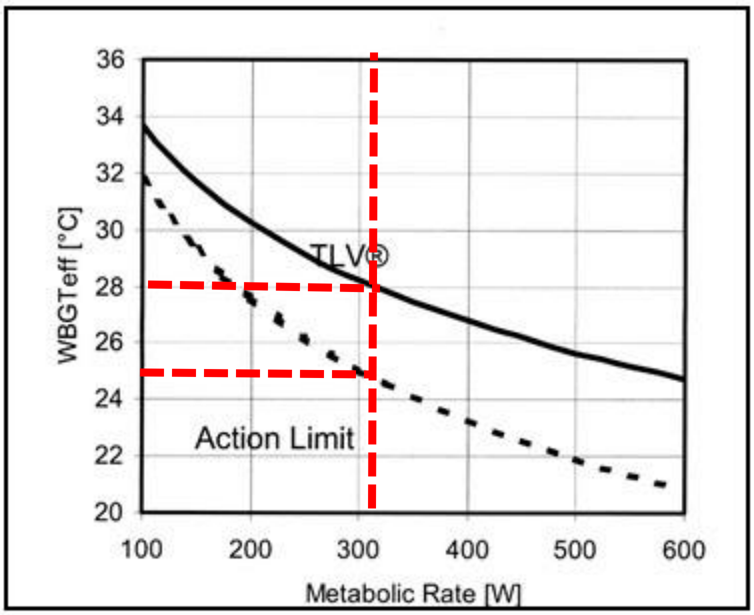

Figure 7.1: Threshold Limit Value and Action Limit (Adapted from ACGIH "2017 TLVs and BEIs" FIGURE 2)

Thus, the TLV and AL estimated were 28.0°C and 25.0 ºC, respectively. These values were used to determine safe and unsafe work hours for our study population.

Health Screening. Occupational health questions, designed as a partnership activity, were incorporated into RMS's standard screening intake forms, administered by trained, bilingual social service and clinical professionals. The forms include questions on HRI, demographics, work history and current job tasks and conditions, along with clinical data and diagnoses made by clinicians, and lifestyle or behavioral factors that impact health. To examine symptoms of HRI, participants reported after their work shifts whether they were experiencing any of the following symptoms: skin rash, muscle cramps or spasms, dizziness or light-headedness, fainting, headache, heavy sweating, extreme weakness or fatigue, nausea, vomiting, or confusion [18, 19]. Two or more of these symptoms constituted our case definition HRI. Also included were cases in which an RMS physician or nurse made an explicit diagnosis of HRI.

Results

Daily Mean, Minimum and Maximum WBGT values. The daily mean, minimum and maximum WBGT values recorded are shown (Table 7.2)

Table 7.2: Daily Mean, Minimum and Maximum WBGT Values (°C)

Day (Date)	**Mean ± (SD)**	**Minimum**	**Maximum**
1 (July 10, 2018)	27.75 ± (2.82)	21.39	30.67
2 (July 17, 2018)	26.72 ± (2.57)	20.50	32.28
3 (July 24, 2018)	26.45 ± (2.37)	21.28	30.67
4 (July 31, 2018)	25.16 ± (0.89)	23.39	26.89
5 (August 7, 2018)	30.44 ± (1.61)	27.78	33.56
6 (August 14, 2018)	27.11 ± (1.33)	24.56	29.39

Daily Maximum WBGT Values and HRI Prevalence. Daily maximum WBGT values and HRI prevalence are displayed (Table 7.3).

Table 7.3: Daily Maximum WBGT Values and HRI Prevalence

Day (Date)	**Daily Maximum WBGT (°C)**	**Number of workers screened**	**HRI Cases**	**HRI Prevalence (%)**
1	30.67	31	2	6.5
2	32.28	28	5	17.8
3	30.67	11	1	9.0
4	26.89	18	1	5.5
5	33.56	26	6	23.1
6	29.39	10	1	10

HRI Prevalence and Rate Ratios. Using the day with the lowest maximum WBGT (i.e., 26.89 °C on July 31) to assign the baseline prevalence rate of HRI (5.5%), rate ratios were then calculated for the other five days (Table 7.4)

Table 7.4: HRI Prevalence and Rate Ratios

$WBGT_{max}$ (°C)	**HRI Prevalence (%)**	**Rate ratio***
30.67	6.5	1.18
32.28	17.8	3.24
30.67	9	1.64
26.89	5.5	1
33.56	23.1	4.20
29.39	10	1.82

*Reference value: **26.89 °C**

Scatter Plots. Scatter plots of WBGT values for all work shifts are illustrated (Figure 7.2)

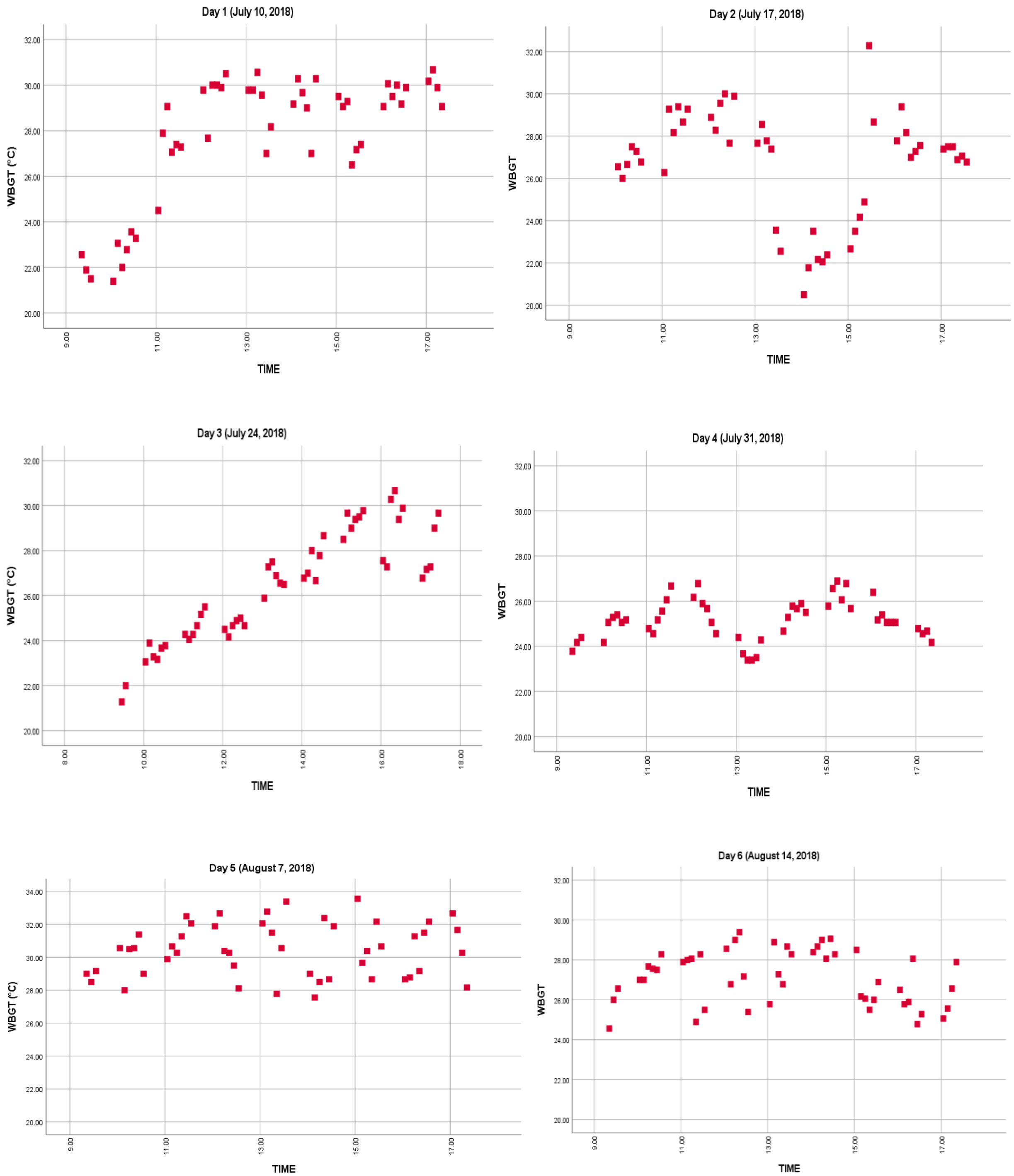

Figure 7.2: Scatter Plots for WBGT Values Recorded on Each Workday/Shift

Assessments Using TLV and AL. To assess workers' susceptibility to heat stress based on the work environment, we used the TLV and AL values determined from Figure 7.1 and compared them to the mean hourly values of WBGT (Figure 7.3).

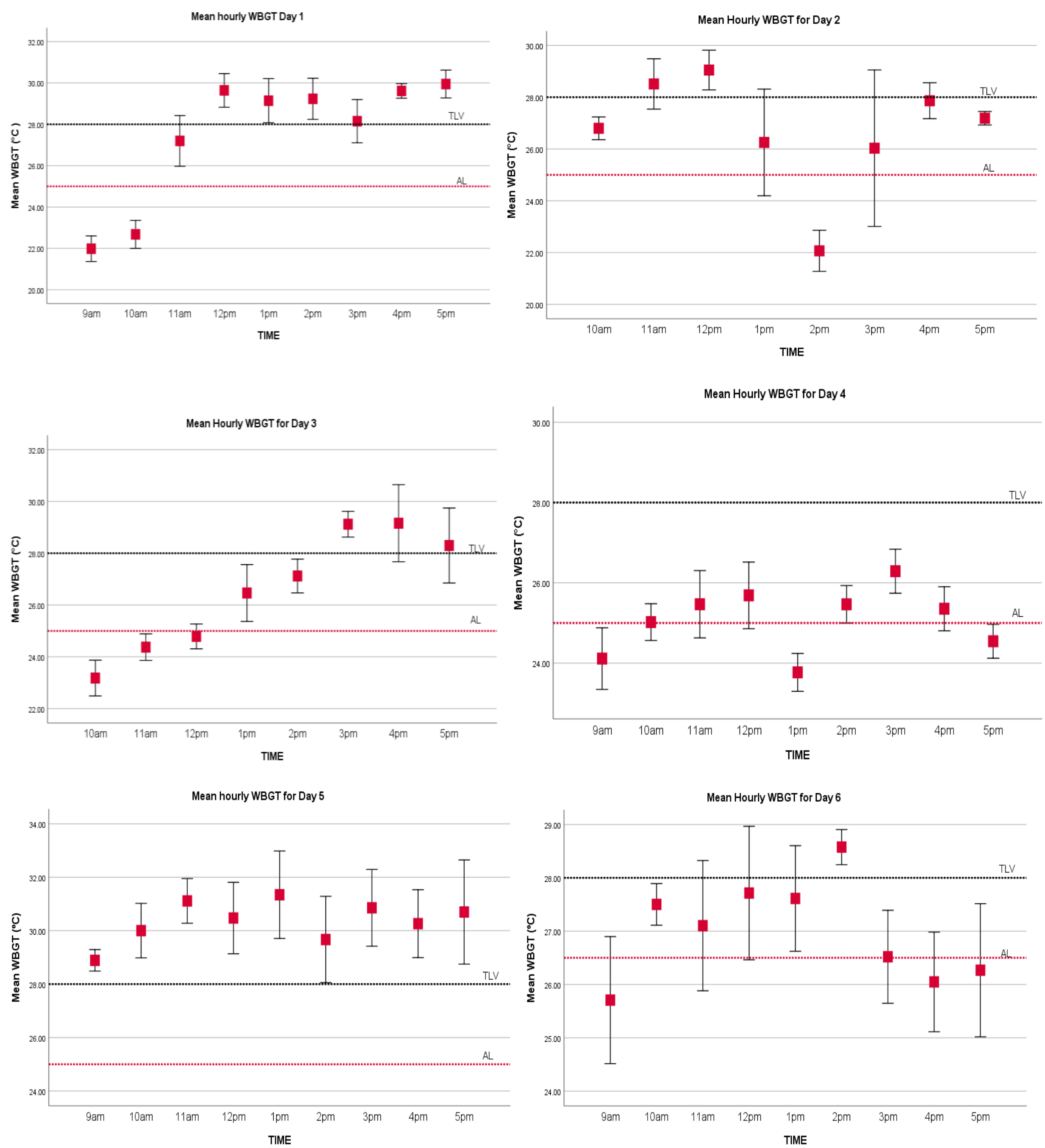

Figure 7.3: Mean Hourly WBGT with TLV and AL for Each Work day/Shift

The AL and TLVs exceeded for each of the six work days are summarized below, with implications for worker protection stated for each day.

Day 1: Apart from the early hours of the work shift (i.e., 9AM and 10 AM), the AL was exceeded for the rest of the shift. The TLV was also exceeded most of the work time. Thus, it is considered unsafe for both non-acclimatized and acclimatized workers to work this shift without taking extra precautions to avoid long heat exposures.

Day 2: Again, the AL was exceeded throughout the shift, and extra precautions should be taken, especially for non-acclimatized workers.

Day 3: Early hours of the work shift (i.e., 10 AM-12 noon) appeared not to pose any health threat to workers but precaution measures are indicated especially for non-acclimatized workers after noon.

Day 4: Only indoor WBGT values were collected for this work shift due to the fact that workers packed tomatoes in a shaded packing house throughout this shift (The baseline prevalence rate of 5.5% [RR=1.00] was obtained on this day).

Day 5: All recorded WBGT values exceeded the TLV and AL. This day was extremely hot and all necessary precautionary measures need to be put in place to protect the health of workers.

Day 6: The AL was exceeded throughout the day. Precautionary measures need to be put in place to protect non-acclimatized crop workers.

Box Plots. Maximum, mean and minimum recorded WBGT values for each work day/shift are also illustrated in the box plots shown in Figure 7.4. Apart from day 4, the AL and TLV were exceeded on most work days.

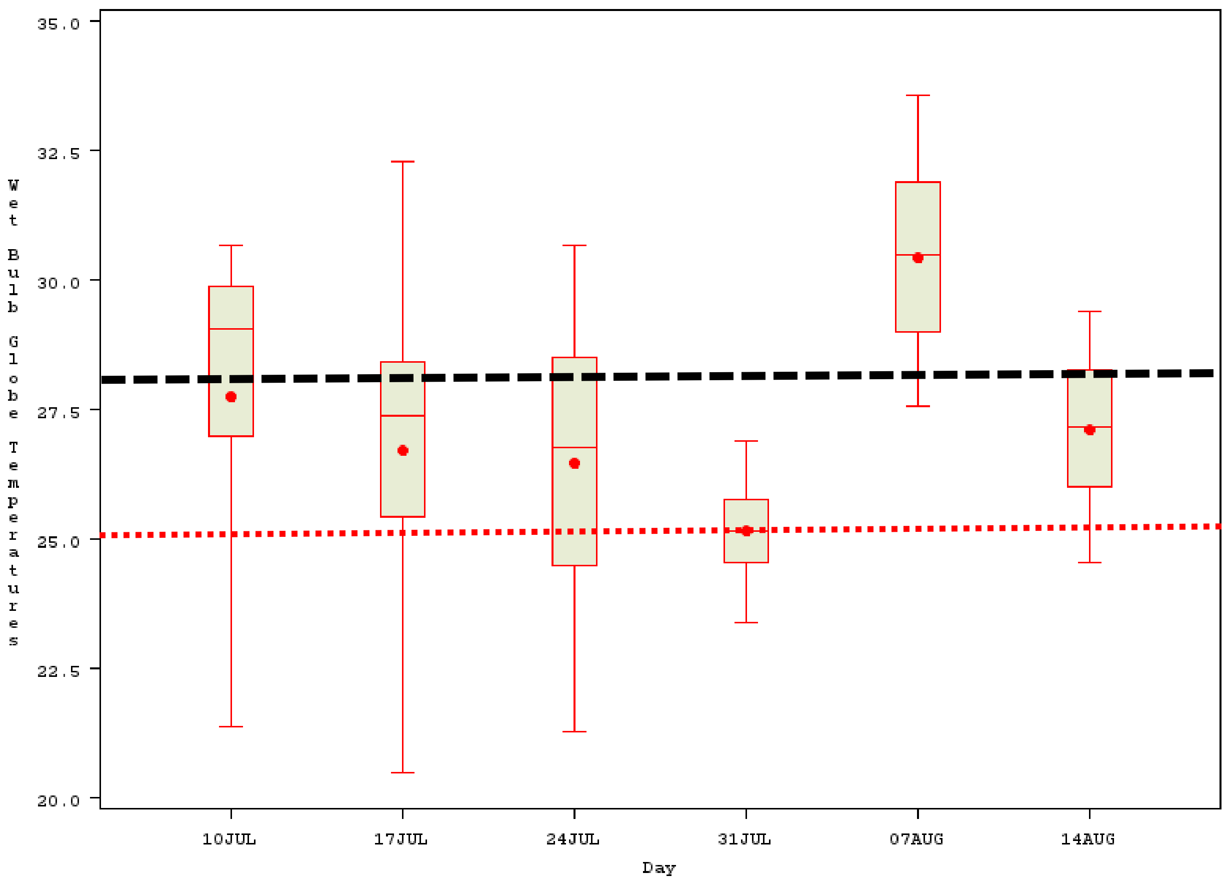

Figure 7.4: Box Plots of Recorded WBGT for Each Work day/Shift

ANOVA. One-way and two-way ANOVA were performed to determine between-day variation in mean WBGT for the six work days, as well as within-day variations for time or hour of work (Figure 7.5).

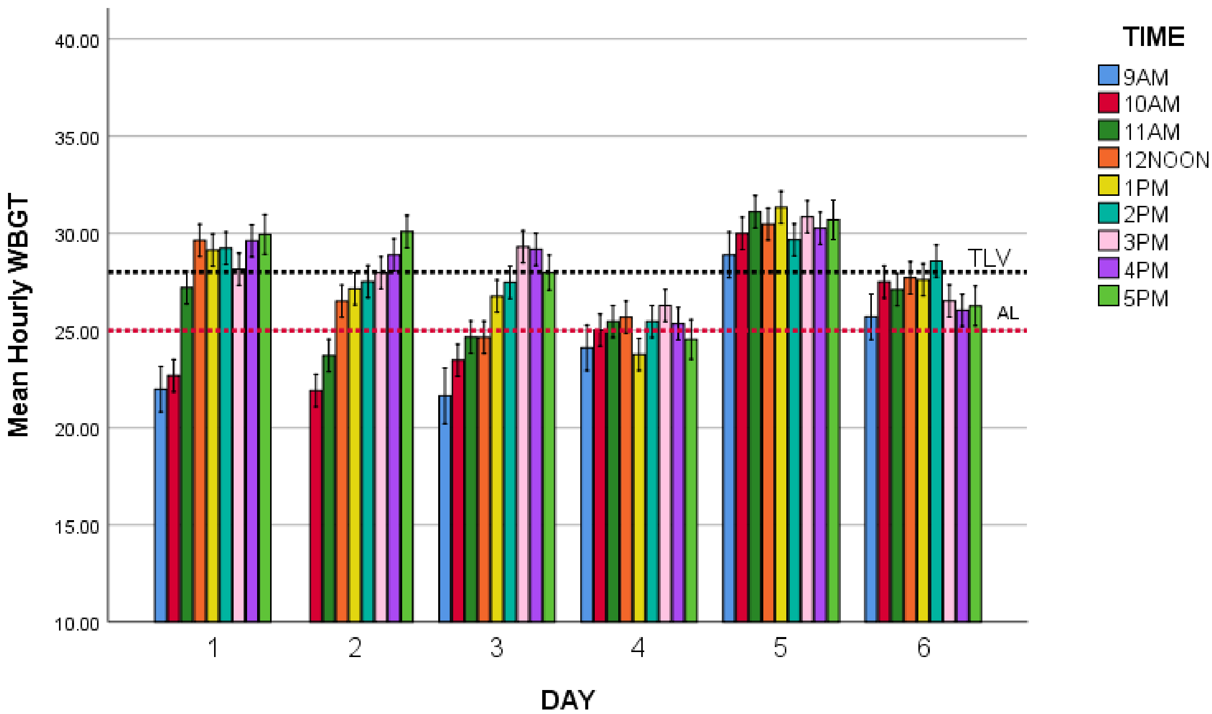

Figure 7.5: ANOVA Results of Mean Hourly WBGT for Different Work Days and Hours

The mean, standard deviation, and additional statistical details for each workday are presented in Appendix F. As shown in Table 7.5, significant differences were observed in average WBGT values between days. Days 4 and 5, with lowest and highest recorded WBGT respectively, varied markedly from all other work days (Appendix G).

Table 7.5: Mean WBGT and Days of Work

	Sum of Squares	**df**	**Mean Square**	**F**	**Significance**
Between Days	771.187	5	154.237	35.826	p<0.001
Within Days	1235.576	287	4.305		
Total	2006.764	292			

Detailed statistics for the two-way ANOVA to determine the effects of days and times (hours) of work on WBGT are presented in Appendix H. As shown in Table 7.6, there were significant interactions between the effects of work days and hours on WBGT. After adjusting for interaction effects, further analyses using Tukey's Honestly Significant Difference (HSD) test at a more stringent significance level (p= 0.025) showed high variations in average hourly WBGT values during the early part of the work season in July, specifically days 1, 2 and 3 (Table 7.7, and Appendix I).

Table 7.6: Mean WBGT and Effects of Days and Hours Worked

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	1752.15	52	33.695	31.762	p< 0.001	.873
Intercept	195849.8	1	195849.821	184611.5	p< 0.001	.999
Day	755.981	5	151.196	142.520	p< 0.001	.748
Work Hours	418.111	8	52.264	49.265	p< 0.001	.622
Day*Work Hours	557.048	39	14.283	13.464	p< 0.001	.686
Error	254.610	240	1.061			
Total	219966.1	293				
Corrected Total	2006.764	292				

Table 7.7: Number of within-day variations between hours that are statistically significant

Work Day (Date)	**Number of statistically significant variations between hours**
1 (July 10)	44
2 (July 17)	42
3 (July 24)	52
4 (July 31)	14
5 (August 7)	14
6 (August 14)	22

Again, days 4 and 5 had the least variation in WBGT. Day 5 was hot and remained hot throughout, while day 4 remained consistently less warm as workers packed tomatoes indoors; the monitoring location was a semi-enclosed structure. Moreover, for days 1, 2 and 3, extreme variations in mean WBGT occurred between the first two hours of the shift (i.e., 9 AM and 10 AM) and late afternoon, ranging from approximately 6 to 8.2 °C.

Regression Analyses. A regression analysis was performed to further assess the correlation between HRI prevalence and WBGT recordings. We used daily maximum WBGT values and HRI prevalence to generate a polynomial regression curve (Figure 7.5).

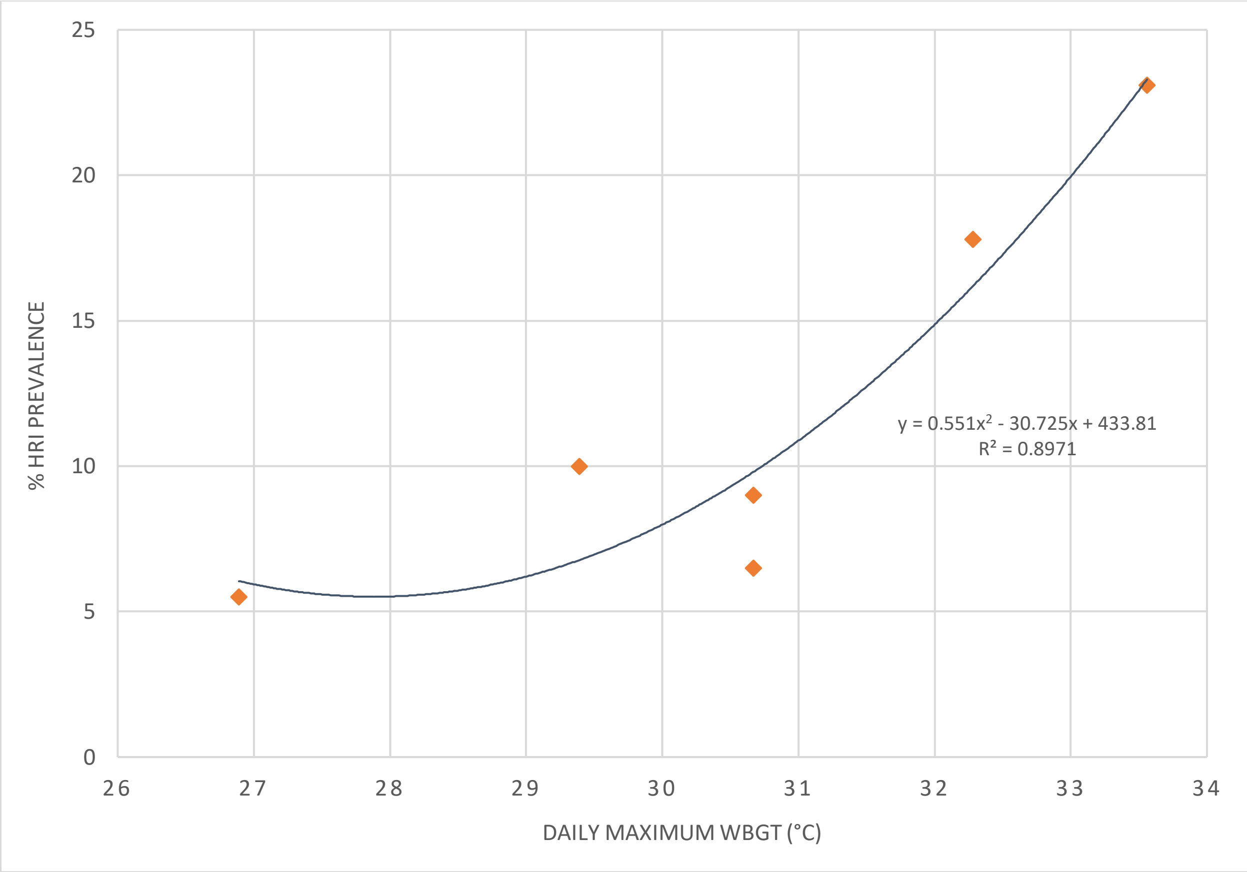

Figure 7.6: Scatter Plot and Trend Line of HRI Prevalence on Daily Maximum WBGT

The plot of HRI prevalence on daily maximum WBGT showed a strong positive correlation (R^2= 0.89; p=0.03). Day 5, with the highest recorded WBGT had the highest HRI prevalence while day 4 (indoor WBGT recordings) had the lowest HRI prevalence.

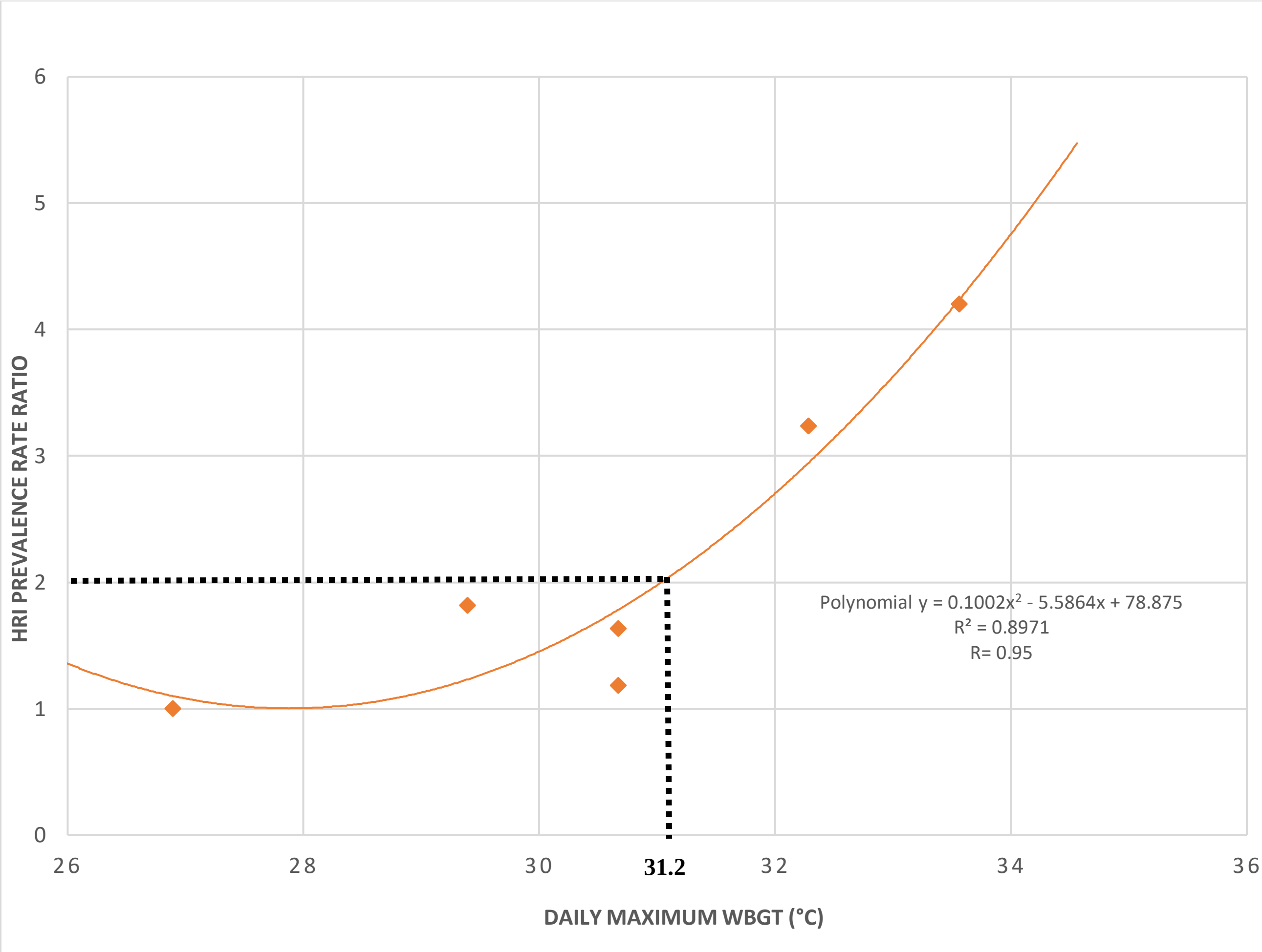

Figure 7.7. Illustration of Attributable Risk

Similarly, there was a strong correlation between rate ratios of HRI prevalence and daily maximum WBGT using the day with the lowest daily maximum WBGT (i.e., 26.89) to assign the baseline prevalence rate. As illustrated by the dotted lines (Figure 7.7), a rate ratio of 2.0 occurs on the fitted polynomial at a daily maximum WBGT value of 31.2 ºC. The canonical equation (Equation 4) for attributable rate percent (AR):

$$\text{(Equation 4)} \quad AR = 1 - 1/RR$$

would simply imply that cases with two or more of the symptoms of HRI seen in this population at screening clinics on days when the maximum WBGT value exceeds 31.2 ºC are *more likely than not* to be due to the outdoor work environment. This inferential reasoning may be helpful in the development of a heat warning system for the regional tomato industry, which is further explained in the discussion.

Discussion

Assessing the risk of heat stress is a necessary step in managing HRI especially among outdoor workers. This study attempted a comprehensive heat stress evaluation in crop workers taking into account the four thermal climate factors-- air temperature, humidity, wind speed and solar radiation-- as well as work load and clothing factors.

Previous studies have shown that outdoor workers in the southeast United States experience heat stress in the summer [18, 19]. Our study used real-time WBGT data from proxy monitoring locations as close as possible to tomato farms in northeast Tennessee, where workers plant, pick and pack tomatoes. The metabolic rate of the study population previously estimated by McQueen [16] was used to determine the threshold limit value (TLV) and action limit (AL) for acclimatized and non-acclimatized workers, respectively.

The analysis revealed that both acclimatized and non-acclimatized crop workers were at risk of occupational HRI. There was not a work day that crop workers could perform continuous outdoor tasks without taking necessary precautions. On some work days, particularly day 5, it was extremely hot and the TLV was exceeded throughout the entire work shift. Thus, acclimatization is necessary but not sufficient in preventing HRI [19]. Further, the ANOVA results indicate that extreme variations in WBGT due to the uncontrolled nature of the work environment existed in July, the early part of the work season. If this trend is seen in subsequent seasons, then a strong case would exist for reliance upon work schedules that allow non-acclimatized workers to acclimatize early in the season. Large hour-to-hour variations in WBGT measurements would likely frustrate the practical application of the ACGIH standard's work-rest routines. By contrast, acclimatization schedules, some of which are independent of WBGT measurements, are relatively straightforward to implement. Additionally, we recommend scheduling outdoor job tasks during the early part of the day, and if possible, switching to indoor tasks in the late afternoon. Provision of frequent breaks under shade structures, cool potable water, and training of supervisors and workers in heat stress prevention and emergency actions are further recommended.

Additional measures need to be taken to protect the health and safety of crop workers. Employers need to provide cool, potable water as close as possible to crews' locations in the fields at no cost to employees. The minimum recommended amount of drinking water to be provided is six to ten quarts, depending upon temperature, humidity, physical activity and other personal characteristics [20]. Also, work scheduling is crucial. Scheduling heavy workloads or tough jobs at cooler times of the day along with frequent breaks should be considered. Employers should be aware that economically disadvantaged workers, such as migrant and seasonal farmworkers (MSFWs), are reluctant to take breaks due to their piece-rate earnings that depend directly on the amount of time spent working. Moreover, there is a need for supervisors to monitor weather conditions at worksites on a regular basis and ensure compliance with measures to protect the health of workers [21].

The strong positive correlation found between HRI prevalence and daily maximum WBGT data confirms the role of outdoor heat in increasing HRI prevalence. Indeed, day 5, the hottest day of our study, had six HRI cases (23% prevalence) recorded followed by five recorded cases of HRI (17.8% prevalence) on day 2, the second hottest day. On the other hand, the lowest HRI prevalence rate was recorded on day 4, which had the lowest maximum WBGT as a result of indoor work.

A major limitation of this study is its small sample size, a common characteristic of most occupational studies especially those focusing on rural jobs such as agriculture. The temporary and hazardous nature of farm work, coupled with unique work conditions of migrant and seasonal farmworkers, makes it difficult to assemble a large population in a longitudinal study. Additionally, we resorted to proxy monitoring locations for WBGT data collection due to a highly publicized immigration raid at a meatpacking plant in Morristown, TN, the heart of the regional Hispanic community, which occurred less than five months before we began our field measurements. This resulted in a sudden shift in attitudes of farm owners with respect to "outsiders" having access to farm premises.

All proxy monitoring locations had higher elevations compared to the exact farm locations (Table 7.1). Thus, our recorded WBGT values may be underestimates, with a hypothetical curve based on measurements taken on the farms lying to the right of our curve in Figure 7.6. The daily maximum WBGT value of 31.2 ºC which we derived from the equation for attributable rate percent, assuming a doubling of the baseline prevalence rate, probably errs on the conservative side. For clinicians participating in our partnership, the WBGT temperature at which a given case is "more likely than not" due to outdoor work may be somewhat higher than 31.2 ºC. Reproducing this work with measurements taken at the picking crews' actual field locations may provide a more sound basis for decision making in the context of a heat warning system for the regional tomato industry.

Also, our inability to conduct physiologic monitoring is a limitation. However, since workers in our study population do not have to don any vapor- or air- impermeable encapsulating protective gear, physiological data were not needed in addition to WBGT data [6].

Moreover, the focus on HRI prevalence alone is inadequate. Further evaluation on work capacity loss may be necessary to inform stakeholders of both the short-term and long-term impacts of heat stress. At the same time, with our study population being temporary and economically disadvantaged migrant workers, evaluating this measure will be difficult, if not impossible.

Conclusions

Crop workers in northeast Tennessee remain at risk of occupational HRI. In addition to acclimatization, farm owners and supervisors need to implement measures to protect the health and safety of these workers. Such measures include adequate cool potable water, proper scheduling, breaks, shade structures, training of supervisors and workers, and monitoring weather conditions on farms. We recommend further evaluation of work-rest cycles for crop workers in northeast Tennessee. Future studies may also evaluate the effect of HRI on work capacity loss.

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CHAPTER 8

DISCUSSION

Studying temperature-health effects in rural areas can be challenging but it is a necessity for climate change adaptation and emergency planning, including formulating effective heat-health action plans (Ebi et al. 2006; Henderson et al. 2013). HRI and heat-related mortality, although preventable, have significant impacts on the lives of individuals who live or work in rural areas. With climate change expected to intensify, there is a need for effective interventions to protect vulnerable individuals and communities. Developing effective public health interventions, including comprehensive heat-health action and acclimatization plans, involves establishing the evidence in order to conceptualize the impacts of both HRI and heat mortality, as well as identifying the specific risk factors that may predispose certain high-risk populations ignored in previous research.

This research aimed to: (1) evaluate the evidence of heat-related mortality in rural communities; (2) identify internal and external risk factors associated with HRI in crop workers; and (3) assess the risk of heat stress based on the risk factor identified in the second aim.

Aim 1 Discussion

Although heat-mortality and morbidity relationships have been explored extensively in large cities and more urbanized areas, predominantly rural communities are not well explored. The first aim examined whether communities classified as rural based on different definitions were vulnerable to heat-related mortality, as others have found in urban communities. A variety of factors account for this inattention to rural areas: lack of climate data due to few weather monitoring stations, lack of research funding and relatively small population sizes, which makes it difficult to conduct research with statistically significant findings (Hashizume et al. 2009; Henderson et al. 2013; Lee et al. 2016). Results from the limited studies focused on rural areas suggest that rural areas may be as vulnerable to heat-related mortality as are urban areas (Li et al. 2017; Odame et al. 2018).

To date, there has been no meta-analysis of epidemiologic literature concerning heat-related mortality in rural settings. This study systematically reviewed the current literature for assessing heat-related mortality risk among rural populations. A comprehensive literature search identified articles published up to April 2018, using appropriate search criteria. The pooled relative risk for studies examining all-cause mortality was 1.030 (1.013, 1.048), implying that 3% excess mortality had heat as the underlying or contributory cause. For studies that examined only cardiovascular mortality, the excess risk was even higher; 11% excess deaths [RR= 1.11 (1.045, 1.181)].

A sensitivity analysis to assess the role of economic development on heat mortality was performed, revealing that developed rural regions had lower excess risks compared with developing ones (2% vs. 3.6%). This finding signifies the role of adaptive capacity, a key pillar of vulnerability in heat-related mortality (Gamble et al. 2016). The study also found excess heat-related mortality in rural areas not to be smaller than in urban areas. Thus, the UHI effect may contribute indeed to higher heat exposures in urban residents, but most of them have access to air conditioning, quality medical facilities and other infrastructure to adapt better and deal with heat impacts.

These findings provide evidence that heat-related issues pose threats to rural inhabitants. Thus, policies and interventions to reduce heat-related outcomes should also consider rural communities worldwide. The results of this study will be viewed as a “pace-setter” to encourage more research in rural populations, subpopulations and other marginalized communities to build upon the evidence of heat-related mortality in these areas.

Aim 2 Discussion

The second aim, focusing on HRI among crop workers in northeast Tennessee examined the role of the outdoor work environment in addition to other occupational and personal characteristics including heat index heat safety training, years worked in agriculture, heat safety training, age group and gender. Cross-sectional data were collected at 16 health screening events of a migrant health center held on or near tomato farms in northeast Tennessee during the summers of 2014, 2015 and 2016 (N= 425 encounters). HRI diagnosed by physicians and nurses, along with cases identified by having two or more HRI signs and symptoms, were counted and analyzed. Daily values of the heat index (HI) were estimated using high quality sources of weather data. Appropriate statistical methods were used to compare the risk of HRI between outdoor and indoor workers, as well as other risk factors known to be associated with HRI. Associations between HRI prevalence and HI were assessed by curve-fitting using 0- and 1-day lag periods.

The prevalence of HRI was 18.8% (55 cases) and 10.7% (12 cases) in outdoor and indoor crop workers, respectively. Those with HRI have an approximately 1.6 times greater chance of being outdoor workers compared to those without HRI. HRI prevalence had a stronger correlation with same day HI (lag 0) than with the previous workday's HI (lag 1). Scatter plots and regression coefficients for HRI prevalence and HI showed statistically significant correlations among outdoor workers but not for indoor workers.

The outdoor environment has been documented to be significantly associated with HRI among MSFWs in different areas of study, while personal factors including age, gender, etc. are not significantly associated with HRI (Arcury et al. 2015). Our findings are consistent with what other studies found. The novelty of this research lies in several aspects, including its utilization of high quality spatially modeled climate data, PRISM, to determine temperature and dew point measures. Heat index values were also calculated using an online tool developed by the National Weather Service. Moreover, a robust multivariate regression model was used to combine all predictor variables in relation to HRI using both PROC LOGISTIC and PROC GLIMMIX functions in SAS 9.4. Recall bias, a limitation of cross-sectional studies was minimized by focusing on HRI diagnoses made on the same day (lag 0), whereas other studies recorded HRI prevalence within a week (Mirabelli et al. 2010; Fleischer et al. 2013; Bethel and Harger 2014; Arcury et al. 2015; Kearney et al. 2016).

This study shows that the outdoor work environment is significantly associated with HRI. While indoor heat exposures can be reduced by modifying the work environment, such options cannot be applied to the outdoor work environment. A further novel aspect of this research is that it was carried out in partnership with a federally qualified health center's migrant health program. Routine health screenings conducted by migrant health programs in the summer months afford opportunities for surveillance and potential interventions to reduce HRIs in outdoor crop workers on a local and regional scale.

Aim 3 Discussion

Given that the outdoor work environment was significantly associated with HRI prevalence, Aim 3 further assessed the risk of heat stress among crop workers using a widely accepted heat stress standard. The Wet Bulb Globe Temperature (WBGT) meter was used to collect data at constant intervals (i.e., 10 minutes) throughout six working days/shifts in the summer of 2018. Work load and clothing factors were used to determine the threshold limit value (TLV) and action limit (AL) for the study population. The prevalence of heat-related illness (HRI) among these workers was also evaluated for each work day/shift in correlation with the daily maximum WBGT.

Both the TLV and AL, 28°C and 25.0°C respectively, were exceeded for most work hours revealing that crop workers were at risk of occupational HRI. In addition, there was a strong significant correlation between daily maximum WBGT and HRI prevalence (R^2= 0.89; p= 0.034). Thus, days with higher daily maximum WBGT had higher HRI prevalence. A regression of rate ratios on daily maximum WBGT combined with the canonical formula for attributable rate percent, revealed that at 31.2 ºC, a given case with two or more symptoms is *as likely as not* to be a case of HRI. While probably somewhat conservative, this critical value could be a key component in the development of an effective local heat warning system, particularly as it might inform the clinical impressions of doctors and nurses who perform health screenings on this marginalized population in the summer (Figure 2.2). Above the critical value, a given case is more likely than not to be HRI. The results of this study emphasize the need for more safety measures to be put in place including the issuing of heat advisories and warnings. Further assessment and evaluation of work-rest cycles is also recommended.

Strength and Limitations

One of the greatest strengths of this research is its focus on rural areas which remain underexplored in terms of heat-related studies. This is the first meta-analysis of heat-related risks in rural areas worldwide. In light of rapidly advancing global climate change, rural populations and MSFWs are considered populations of concern (Gamble et al. 2016) and need to be given greater attention. To date, few studies have focused on rural populations and MSFWs, a key rural sub-population.

Again, the cross-sectional studies (Aims 2 and 3) are among the first to explore HRI among crop workers in the fresh tomato industry. The strategic formation and sustenance of a long-term community partnership with a local migrant health center in northeast Tennessee for the purpose of data surveillance and possible interventions, is another key strength of the study. Community-based participatory research (CBPR) has a reputation for developing sustainable interventions due to its community engagement (O'Toole et al. 2003; Faridi et al. 2007). Thus, potential heat health interventions developed from this community partnership, including a local heat warning system, may prove both efficient and effective in controlling heat stress in our study population.

An additional strength of this study is its utilization of high-quality climate data tools for estimating the heat index. High-quality weather data sources such as PRISM, and heat index calculation tools developed by the National Weather Service (NWS) are recognized by experts in the field of occupational health and safety (Lemke and Kjellstrom 2012; OSHA 2017). The heat index can be used as an initial screening tool in the absence of WBGT measurements (Tustin et al. 2018; Morris et al. 2019). Further, this study is among the first to find evidence of HRI risk in crop workers in northeast Tennessee. The lessons learned, and information garnered from this research may form the basis for development of appropriate heat stress risk management tools.

Most occupational and rural studies are generally limited in sample size; this study is not exempt. Rural and remote communities including MSFWs have small and sparsely distributed populations (Henderson 2013). Sample sizes used in previous occupational heat stress studies are small, usually ranging from 100 to 400 workers (Mirabelli et al. 2010; Fleischer et al. 2013; Bethel and Harger 2014; Arcury et al. 2015; Kearney et al. 2016). In addition, MSFWs and other rural populations have distinct characteristics including high proportions of vulnerable groups, especially the elderly and children, the poor, the underemployed, the unemployed, as well as uninsured and underinsured residents. Quality healthcare facilities are often lacking. Thus, they are likely to experience disproportionately higher rates of chronic diseases than people elsewhere (Hassenger and Hobbs 1992; Hart et al. 2005), limiting the generalization of these results to non-rural residents.

Further, using only eleven studies for the meta-analysis is an acknowledged limitation, even though some meta-analyses have used fewer. The stringent exclusion criteria, applied in an attempt to compare only "apples to apples" in order to increase the validity of the results also limited the number of studies used. For instance, our exclusion of studies on heat waves due to their inconsistent definitions reduced the number of studies selected. Moreover, a more rigorous methodology could have been explored to use a wider range of temperature metrics including daily maximum and weekly mean temperatures instead of excluding them from our final analysis.

The cross-sectional nature of this study also has some inherent weaknesses. Apart from its susceptibility to recall and other forms of biases, which we attempted to curtail by limiting the recall period to within 24 hours, cross-sectional studies cannot be used for causal inferences (Setia 2016). Although some risk factors associated with occupational heat stress were explored, additional specific personal and occupational risk factors, such as different types of medication used on the job, should be examined. Some medications including alcohol, anticholinergics, antihistamines and tricyclic antidepressants are known to affect the body's heat dissipation mechanisms (Sandor 1997; Adelukan et al. 1999; Wexler 2002; Nichols 2014).

Summary

In summary, there is evidence of heat-related mortality and HRI in rural residents, including MSFWs in rural northeast Tennessee. Rural communities in both developed and developing countries remain at risk in the light of a rapidly changing global climate. Outdoor workers are at higher risk because their heat exposures are greater in frequency, duration and intensity. The risk factors commonly known to be associated with HRI were explored. The study found that the outdoor work environment was the only risk factor associated with HRI prevalence in crop workers. Given that a worker had HRI, the odds of working outdoors were 1.6 times greater than for those who worked indoors. Additional risk factors associated with occupational heat stress can be further explored with more rigorous study designs that can establish causality. The use of WBGT, the gold standard for occupational heat stress, found strong statistically significant correlations between the daily maximum WBGT and HRI prevalence (R^2= 0.89; p= 0.03). Although further evaluation of work-rest cycles is recommended, protective measures in addition to acclimatization need to be put in place to reduce the burden of HRI in this population.

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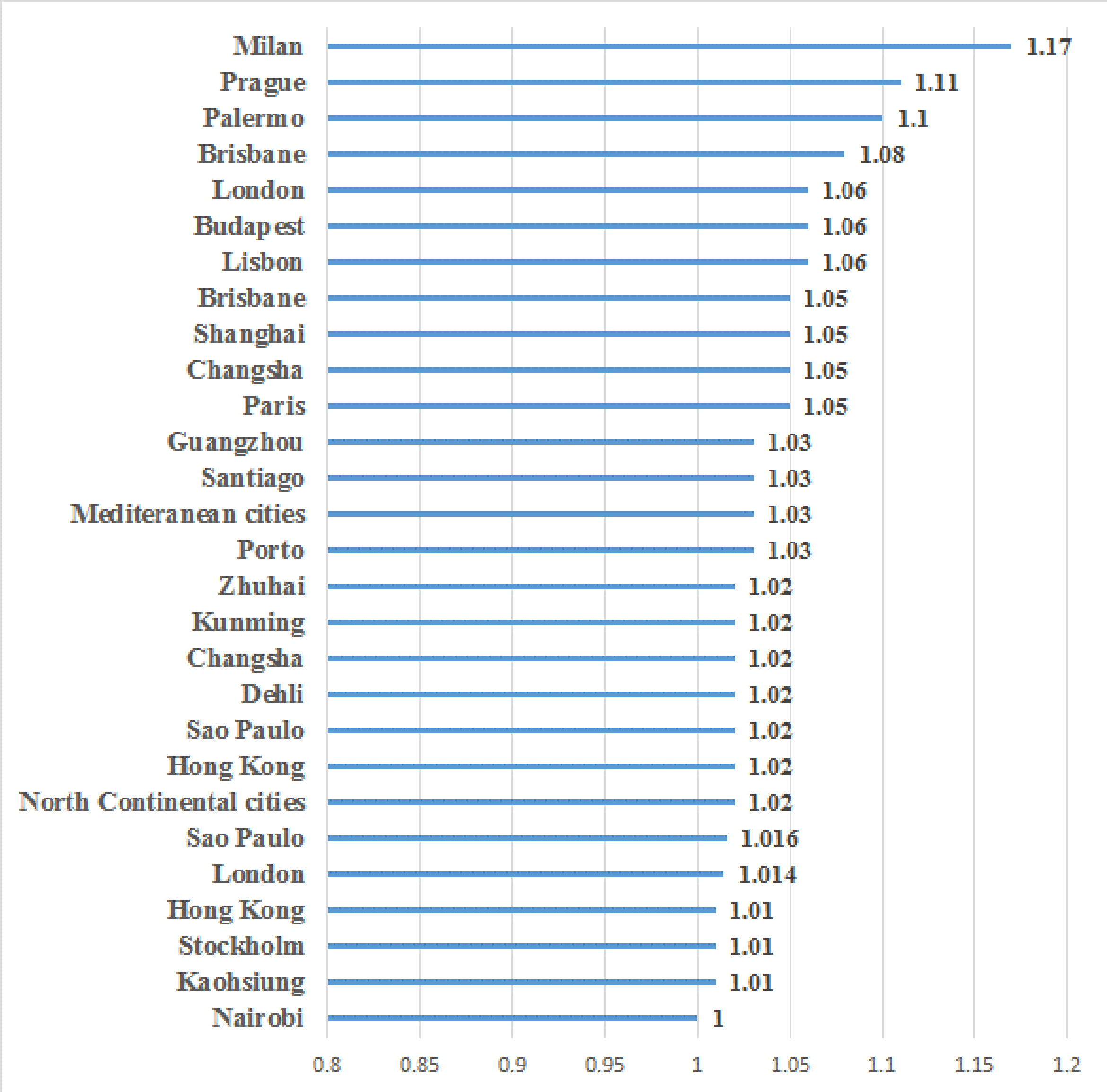
APPENDICES

Appendix A. Relative Risks for Heat-related Mortality Studies in Urban Areas



NB: Unit: RR per 1°C increase; Data adopted from Benmarhnia et al. 2015

Appendix B. Heat Index Values Recorded and HRI Prevalence for Lags 0 and 1

Date of Screening	***Heat Index (°F)*** Lag 0	***Heat Index (°F)*** Lag 1	***Patient encounters (N)***	***Cases of HRI (n)***	***Prevalence (%)***
2014					
7/15	96	96	30	3	10
7/22	89	85	18	7	38.9
7/29	82	94	32	1	3.1
8/5	86	84	37	4	10.8
8/19	85	87	32	4	12.5
8/26	88	92	25	1	4
2015					
7/14	94	90	40	10	25
7/21	97	96	9	4	44.4
8/11	94	94	32	8	25
8/18	88	88	24	3	12.5
2016					
7/12	91	89	34	8	23.5
7/19	98	95	21	1	4.8
7/26	101	101	22	8	36.4
8/9	95	96	23	1	4.3
8/17	97	92	19	3	15.8
8/23	83	83	27	1	3.7

Appendix C. Heat Index Values and HRI Prevalence for Outdoor and Indoor Workers (Lag 0)

Date of Screening	**Heat Index (°F)**	**HRI cases among Outdoor Crop Workers (Prevalence %)**	**HRI cases among Indoor Crop Workers (Prevalence %)**
2014			
7/15	96	3 (10)	0
7/22	89	6 (33.3)	1 (5.5)
7/29	82	1 (3.1)	0
8/5	86	3 (8.1)	1 (2.7)
8/19	85	2 (6.25)	2 (6.25)
8/26	88	1 (4)	0
2015			
7/14	94	7 (17.5)	3 (7.5)
7/21	97	3 (33.3)	1 (11.1)
8/11	94	7 (21.9)	1 (3.1)
8/18	88	2 (8.3)	1 (4.2)
2016			
7/12	91	7 (20.6)	1 (2.9)
7/19	98	1 (4.8)	0
7/26	101	8 (36.4)	0
8/9	95	1 (4.3)	0
8/17	97	3 (15.8)	0
8/23	83	0	1 (3.7)

Appendix D. WBGT Values (°C) Collected on Each Workday/Shift

Time of Recording	Day 1 (July 10)	Day 2 (July 17)	Day 3 (July 24)	Day 4* (July 31)	Day 5 (August 7)	Day 6 (August 14)
09.35 am	22.56	-	-	23.78	29.00	24.56
09.45 am	21.89	-	-	24.17	28.50	26.00
09.55 am	21.50	-	21.28	24.39	29.17	26.56
10.05 am	21.39	26.56	22.00	24.17	30.56	27.00
10.15 am	23.06	26.00	23.06	25.06	28.00	27.00
10.25 am	22.00	26.67	23.89	25.28	30.50	27.67
10.35 am	22.78	27.50	23.28	25.39	30.56	27.56
10.45 am	23.56	27.28	23.17	25.06	31.39	27.50
10.55 am	23.28	26.78	23.67	25.17	29.00	28.28
11.05 am	24.50	26.28	23.78	24.78	29.89	27.89
11.15 am	27.89	29.28	24.28	24.56	30.67	28.00
11.25 am	29.06	28.17	24.06	25.17	30.28	28.06
11.35 am	27.06	29.39	24.28	25.56	31.28	24.89
11.45 am	27.39	28.67	24.67	26.06	32.50	28.28
11.55 am	27.28	29.28	25.17	26.67	32.06	25.50
12.05 pm	29.78	28.89	25.50	26.17	31.89	28.56
12.15 pm	27.67	28.28	24.50	26.78	32.67	26.78
12.25 pm	30.00	29.56	24.17	25.89	30.39	29.00
12.35 pm	30.00	30.00	24.67	25.67	30.28	29.39
12.45 pm	29.89	27.67	24.89	25.06	29.50	27.17
12.55 pm	30.50	29.89	25.00	24.56	28.11	25.39
01.05 pm	29.78	27.67	24.67	24.39	32.06	25.78
01.15 pm	29.78	28.56	25.89	23.67	32.78	28.89
01.25 pm	30.56	27.78	27.28	23.39	31.50	27.28
01.35 pm	29.56	27.39	27.50	23.39	27.78	26.78
01.45 pm	27.00	23.56	26.89	23.50	30.56	28.67
01.55 pm	28.17	22.56	26.56	24.28	33.39	28.28
02.05 pm	29.17	20.50	26.50	24.67	29.00	28.39
02.15 pm	30.28	21.78	26.78	25.28	27.56	28.67
02.25 pm	29.67	23.50	27.00	25.78	28.50	29.00
02.35 pm	29.00	22.17	28.00	25.67	32.39	28.06
02.45 pm	27.00	22.06	26.67	25.89	28.67	29.06
02.55 pm	30.28	22.39	27.78	25.50	31.89	28.28
03.05 pm	29.50	22.67	28.67	25.78	33.56	28.50
03.15 pm	29.06	23.50	28.50	26.56	29.67	26.17
03.25 pm	29.28	24.17	29.67	26.89	30.39	26.06
03.35 pm	26.50	24.89	29.00	26.06	28.67	25.50
03.45 pm	27.17	32.28	29.39	26.78	32.17	26.00
03.55 pm	27.39	28.67	29.50	25.67	30.67	26.89
04.05 pm	29.06	27.78	29.78	26.39	28.67	26.50
04.15 pm	30.06	29.39	27.56	25.17	28.78	25.78
04.25 pm	29.50	28.17	27.28	25.39	31.28	25.89
04.35 pm	30.00	27.00	30.28	25.06	29.17	28.06
04.45 pm	29.17	27.28	30.67	25.06	31.50	24.78
04.55 pm	29.89	27.56	29.39	25.06	32.17	25.28
05.05 pm	30.17	27.39	29.89	24.78	32.67	25.06
05.15 pm	30.67	27.50	26.78	24.56	31.67	25.56
05.25 pm	29.89	27.50	27.17	24.67	30.28	26.56
05. 35 pm	29.06	26.89	27.28	24.17	28.17	27.89
05.45 pm	-	27.06	29.00	-	-	-
05.55 pm	-	26.78	29.67	-	-	-

- denotes no WBGT reading *denotes indoor WBGT readings

Appendix E. Descriptive Statistics for Effect of Days on WBGT

Day	**N**	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval**		**Min**	**Max**
					Lower	Upper		
1	49	27.75	2.85	0.407	26.93	28.56	21.39	30.67
2	48	26.72	2.59	0.375	25.96	27.47	20.50	32.28
3	49	26.45	2.39	0.343	25.76	27.14	21.28	30.67
4	49	25.16	0.91	0.129	24.89	25.41	23.39	26.89
5	49	30.44	1.62	0.232	29.97	30.90	27.56	33.56
6	49	27.11	1.34	0.192	26.73	27.50	24.56	29.39
Total	293	27.27	2.62	0.153	26.97	27.57	20.50	33.56

Appendix F. Multiple Comparison for Effects of Days on WBGT

(I) DAY	(J) DAY	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.02624	.42137	.148	-.1827	2.2352
	3	1.29252*	.41919	.027	.0898	2.4952
	4	2.58844*	.41919	.000	1.3857	3.7911
	5	-2.69615*	.41919	.000	-3.8988	-1.4935
	6	.63052	.41919	.662	-.5722	1.8332
2	1	-1.02624	.42137	.148	-2.2352	.1827
	3	.26628	.42137	.989	-.9427	1.4752
	4	1.56220*	.42137	.003	.3533	2.7711
	5	-3.72239*	.42137	.000	-4.9313	-2.5134
	6	-.39572	.42137	.936	-1.6047	.8132
3	1	-1.29252*	.41919	.027	-2.4952	-.0898
	2	-.26628	.42137	.989	-1.4752	.9427
	4	1.29592*	.41919	.026	.0932	2.4986
	5	-3.98866*	.41919	.000	-5.1914	-2.7860
	6	-.66200	.41919	.613	-1.8647	.5407
4	1	-2.58844*	.41919	.000	-3.7911	-1.3857
	2	-1.56220*	.42137	.003	-2.7711	-.3533
	3	-1.29592*	.41919	.026	-2.4986	-.0932
	5	-5.28458*	.41919	.000	-6.4873	-4.0819
	6	-1.95791*	.41919	.000	-3.1606	-.7552
5	1	2.69615*	.41919	.000	1.4935	3.8988
	2	3.72239*	.42137	.000	2.5134	4.9313
	3	3.98866*	.41919	.000	2.7860	5.1914
	4	5.28458*	.41919	.000	4.0819	6.4873
	6	3.32667*	.41919	.000	2.1240	4.5294
6	1	-.63052	.41919	.662	-1.8332	.5722
	2	.39572	.42137	.936	-.8132	1.6047
	3	.66200	.41919	.613	-.5407	1.8647
	4	1.95791*	.41919	.000	.7552	3.1606
	5	-3.32667*	.41919	.000	-4.5294	-2.1240

Appendix G. Descriptive Statistics for Effects of Days and Hours of Work on WBGT

DAY	TIME	Mean	Std. Deviation	N
Day 1	10AM	22.6759	.82508	6
	11AM	27.1944	1.50134	6
	12NOON	29.6389	.99737	6
	1PM	29.1389	1.30514	6
	2PM	29.2315	1.21788	6
	3PM	28.1481	1.27931	6
	4PM	29.6111	.43461	6
	5PM	29.9444	.67434	4
	9AM	21.9815	.53383	3
	Total	27.7460	2.85024	49
Day 2	10AM	21.9100	.74135	6
	11AM	23.7150	.74782	6
	12NOON	26.5117	.31205	6
	1PM	27.1500	.19473	6
	2PM	27.5200	.09187	6
	3PM	27.9750	.26006	6
	4PM	28.8917	.31934	6
	5PM	30.0850	1.10498	6
	Total	26.7198	2.59750	48
Day 3	10AM	23.4722	.34916	6
	11AM	24.6574	.56918	6
	12NOON	24.6481	.29537	6
	1PM	26.7685	.58311	6
	2PM	27.4815	.79401	6
	3PM	29.3056	.47758	6
	4PM	29.1759	1.42959	6
	5PM	27.9778	1.27330	5
	9AM	21.6389	.51069	2
	Total	26.4535	2.39814	49
Day 4	10AM	25.0185	.43697	6
	11AM	25.4630	.79866	6
	12NOON	25.6852	.79245	6

	1PM	23.7685	.45054	6
	2PM	25.4630	.44537	6
	3PM	26.2870	.52401	6
	4PM	25.3519	.52431	6
	5PM	24.5417	.26595	4
	9AM	24.1111	.30932	3
	Total	25.1576	.90838	49
Day 5	10AM	30.0000	1.24870	6
	11AM	31.1111	1.02319	6
	12NOON	30.4722	1.63630	6
	1PM	31.3426	2.00537	6
	2PM	29.6667	1.98046	6
	3PM	30.8519	1.75881	6
	4PM	30.2593	1.55820	6
	5PM	30.6944	1.94920	4
	9AM	28.8889	.34694	3
	Total	30.4422	1.62288	49
Day 6	10AM	27.5017	.47768	6
	11AM	27.1033	1.49614	6
	12NOON	27.7150	1.53282	6
	1PM	27.6133	1.21306	6
	2PM	28.5767	.40282	6
	3PM	26.5200	1.06791	6
	4PM	26.0483	1.14428	6
	5PM	26.2675	1.24856	4
	9AM	25.7067	1.03176	3
	Total	27.1155	1.34199	49
Total	10AM	25.0964	2.96442	36
	11AM	26.5407	2.62545	36
	12NOON	27.4452	2.32511	36
	1PM	27.6303	2.56655	36
	2PM	27.9899	1.70208	36
	3PM	28.1813	1.85880	36
	4PM	28.2230	2.09857	36
	5PM	28.3774	2.45334	27
	9AM	24.6673	2.78747	14
	Total	27.2743	2.62154	293

Appendix H. Pairwise Comparisons for Effects of Days and Hours of Work

DAY	(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.[d]	97.5% Confidence Interval for Difference[d] Lower Bound	Upper Bound
Day 1	10AM	11AM	-4.519*	.595	.000	-5.860	-3.177
		12NOON	-6.963*	.595	.000	-8.304	-5.622
		1PM	-6.463*	.595	.000	-7.804	-5.122
		2PM	-6.556*	.595	.000	-7.897	-5.214
		3PM	-5.472*	.595	.000	-6.814	-4.131
		4PM	-6.935*	.595	.000	-8.276	-5.594
		5PM	-7.269*	.665	.000	-8.768	-5.769
		9AM	.694	.728	.341	-.948	2.337
	11AM	10AM	4.519*	.595	.000	3.177	5.860
		12NOON	-2.444*	.595	.000	-3.786	-1.103
		1PM	-1.944*	.595	.001	-3.286	-.603
		2PM	-2.037*	.595	.001	-3.378	-.696
		3PM	-.954	.595	.110	-2.295	.388
		4PM	-2.417*	.595	.000	-3.758	-1.075
		5PM	-2.750*	.665	.000	-4.250	-1.250
		9AM	5.213*	.728	.000	3.570	6.856
	12NOON	10AM	6.963*	.595	.000	5.622	8.304
		11AM	2.444*	.595	.000	1.103	3.786
		1PM	.500	.595	.401	-.841	1.841
		2PM	.407	.595	.494	-.934	1.749
		3PM	1.491*	.595	.013	.149	2.832
		4PM	.028	.595	.963	-1.314	1.369
		5PM	-.306	.665	.646	-1.805	1.194
		9AM	7.657*	.728	.000	6.015	9.300
	1PM	10AM	6.463*	.595	.000	5.122	7.804
		11AM	1.944*	.595	.001	.603	3.286
		12NOON	-.500	.595	.401	-1.841	.841
		2PM	-.093	.595	.876	-1.434	1.249
		3PM	.991	.595	.097	-.351	2.332
		4PM	-.472	.595	.428	-1.814	.869
		5PM	-.806	.665	.227	-2.305	.694

	9AM	7.157*	.728	.000	5.515	8.800
2PM	10AM	6.556*	.595	.000	5.214	7.897
	11AM	2.037*	.595	.001	.696	3.378
	12NOON	-.407	.595	.494	-1.749	.934
	1PM	.093	.595	.876	-1.249	1.434
	3PM	1.083	.595	.070	-.258	2.425
	4PM	-.380	.595	.524	-1.721	.962
	5PM	-.713	.665	.285	-2.213	.787
	9AM	7.250*	.728	.000	5.607	8.893
3PM	10AM	5.472*	.595	.000	4.131	6.814
	11AM	.954	.595	.110	-.388	2.295
	12NOON	-1.491*	.595	.013	-2.832	-.149
	1PM	-.991	.595	.097	-2.332	.351
	2PM	-1.083	.595	.070	-2.425	.258
	4PM	-1.463*	.595	.015	-2.804	-.122
	5PM	-1.796*	.665	.007	-3.296	-.297
	9AM	6.167*	.728	.000	4.524	7.809
4PM	10AM	6.935*	.595	.000	5.594	8.276
	11AM	2.417*	.595	.000	1.075	3.758
	12NOON	-.028	.595	.963	-1.369	1.314
	1PM	.472	.595	.428	-.869	1.814
	2PM	.380	.595	.524	-.962	1.721
	3PM	1.463*	.595	.015	.122	2.804
	5PM	-.333	.665	.617	-1.833	1.166
	9AM	7.630*	.728	.000	5.987	9.272
5PM	10AM	7.269*	.665	.000	5.769	8.768
	11AM	2.750*	.665	.000	1.250	4.250
	12NOON	.306	.665	.646	-1.194	1.805
	1PM	.806	.665	.227	-.694	2.305
	2PM	.713	.665	.285	-.787	2.213
	3PM	1.796*	.665	.007	.297	3.296
	4PM	.333	.665	.617	-1.166	1.833
	9AM	7.963*	.787	.000	6.189	9.737
9AM	10AM	-.694	.728	.341	-2.337	.948
	11AM	-5.213*	.728	.000	-6.856	-3.570
	12NOON	-7.657*	.728	.000	-9.300	-6.015
	1PM	-7.157*	.728	.000	-8.800	-5.515
	2PM	-7.250*	.728	.000	-8.893	-5.607

		3PM	-6.167*	.728	.000	-7.809	-4.524
		4PM	-7.630*	.728	.000	-9.272	-5.987
		5PM	-7.963*	.787	.000	-9.737	-6.189
Day 2	10AM	11AM	-1.805*	.595	.003	-3.146	-.464
		12NOON	-4.602*	.595	.000	-5.943	-3.260
		1PM	-5.240*	.595	.000	-6.581	-3.899
		2PM	-5.610*	.595	.000	-6.951	-4.269
		3PM	-6.065*	.595	.000	-7.406	-4.724
		4PM	-6.982*	.595	.000	-8.323	-5.640
		5PM	-8.175*	.595	.000	-9.516	-6.834
		9AM	.b	.	.	.	.
	11AM	10AM	1.805*	.595	.003	.464	3.146
		12NOON	-2.797*	.595	.000	-4.138	-1.455
		1PM	-3.435*	.595	.000	-4.776	-2.094
		2PM	-3.805*	.595	.000	-5.146	-2.464
		3PM	-4.260*	.595	.000	-5.601	-2.919
		4PM	-5.177*	.595	.000	-6.518	-3.835
		5PM	-6.370*	.595	.000	-7.711	-5.029
		9AM	.b	.	.	.	.
	12NOON	10AM	4.602*	.595	.000	3.260	5.943
		11AM	2.797*	.595	.000	1.455	4.138
		1PM	-.638	.595	.284	-1.980	.703
		2PM	-1.008	.595	.091	-2.350	.333
		3PM	-1.463*	.595	.015	-2.805	-.122
		4PM	-2.380*	.595	.000	-3.721	-1.039
		5PM	-3.573*	.595	.000	-4.915	-2.232
		9AM	.b	.	.	.	.
	1PM	10AM	5.240*	.595	.000	3.899	6.581
		11AM	3.435*	.595	.000	2.094	4.776
		12NOON	.638	.595	.284	-.703	1.980
		2PM	-.370	.595	.534	-1.711	.971
		3PM	-.825	.595	.167	-2.166	.516
		4PM	-1.742*	.595	.004	-3.083	-.400
		5PM	-2.935*	.595	.000	-4.276	-1.594
		9AM	.b	.	.	.	.
	2PM	10AM	5.610*	.595	.000	4.269	6.951
		11AM	3.805*	.595	.000	2.464	5.146
		12NOON	1.008	.595	.091	-.333	2.350

		1PM	.370	.595	.534	-.971	1.711
		3PM	-.455	.595	.445	-1.796	.886
		4PM	-1.372*	.595	.022	-2.713	-.030
		5PM	-2.565*	.595	.000	-3.906	-1.224
		9AM	.[b]	.	.	.	.
	3PM	10AM	6.065*	.595	.000	4.724	7.406
		11AM	4.260*	.595	.000	2.919	5.601
		12NOON	1.463*	.595	.015	.122	2.805
		1PM	.825	.595	.167	-.516	2.166
		2PM	.455	.595	.445	-.886	1.796
		4PM	-.917	.595	.125	-2.258	.425
		5PM	-2.110*	.595	.000	-3.451	-.769
		9AM	.[b]	.	.	.	.
	4PM	10AM	6.982*	.595	.000	5.640	8.323
		11AM	5.177*	.595	.000	3.835	6.518
		12NOON	2.380*	.595	.000	1.039	3.721
		1PM	1.742*	.595	.004	.400	3.083
		2PM	1.372*	.595	.022	.030	2.713
		3PM	.917	.595	.125	-.425	2.258
		5PM	-1.193	.595	.046	-2.535	.148
		9AM	.[b]	.	.	.	.
	5PM	10AM	8.175*	.595	.000	6.834	9.516
		11AM	6.370*	.595	.000	5.029	7.711
		12NOON	3.573*	.595	.000	2.232	4.915
		1PM	2.935*	.595	.000	1.594	4.276
		2PM	2.565*	.595	.000	1.224	3.906
		3PM	2.110*	.595	.000	.769	3.451
		4PM	1.193	.595	.046	-.148	2.535
		9AM	.[b]	.	.	.	.
	9AM	10AM	.[c]	.	.	.	.
		11AM	.[c]	.	.	.	.
		12NOON	.[c]	.	.	.	.
		1PM	.[c]	.	.	.	.
		2PM	.[c]	.	.	.	.
		3PM	.[c]	.	.	.	.
		4PM	.[c]	.	.	.	.
		5PM	.[c]	.	.	.	.
Day 3	10AM	11AM	-1.185	.595	.047	-2.526	.156

	12NOON	-1.176	.595	.049	-2.517	.165
	1PM	-3.296*	.595	.000	-4.638	-1.955
	2PM	-4.009*	.595	.000	-5.351	-2.668
	3PM	-5.833*	.595	.000	-7.175	-4.492
	4PM	-5.704*	.595	.000	-7.045	-4.362
	5PM	-4.506*	.624	.000	-5.912	-3.099
	9AM	1.833	.841	.030	-.064	3.730
11AM	10AM	1.185	.595	.047	-.156	2.526
	12NOON	.009	.595	.988	-1.332	1.351
	1PM	-2.111*	.595	.000	-3.452	-.770
	2PM	-2.824*	.595	.000	-4.165	-1.483
	3PM	-4.648*	.595	.000	-5.989	-3.307
	4PM	-4.519*	.595	.000	-5.860	-3.177
	5PM	-3.320*	.624	.000	-4.727	-1.914
	9AM	3.019*	.841	.000	1.122	4.915
12NOON	10AM	1.176	.595	.049	-.165	2.517
	11AM	-.009	.595	.988	-1.351	1.332
	1PM	-2.120*	.595	.000	-3.462	-.779
	2PM	-2.833*	.595	.000	-4.175	-1.492
	3PM	-4.657*	.595	.000	-5.999	-3.316
	4PM	-4.528*	.595	.000	-5.869	-3.186
	5PM	-3.330*	.624	.000	-4.736	-1.923
	9AM	3.009*	.841	.000	1.112	4.906
1PM	10AM	3.296*	.595	.000	1.955	4.638
	11AM	2.111*	.595	.000	.770	3.452
	12NOON	2.120*	.595	.000	.779	3.462
	2PM	-.713	.595	.232	-2.054	.628
	3PM	-2.537*	.595	.000	-3.878	-1.196
	4PM	-2.407*	.595	.000	-3.749	-1.066
	5PM	-1.209	.624	.054	-2.616	.198
	9AM	5.130*	.841	.000	3.233	7.027
2PM	10AM	4.009*	.595	.000	2.668	5.351
	11AM	2.824*	.595	.000	1.483	4.165
	12NOON	2.833*	.595	.000	1.492	4.175
	1PM	.713	.595	.232	-.628	2.054
	3PM	-1.824*	.595	.002	-3.165	-.483
	4PM	-1.694*	.595	.005	-3.036	-.353
	5PM	-.496	.624	.427	-1.903	.910

		9AM	5.843*	.841	.000	3.946	7.739
	3PM	10AM	5.833*	.595	.000	4.492	7.175
		11AM	4.648*	.595	.000	3.307	5.989
		12NOON	4.657*	.595	.000	3.316	5.999
		1PM	2.537*	.595	.000	1.196	3.878
		2PM	1.824*	.595	.002	.483	3.165
		4PM	.130	.595	.828	-1.212	1.471
		5PM	1.328	.624	.034	-.079	2.735
		9AM	7.667*	.841	.000	5.770	9.564
	4PM	10AM	5.704*	.595	.000	4.362	7.045
		11AM	4.519*	.595	.000	3.177	5.860
		12NOON	4.528*	.595	.000	3.186	5.869
		1PM	2.407*	.595	.000	1.066	3.749
		2PM	1.694*	.595	.005	.353	3.036
		3PM	-.130	.595	.828	-1.471	1.212
		5PM	1.198	.624	.056	-.209	2.605
		9AM	7.537*	.841	.000	5.640	9.434
	5PM	10AM	4.506*	.624	.000	3.099	5.912
		11AM	3.320*	.624	.000	1.914	4.727
		12NOON	3.330*	.624	.000	1.923	4.736
		1PM	1.209	.624	.054	-.198	2.616
		2PM	.496	.624	.427	-.910	1.903
		3PM	-1.328	.624	.034	-2.735	.079
		4PM	-1.198	.624	.056	-2.605	.209
		9AM	6.339*	.862	.000	4.395	8.283
	9AM	10AM	-1.833	.841	.030	-3.730	.064
		11AM	-3.019*	.841	.000	-4.915	-1.122
		12NOON	-3.009*	.841	.000	-4.906	-1.112
		1PM	-5.130*	.841	.000	-7.027	-3.233
		2PM	-5.843*	.841	.000	-7.739	-3.946
		3PM	-7.667*	.841	.000	-9.564	-5.770
		4PM	-7.537*	.841	.000	-9.434	-5.640
		5PM	-6.339*	.862	.000	-8.283	-4.395
Day 4	10AM	11AM	-.444	.595	.456	-1.786	.897
		12NOON	-.667	.595	.263	-2.008	.675
		1PM	1.250	.595	.037	-.091	2.591
		2PM	-.444	.595	.456	-1.786	.897
		3PM	-1.269	.595	.034	-2.610	.073

	4PM	-.333	.595	.576	-1.675	1.008
	5PM	.477	.665	.474	-1.023	1.976
	9AM	.907	.728	.214	-.735	2.550
11AM	10AM	.444	.595	.456	-.897	1.786
	12NOON	-.222	.595	.709	-1.564	1.119
	1PM	1.694*	.595	.005	.353	3.036
	2PM	-3.997E-15	.595	1.000	-1.341	1.341
	3PM	-.824	.595	.167	-2.165	.517
	4PM	.111	.595	.852	-1.230	1.452
	5PM	.921	.665	.167	-.578	2.421
	9AM	1.352	.728	.065	-.291	2.995
12NOON	10AM	.667	.595	.263	-.675	2.008
	11AM	.222	.595	.709	-1.119	1.564
	1PM	1.917*	.595	.001	.575	3.258
	2PM	.222	.595	.709	-1.119	1.564
	3PM	-.602	.595	.313	-1.943	.739
	4PM	.333	.595	.576	-1.008	1.675
	5PM	1.144	.665	.087	-.356	2.643
	9AM	1.574	.728	.032	-.069	3.217
1PM	10AM	-1.250	.595	.037	-2.591	.091
	11AM	-1.694*	.595	.005	-3.036	-.353
	12NOON	-1.917*	.595	.001	-3.258	-.575
	2PM	-1.694*	.595	.005	-3.036	-.353
	3PM	-2.519*	.595	.000	-3.860	-1.177
	4PM	-1.583*	.595	.008	-2.925	-.242
	5PM	-.773	.665	.246	-2.273	.726
	9AM	-.343	.728	.639	-1.985	1.300
2PM	10AM	.444	.595	.456	-.897	1.786
	11AM	3.997E-15	.595	1.000	-1.341	1.341
	12NOON	-.222	.595	.709	-1.564	1.119
	1PM	1.694*	.595	.005	.353	3.036
	3PM	-.824	.595	.167	-2.165	.517
	4PM	.111	.595	.852	-1.230	1.452
	5PM	.921	.665	.167	-.578	2.421
	9AM	1.352	.728	.065	-.291	2.995
3PM	10AM	1.269	.595	.034	-.073	2.610
	11AM	.824	.595	.167	-.517	2.165
	12NOON	.602	.595	.313	-.739	1.943

		1PM	2.519*	.595	.000	1.177	3.860
		2PM	.824	.595	.167	-.517	2.165
		4PM	.935	.595	.117	-.406	2.276
		5PM	1.745*	.665	.009	.246	3.245
		9AM	2.176*	.728	.003	.533	3.819
	4PM	10AM	.333	.595	.576	-1.008	1.675
		11AM	-.111	.595	.852	-1.452	1.230
		12NOON	-.333	.595	.576	-1.675	1.008
		1PM	1.583*	.595	.008	.242	2.925
		2PM	-.111	.595	.852	-1.452	1.230
		3PM	-.935	.595	.117	-2.276	.406
		5PM	.810	.665	.224	-.689	2.310
		9AM	1.241	.728	.090	-.402	2.883
	5PM	10AM	-.477	.665	.474	-1.976	1.023
		11AM	-.921	.665	.167	-2.421	.578
		12NOON	-1.144	.665	.087	-2.643	.356
		1PM	.773	.665	.246	-.726	2.273
		2PM	-.921	.665	.167	-2.421	.578
		3PM	-1.745*	.665	.009	-3.245	-.246
		4PM	-.810	.665	.224	-2.310	.689
		9AM	.431	.787	.585	-1.344	2.205
	9AM	10AM	-.907	.728	.214	-2.550	.735
		11AM	-1.352	.728	.065	-2.995	.291
		12NOON	-1.574	.728	.032	-3.217	.069
		1PM	.343	.728	.639	-1.300	1.985
		2PM	-1.352	.728	.065	-2.995	.291
		3PM	-2.176*	.728	.003	-3.819	-.533
		4PM	-1.241	.728	.090	-2.883	.402
		5PM	-.431	.787	.585	-2.205	1.344
Day 5	10AM	11AM	-1.111	.595	.063	-2.452	.230
		12NOON	-.472	.595	.428	-1.814	.869
		1PM	-1.343*	.595	.025	-2.684	-.001
		2PM	.333	.595	.576	-1.008	1.675
		3PM	-.852	.595	.153	-2.193	.489
		4PM	-.259	.595	.663	-1.601	1.082
		5PM	-.694	.665	.297	-2.194	.805
		9AM	1.111	.728	.128	-.532	2.754
	11AM	10AM	1.111	.595	.063	-.230	2.452

	12NOON	.639	.595	.284	-.702	1.980
	1PM	-.231	.595	.697	-1.573	1.110
	2PM	1.444*	.595	.016	.103	2.786
	3PM	.259	.595	.663	-1.082	1.601
	4PM	.852	.595	.153	-.489	2.193
	5PM	.417	.665	.531	-1.083	1.916
	9AM	2.222*	.728	.003	.579	3.865
12NOON	10AM	.472	.595	.428	-.869	1.814
	11AM	-.639	.595	.284	-1.980	.702
	1PM	-.870	.595	.145	-2.212	.471
	2PM	.806	.595	.177	-.536	2.147
	3PM	-.380	.595	.524	-1.721	.962
	4PM	.213	.595	.721	-1.128	1.554
	5PM	-.222	.665	.738	-1.722	1.277
	9AM	1.583	.728	.031	-.059	3.226
1PM	10AM	1.343*	.595	.025	.001	2.684
	11AM	.231	.595	.697	-1.110	1.573
	12NOON	.870	.595	.145	-.471	2.212
	2PM	1.676*	.595	.005	.335	3.017
	3PM	.491	.595	.410	-.851	1.832
	4PM	1.083	.595	.070	-.258	2.425
	5PM	.648	.665	.331	-.851	2.148
	9AM	2.454*	.728	.001	.811	4.096
2PM	10AM	-.333	.595	.576	-1.675	1.008
	11AM	-1.444*	.595	.016	-2.786	-.103
	12NOON	-.806	.595	.177	-2.147	.536
	1PM	-1.676*	.595	.005	-3.017	-.335
	3PM	-1.185	.595	.047	-2.526	.156
	4PM	-.593	.595	.320	-1.934	.749
	5PM	-1.028	.665	.123	-2.527	.472
	9AM	.778	.728	.287	-.865	2.421
3PM	10AM	.852	.595	.153	-.489	2.193
	11AM	-.259	.595	.663	-1.601	1.082
	12NOON	.380	.595	.524	-.962	1.721
	1PM	-.491	.595	.410	-1.832	.851
	2PM	1.185	.595	.047	-.156	2.526
	4PM	.593	.595	.320	-.749	1.934
	5PM	.157	.665	.813	-1.342	1.657

		9AM	1.963*	.728	.008	.320	3.606
	4PM	10AM	.259	.595	.663	-1.082	1.601
		11AM	-.852	.595	.153	-2.193	.489
		12NOON	-.213	.595	.721	-1.554	1.128
		1PM	-1.083	.595	.070	-2.425	.258
		2PM	.593	.595	.320	-.749	1.934
		3PM	-.593	.595	.320	-1.934	.749
		5PM	-.435	.665	.513	-1.935	1.064
		9AM	1.370	.728	.061	-.272	3.013
	5PM	10AM	.694	.665	.297	-.805	2.194
		11AM	-.417	.665	.531	-1.916	1.083
		12NOON	.222	.665	.738	-1.277	1.722
		1PM	-.648	.665	.331	-2.148	.851
		2PM	1.028	.665	.123	-.472	2.527
		3PM	-.157	.665	.813	-1.657	1.342
		4PM	.435	.665	.513	-1.064	1.935
		9AM	1.806*	.787	.023	.031	3.580
	9AM	10AM	-1.111	.728	.128	-2.754	.532
		11AM	-2.222*	.728	.003	-3.865	-.579
		12NOON	-1.583	.728	.031	-3.226	.059
		1PM	-2.454*	.728	.001	-4.096	-.811
		2PM	-.778	.728	.287	-2.421	.865
		3PM	-1.963*	.728	.008	-3.606	-.320
		4PM	-1.370	.728	.061	-3.013	.272
		5PM	-1.806*	.787	.023	-3.580	-.031
Day 6	10AM	11AM	.398	.595	.504	-.943	1.740
		12NOON	-.213	.595	.720	-1.555	1.128
		1PM	-.112	.595	.851	-1.453	1.230
		2PM	-1.075	.595	.072	-2.416	.266
		3PM	.982	.595	.100	-.360	2.323
		4PM	1.453*	.595	.015	.112	2.795
		5PM	1.234	.665	.065	-.265	2.734
		9AM	1.795*	.728	.014	.152	3.438
	11AM	10AM	-.398	.595	.504	-1.740	.943
		12NOON	-.612	.595	.305	-1.953	.730
		1PM	-.510	.595	.392	-1.851	.831
		2PM	-1.473*	.595	.014	-2.815	-.132
		3PM	.583	.595	.328	-.758	1.925

		4PM	1.055	.595	.077	-.286	2.396
		5PM	.836	.665	.210	-.664	2.335
		9AM	1.397	.728	.056	-.246	3.039
	12NOON	10AM	.213	.595	.720	-1.128	1.555
		11AM	.612	.595	.305	-.730	1.953
		1PM	.102	.595	.864	-1.240	1.443
		2PM	-.862	.595	.149	-2.203	.480
		3PM	1.195	.595	.046	-.146	2.536
		4PM	1.667*	.595	.005	.325	3.008
		5PM	1.447	.665	.030	-.052	2.947
		9AM	2.008*	.728	.006	.366	3.651
	1PM	10AM	.112	.595	.851	-1.230	1.453
		11AM	.510	.595	.392	-.831	1.851
		12NOON	-.102	.595	.864	-1.443	1.240
		2PM	-.963	.595	.107	-2.305	.378
		3PM	1.093	.595	.067	-.248	2.435
		4PM	1.565*	.595	.009	.224	2.906
		5PM	1.346	.665	.044	-.154	2.845
		9AM	1.907*	.728	.009	.264	3.549
	2PM	10AM	1.075	.595	.072	-.266	2.416
		11AM	1.473*	.595	.014	.132	2.815
		12NOON	.862	.595	.149	-.480	2.203
		1PM	.963	.595	.107	-.378	2.305
		3PM	2.057*	.595	.001	.715	3.398
		4PM	2.528*	.595	.000	1.187	3.870
		5PM	2.309*	.665	.001	.810	3.809
		9AM	2.870*	.728	.000	1.227	4.513
	3PM	10AM	-.982	.595	.100	-2.323	.360
		11AM	-.583	.595	.328	-1.925	.758
		12NOON	-1.195	.595	.046	-2.536	.146
		1PM	-1.093	.595	.067	-2.435	.248
		2PM	-2.057*	.595	.001	-3.398	-.715
		4PM	.472	.595	.428	-.870	1.813
		5PM	.252	.665	.704	-1.247	1.752
		9AM	.813	.728	.265	-.829	2.456
	4PM	10AM	-1.453*	.595	.015	-2.795	-.112
		11AM	-1.055	.595	.077	-2.396	.286
		12NOON	-1.667*	.595	.005	-3.008	-.325

	1PM	-1.565*	.595	.009	-2.906	-.224
	2PM	-2.528*	.595	.000	-3.870	-1.187
	3PM	-.472	.595	.428	-1.813	.870
	5PM	-.219	.665	.742	-1.719	1.280
	9AM	.342	.728	.639	-1.301	1.984
5PM	10AM	-1.234	.665	.065	-2.734	.265
	11AM	-.836	.665	.210	-2.335	.664
	12NOON	-1.447	.665	.030	-2.947	.052
	1PM	-1.346	.665	.044	-2.845	.154
	2PM	-2.309*	.665	.001	-3.809	-.810
	3PM	-.252	.665	.704	-1.752	1.247
	4PM	.219	.665	.742	-1.280	1.719
	9AM	.561	.787	.477	-1.214	2.335
9AM	10AM	-1.795*	.728	.014	-3.438	-.152
	11AM	-1.397	.728	.056	-3.039	.246
	1PM	-1.907*	.728	.009	-3.549	-.264
	2PM	-2.870*	.728	.000	-4.513	-1.227
	3PM	-.813	.728	.265	-2.456	.829
	4PM	-.342	.728	.639	-1.984	1.301
	5PM	-.561	.787	.477	-2.335	1.214

Based on estimated marginal means

*. The mean difference is significant at the .025 level.

b. The level combination of factors in (J) is not observed.

c. The level combination of factors in (I) is not observed.

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

VITA

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	Li, Y., Odame, E., Silver, K., and Zheng, S. Comparing Urban and Rural Vulnerability to Heat-Related Mortality: A Systematic Review and Meta-analysis. *J Global Epid and Environ Health*. Published October 27, 2017.