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The geography of extreme heat hazards for American football players

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A B S T R A C T

American Football players are among the most susceptible athletes to heat-related illnesses. Environmental conditions are an important factor when considering risk rates for these illnesses. Thus, we examine the spatio-temporal variations in the wet bulb globe temperature (WBGT), a commonly used metric for heat exposure, and quantify the hazard for extreme heat using safety thresholds specifically derived for athletes from the American College of Sports Medicine (ACSM). The objective is to provide better information on heat-related hazards to help mitigate the risk of exertional heat illnesses (EHI) among football players. We created a unique 15-year climatology (1991–2005) of August WBGTs for 217 locations across the contiguous United States using weather station observations and a WBGT model. Thirteen 3-h overlapping training session times ranging from 6–9 a.m. to 6–9 p.m. were examined to identify how the WBGT varies with the time of day the practice session was held and how frequently the WBGT during those sessions posed a hazard for extreme heat by exceeding two ACSM safety thresholds (30.1 °C and 32.3 °C). Maximum hazards for extreme heat are located in an arc across the Southern tier of the country, stretching from eastern Texas through to South Carolina as well as across southern Arizona and southeastern California. Climatologically, practice sessions early in the morning and later in the evening were best for minimizing heat exposure while those held from late morning through afternoon, particularly the noon-3 p.m. and 1–4 p.m. periods, had the highest WBGT values and were the practice periods that most frequently exceeded safety thresholds. Delaying the start of afternoon practices a few hours, however, may substantially reduce the likelihood of oppressive conditions and reduce the risk for heat illnesses.

Introduction

Extreme heat is a leading weather-related killer across the United States and results in 100's of deaths per year (NWS, 2013). It also causes many heat-related illnesses including heat cramps, heat exhaustion, and most dangerously, heat stroke (NWS, 2013). The risk for adverse outcomes from extreme heat is not evenly distributed through the population but rather varies by factors such as age, health, and level of poverty which affect social vulnerability and by exposure with vulnerable groups including outdoor laborers and urban dwellers (O'Neill & Ebi, 2009). Identifying the most "at risk" populations is an important aspect in developing a heat policy as it allows for targeting of mitigation measures. Several heat-specific vulnerability indices have been developed to geographically identify susceptible populations for heat morbidity and mortality (e.g. Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006; Harlan, Declet-Barreto, Stefanov, & Petitti, 2013; Johnson, Stanforth, Lulla, & Luber, 2012; Reid et al., 2012; Reid et al., 2009; Rinner et al., 2010; Uejio et al., 2011; Vescovi, Rebetez, & Rong, 2005).

These heat vulnerability studies, however, have not specifically considered risks to a subset of the population like athletes who often perform strenuous activities in hot conditions. This study will focus on American Interscholastic Football players as they are highly susceptible to exertional heat illnesses and suffer a disproportionate number of heat-related injuries compared with other athletes (Kerr, Casa, Marshall, & Comstock, 2013). Heat is also among the top three causes of fatalities among football players (Boden, Breit, Beachler, Williams, & Mueller, 2013) and has contributed to 123 deaths over the 1960–2009 period (Mueller & Colgate, 2010, 30 pp.). Also of concern is that since the mid-1990s, there has been a near tripling of heat-related deaths to almost three per year (Grundstein et al., 2012). The greater risk of heat-

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illnesses for football players is related to the timing of pre-season practice in late July and August where the likelihood of extreme heat is high (Cooper, Ferrara, & Broglio, 2006; Grundstein et al., 2012) and also factors such as their physical characteristics (Godek, Godek, & Bartolozzi, 2004) and the equipment they must wear (e.g. Armstrong et al., 2010; Brothers, Mitchell, & Smith, 2004; Fox, Mathews, Kaufman, & Bower, 1966; Kulka & Kenney, 2002; Mathews, Fox, & Tanzi, 1969; McCullough & Kenney, 2003) that increase their vulnerability. Heat-related morbidity and mortality among football players, however, are not evenly distributed across the country. Grundstein et al. (2012) mapped the distribution of 123 heat-related football fatalities from 1980 to 2009 and found a concentration in deaths across the Southeastern portion of the country. The highest rates of heat-related illnesses among football players where observed in Arizona, Alabama, Florida, and Kentucky (Kerr et al., 2013).

Given this threat, a number of governing bodies have adopted heat policies to reduce the risk for heat-related illnesses, which include heat thresholds for activity modification and periods for acclimatization. Presently, the National Football League (NFL) and the National Collegiate Athletic Association (NCAA) have implemented heat policies for their athletes (Korey Stringer Institute, 2013a). Also, several states have developed heat policies for their youth athletes that have been endorsed by the National Athletic Trainers' Association (NATA) and the Korey Stringer Institute (KSI; Korey Stringer Institute, 2013a). A good example of a comprehensive heat policy for high school athletes was adopted in 2012 by the Georgia High School Association (GHSA) which includes guidelines for pre-season heat acclimatization and for adjustments in training intensity, work-to-rest ratios, and equipment under different environmental conditions (GHSA, 2013).

Minimizing exposure to extreme heat is an important component of many heat policies and one way to help mitigate the possibility of a heat-illness. In considering heat-related hazards, there are a variety of metrics that are used operationally to quantify heat exposure. The National Oceanic and Atmospheric Administration's (NOAA) heat watch-warning-advisory system utilizes the heat index (Rothfusz, 1990; Steadman, 1979), which integrates ambient air temperature and humidity, in conjunction with a series of public service messages that vary depending the likelihood and magnitude of hazardous conditions (NOAA 2013). Many youth heat-policy guidelines such as the Oregon School Activities Association (OSAA, 2013) use the heat index as it is well-known and data are readily available. The heat index, however, is not necessarily the best metric for athletes due to a number of assumptions in its computation (Grundstein et al., 2012). For instance, it assumes that the individual is shaded, dressed lightly, and not engaged in strenuous activity (Rothfusz, 1990).

Within athletics, the wet bulb globe temperature (WBGT) is the most commonly used measure for heat exposure and is designed to integrate the influences of air temperature, wind speed, humidity, and solar radiation on human comfort (Yaglou & Minard, 1957). It is calculated as a weighted average of the dry bulb (DB), natural wet bulb (NWB), and globe temperatures (GT) as follows: $WBGT = 0.7^{*}NWB + 0.2^{*}GT + 0.1^{*}DB$. Organizations such as Sports Medicine Australia, NATA, the American College of Sports Medicine (ACSM), and the American Academy of Pediatrics have established safety guidelines based on the WBGT to reduce the risk for injuries associated with oppressive heat (American Academy of Pediatrics, 2000; Armstrong et al., 2007; Binkley, Beckett, Casa, Kleiner, & Plummer, 2002; Sports Medicine Australia, 2012). Many high schools and colleges in the United States, including the high school heat policy in Georgia, rely on guidelines from the ACSM (Armstrong et al., 2007) in establishing their heat policies.

The WBGT, however, is not routinely measured like meteorological variables such as temperature, wind speed, or humidity. As a result, no climatology of WBGT across the contiguous United States has ever been created. A WBGT climatology would be useful for identifying areas with particular hazards for heat and may help inform the development of heat policies and strategies. Also, temperature and other meteorological variables that influence the human heat-balance like solar radiation, wind speed, and humidity change through the course of the day, resulting in differing values of WBGT and levels of hazard for oppressive heat at given locations. Football practices are held at various times through the day, often with the primary concern to coordinate with the school day. To date, no research has examined how changes in practice times can enhance or mitigate the hazard from extreme heat. This assessment, then, seeks to examine two research questions:

- Where do the greatest hazards for extreme heat with regard to American Football practices occur across the contiguous U.S.?
- How does the hazard from extreme heat vary among different practice times?

Methods

We developed a unique 15-year climatology (1991–2005) of August WBGTs for 217 locations across the contiguous United States using weather station observations and a WBGT model developed by Liljegren, Carhart, Lawday, Tschopp, and Sharp (2008). The model is physically-based and explicitly calculates the wet bulb and globe temperatures under different meteorological conditions (e.g. differences in air temperature, relative humidity, wind speed, solar radiation, and surface pressure). The simulated wet bulb and globe temperatures are combined with the observed dry bulb temperature to create the modeled WBGT. The advantage of using a physically-based model over a statistical one based on regression analysis (e.g. Hunter & Minyard, 1999) is that it has wide geographic applicability and is not tied to the particular conditions at one location. Liljegren et al. (2008) documented the robustness of the model by finding an accuracy ≤ 1 °C at multiple test sites in different climate regions. We used hourly meteorological input data from the National Solar Radiation Database (NSRDB; NREL, 2007, 472 pp.). While other stations are available within the dataset, we relied on the class I stations which have the highest quality modeled solar radiation and have the most complete periods of record. Wind speeds in the NSRDB dataset are collected at 10 m and were adjusted to 2 m using a logarithmic wind profile to represent the wind speeds on the practice field more accurately (Stull, 2000).

Our analysis focuses on the month of August, as it is typically the first month of football practice and studies have shown this as the most dangerous period for heat-related illnesses among football players (e.g. Cooper et al., 2006; Grundstein et al., 2012). Thirteen overlapping 3-h training sessions, ranging from 6–9 a.m. to 6–9 p.m. LDT, were considered to identify how the WBGT varies with the time of the practice session and when there would be an increased hazard for extreme heat. For each training period at each of the 217 stations, we calculated the average WBGT. Also, heat-related hazards are identified using ACSM safety categories (Armstrong et al., 2007), with a focus on two key thresholds where practices would need to be limited (30.1 °C) or canceled (32.3 °C). A heat hazard is defined as WBGT values $\geq$30.1 °C and an extreme heat hazard as those values $>$32.3 °C. We identify the frequency of heat and extreme heat hazards by computing the percentage of hours within each 3-h time period where the WBGT exceeds the two thresholds.