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Regional heat safety thresholds for athletics in the contiguous United States

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ABSTRACT

Exertional heat illnesses affect thousands of athletes each year across the United States (U.S.). Heat safety guidelines such as those developed by the American College of Sports Medicine (ACSM) are widely used to direct activities based on environmental conditions but rely on a uniform set of heat safety categories. Due to geographic variations in heat exposure and acclimatization, however, lower heat safety thresholds may be needed in areas with cooler climates. Our study addresses this shortcoming by developing regional guidelines for athletic activity that use relative thresholds of a commonly used heat metric – the wet bulb globe temperature (WBGT). We employed a unique WBGT climatology for the contiguous U.S. to determine locally extreme WBGTs, defined as the 90th percentile warm season daily maximum value, for 217 stations. Three heat safety regions were identified based on local extremes: Category 3 (WBGTs $\geq$ 32.3 °C), Category 2 (30.1–32.2 °C), and Category 1 ($\leq$30 °C). Geographically, Category 3 encompasses much of the southeastern quadrant of the U.S. along with portions of the Southwest, and the Central Valley of California; Category 2 areas extend in an arc from the interior Northwest through Nevada and portions of the Midwest, Ohio Valley, and Northeast; and Category 1 locations include the Pacific Coast, New England, and the northern tier of the country. Associated regional activity guidelines based on those developed by the ACSM and the Georgia High School Association (GHSA) were developed for each heat safety region.

Introduction

Each year, thousands of athletes across the United States (U.S) suffer exertional heat illnesses (EHIs) such as heat cramps, heat exhaustion, and most seriously heat stroke (Kerr, Casa, Marshall, & Comstock, 2013; Nelson, Collins, Comstock, & McKenzie, 2011). Epidemiological studies show that heat illneses are a particular problem for high school athletes and especially football players, where they are a prominent cause of death and disability (Huffman, Yard, Fields, Collins, & Comstock, 2008; Kerr et al. 2013; Yard et al. 2010). Further, injuries from heat illnesses have wide geographic distribution and are not necessarily concentrated in southern areas of the country. For example, EHI rates for football players in many northern and midwestern states such as Nebraska, Iowa, and Minnesota are comparable to those in southern states like Georgia and South Carolina (Kerr et al. 2013).

EHIs are a multifaceted problem with contributing factors including environmental, behavioral, and health-related components (Casa, Armstrong, Ganio, & Yeargin, 2005; Rav-Acha, Hadad, Epstein, Heled, & Moran, 2004). Meteorological conditions, however, are still an important consideration in developing appropriate heat safety policies. Indeed, Cooper, Ferrara, and Broglio (2006) identified elevated heat injuries among football players with increased heat exposure. Similarly, Grundstein et al. (2012) found that the vast majority of football hyperthermia deaths occurred during weather that was unusually hot and humid by local standards.

Given the significance and frequency of heat injuries among athletes, the American College of Sports Medicine (ACSM) provides recommendations for individuals participating in hot environments (Armstrong et al. 2007). The ACSM uses the wet-bulb globe temperature (WBGT), which integrates the influences of sun exposure, air temperature, humidity, and windspeed, as a metric for heat intensity. The WBGT is computed as a weighted average of the wet-bulb temperature (WB), the dry-bulb temperature (DB),

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Table 1
Statistics for extreme warm season wet-bulb globe temperatures by heat safety category. All values rounded to the nearest whole number.

	Cat 1	Cat 2	Cat 3
Median	29	31	35
Max	30	34	38
Min	22	30	32
StDev	1.5	0.7	1.8
Count	67	63	92

and the globe temperature (GT) as follows (Yaglou & Minard, 1957): WBGT = 0.7*WB + 0.2*GT + 0.1*DB. Based on the WBGT, the ACSM makes specific recommendations on the length, intensity, and duration of activities along with suggestions about hydration and rest breaks. As an example, the ACSM guidelines recommend that intense exercise should be limited for acclimatized, fit, and healthy athletes at a 30.1 °C WBGT and all activities should cease when environmental conditions ≥32.3 °C WBGT.

Unfortunately, a “one size fits all” approach does not account for regional variations in acclimatization to heat. Heat acclimatization involves the physiological adaptations that occur after repeated exposures to hot environments (Armstrong & Maresh, 1991; Binkley, Beckett, Casa, Kleiner, & Plummer, 2002; Pandolf, 1998). These changes to the thermoregulatory system make an individual more resistant to heat stress and include greater sweat rates along with increased heart function, skin circulation, and fluid balance (Binkley et al. 2002; Eichna, Beam, Ashe, & Nelson, 1945; Nadel, Pandolf, Roberts, & Stolwijk, 1974; Nielsen et al. 1993; Roberts, Wenger, Stolwijk, & Nadel, 1977; Sawka, Leon, Montain, & Sonna, 2011; Taylor, 1986). The magnitude of these physiological changes depends on the intensity, duration, and frequency of heat exposures (Department of Army and Air Force 2003). Also, acclimatization has been documented to vary in different environments. For instance, greater sweat rate increases were found in those acclimatized to hot-humid climates than hot-dry ones (Fox, Goldsmith, Hampton, & Hunt, 1967). Thus, individuals become acclimatized to the climate conditions where they work or train. One can imagine the very different environmental conditions an American football player in Minneapolis, MN might experience and acclimatize to in an early season practice compared to one in Miami, FL. Simply looking at air temperatures, it is evident that the average (1981–2010) August daytime maximum temperature is far greater in Miami (32.8 ± 0.6 °C) than in Minneapolis (26.9 ± 1.7 °C). Indeed, an extremely hot day in Minneapolis (e.g. +2 standard deviations = 30.3 °C) would still be cooler than a typical day in Miami.

The results of differential degrees of acclimatization are presented in an epidemiological study of heat illnesses among U.S. soldiers (Carter et al. 2005). A key finding is that soldiers from northern states, presumed to have lower degrees of acclimatization, had considerably greater rates of EHIs than those from southern states. In studies of the general population, it is well established that exposure-response relationships to heat vary geographically, with lower minimum mortality and morbidity thresholds in regions with cooler climates due to a combination of behavioral (e.g. greater prevalence of air conditioning) and physiological adaptation (Curreiro et al., 2002; Kalkstein & Davis, 1989; Keatinge et al. 2000; Ye et al. 2012). Grimmer et al. (2006) investigated the frequencies of hot weather among regions in Australia and noted the importance of considering the climatological conditions in developing athletic heat safety policies. While overall EHIs may be greater in hotter climates due to greater exposures, they note that athletes in cooler regions may be highly vulnerable to sudden hot spells because they are not well acclimatized to such extreme conditions. Also, the staff and players in cooler climates may not be familiar with heat safety protocols. As such, they suggest site-specific heat safety guidelines.

An important consideration in designing local guidelines, then, is quantifying locally oppressive conditions. Many studies of heat-health relationships account for acclimatization in assessing heat intensity by using relative thresholds determined from climatological data (e.g. Robinson, 2001; Hajat et al. 2006; Medina-Ramon & Schwartz, 2007; Anderson & Bell, 2011; Smith, Zaitchik, & Gohlke, 2013). These investigations have relied primarily on air temperature and physiological measures like the heat index. No work on relative thresholds has been done with the WBGT because these data are not commonly measured. Employing a unique WBGT climatology covering the contiguous U.S., our study addresses this shortcoming by developing regional heat safety categories for athletic activity that use relative thresholds of WBGT to account for local acclimatization. The results of our study include 1) a map of

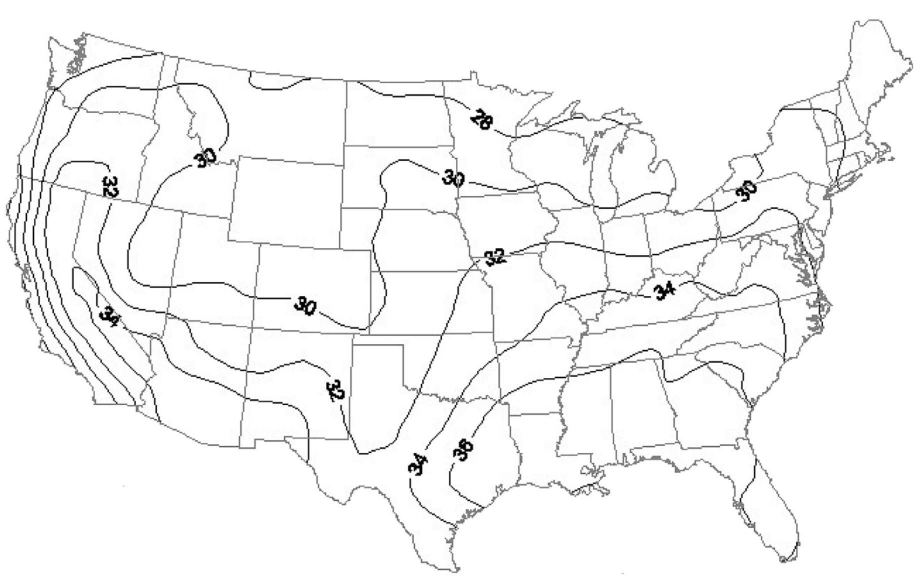

Fig. 1. 90th percentile warm season maximum daily wet-bulb globe temperatures (°C).

heat safety regions and 2) regional heat safety tables with activity guidelines informed by climatological conditions.

Methodology

WBGTs in our analysis were obtained from a climatology that covers the period 1991–2005 and includes hourly WBGTs for 217 stations across the contiguous U.S. (Grundstein, Elguindi, Ferrara, & Cooper, 2013; Grundstein, Cooper, Ferrara, & Knox, 2014). The WBGTs were generated from a physically-based WBGT model (Liljegren, Carhart, Lawday, Tschopp, & Sharp, 2008) using meteorological data from airport weather observing stations compiled in the National Solar Radiation Database (NSRDB; National Renewable Energy Laboratory 2007). We relied on modeled WBGTs because observed data are rarely collected either temporally or spatially in a suitable manner for climatological analysis. The Liljegren et al. (2008) model has been tested in a variety of locations with different climates across the U.S. and found to be accurate to within 1 °C. Further, Patel, Mullen, & Santee (2013) also observed strong performance by the Liljegren model in studies conducted in Georgia and found that it outperformed another physically-based WBGT model by Matthew, Santee, & Berglund (2001). It is important to note that micrometeorological conditions can vary between the airport and playing fields where most training occurs. However, the scope of our study is at a broad spatial scale with a focus on the differences in climate conditions between regions.

Our study develops regional WBGT safety guidelines by determining locally defined extreme conditions. To be conservative, we made an *a priori* decision to retain the existing ACSM threshold as an upper limit for physical activities (32.3 °C), regardless of the results of our objective analysis on extreme WBGTs. It should be noted that this is the upper limit applied by the ACSM for low-risk, fit, and acclimatized individuals. In the development of our heat safety thresholds, we will make a similar assumption about health and fitness, and that the athletes will follow a heat acclimatization plan so that they are acclimatized to local conditions. Studies of heat-health relationships most frequently use relative thresholds of heat intensity that range from the 90th to the 99th percentiles (e.g. Robinson, 2001; Hajat et al. 2006; Medina-Ramon & Schwartz, 2007; Anderson & Bell, 2011; Smith et al. 2013). These studies have focused on heat-health relationships in the general population and not athletes, whose increased metabolic heat production may enhance the risk for a heat illness under cooler conditions. Thus, we opted to use the lower end of this range, the 90th percentile warm season (May–September) WBGT, to determine extreme local conditions. When this relative threshold is considered in the context of the current ACSM upper limit, 58% of stations have extreme WBGTs that fall below 32.3 °C and would have a lower defined critical WBGT.

We identified three heat safety regions by grouping stations together based on extreme WBGTs. Stations with WBGTs ≥32.3 °C were placed in the "hot" Category 1, those with WBGTs 30.1–32.2 °C in the "moderate" Category 2, and the remaining stations with WBGTs ≤30 °C in the "mild" Category 1. Our categorization scheme resulted in roughly equal numbers of stations in Category 1 and 2 regions with 67 and 63 respectively, and 92 in Category 3. For each region, we created a modified version of the ACSM table using the median 90th percentile WBGTs among category 1 and 2 stations (i.e. 29 °C and 31 °C respectively) and 32.3 °C for category 3 as critical upper limits for practices (Table 1). It is interesting to note that 32.3 °C provides a conservative measure of extreme heat in Category 3 areas as the median 90th percentile warm season WBGT is 35 °C. Activity recommendations in the ACSM heat safety table were adjusted based on the difference between the ACSM critical WBGT maximum (32.3 °C) and the categorical median 90th percentile WBGT. Thus, WBGT cutoffs between categories in the ACSM table would be adjusted downward by 1.3 °C (32.3–31 °C) for Category 2 and 3.3 °C (32.3–29 °C) for Category 3 to account for lower heat acclimatization. Following the procedure above, we also constructed a heat safety table modeled on the practice policy adopted in 2012 by the Georgia High School Association (GHSA 2014). This table is based largely on the ACSM safety thresholds so the categories themselves are not unique to Georgia. Rather, we included the Georgia policy as it provides detailed information on work to rest periods and equipment adjustment with variations in heat exposure. Also, acknowledging the high risk for EHIs among football players, it includes football-specific recommendations.

Results

We first investigated the geographic patterns of the 90th percentile warm season maximum WBGT to identify locally extreme conditions (Fig. 1). There is large regional variability in

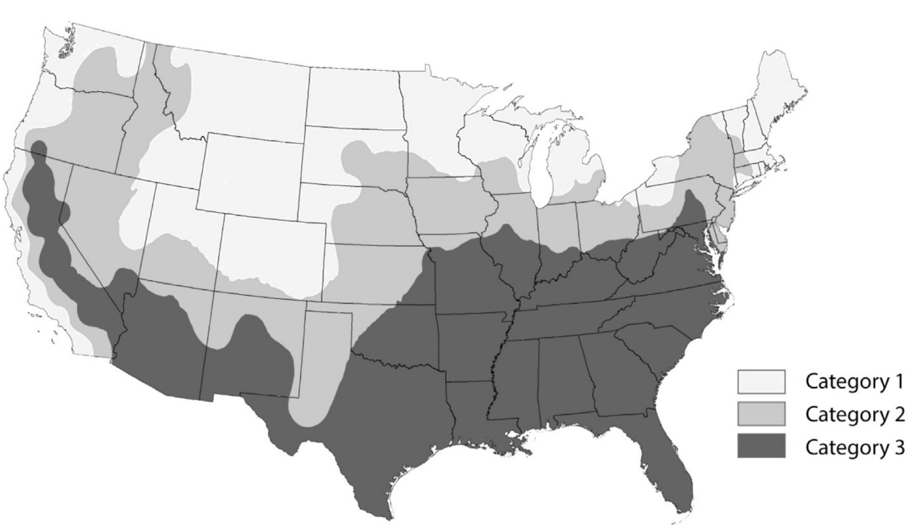

Fig. 2. Heat safety regions.

extreme WBGTs across the contiguous U.S., ranging from >36 °C across portions of the Southeast and southern Arizona to ≤26 °C along the Pacific Coast. In the context of 32.3 °C, "cooler" areas like the Pacific Northwest would experience such conditions very rarely (≤5% of warm season days) compared with "hotter" areas such as in the Southeast where 20–35% of warm season days may exceed the ACSM limit. Intermediate WBGTs of 30–34 °C are located across the Midwest, Ohio Valley, and Northeast. A strong gradient in extreme WBGTs is located along the Pacific Coast in response to the North-South oriented mountain ranges that confine mild, maritime polar air to coastal areas. On the leeward side of the mountains, such as the Central Valley of California, values may exceed 34 °C.

Considering local extreme WBGTs, three heat safety regions were identified (Fig. 2). Category 3 encompasses much of the southeastern quadrant of the U.S. along with portions of New Mexico, Arizona, and the Central Valley of California. Locations within Category 3 would follow the existing ACSM safety guidelines. Category 2 areas extend in an arc from the interior Northwest through Nevada, portions of the Midwest, northern Ohio Valley, and the Northeast. Finally, Category 1 includes the Pacific Coast, New England, and the northern tier of the country.

For each region, we developed revised heat safety tables with information on adjusting activity levels, work to rest intervals, and equipment with variations in WBGT. Our first table is based on one provided by the ACSM (Armstrong et al., 2007). We revised the ACSM heat safety guidelines using the lower maximum WBGT for canceling practice within Category 1 and 2 areas (Table 2). The new guidelines would require practice to be canceled at 29 °C (31 °C) WBGT in Category 1 (2) regions rather than 32.3 °C to account for the lower degree of acclimatzation among residents in those areas. Subsequent categories were adjusted downward in similar increments to the original ACSM chart. For instance, intense or prolonged exercise should be made with discretion starting at 26.6 °C in Category 2 areas and 24.6 °C in Category 1 areas.

A second chart is based on one used by the Georgia High Schools Association (GHSA 2014, Table 3). The guidelines remain unchanged for Category 3 locations but safety thresholds were adjusted downward 1.3 °C (32.3–31 °C) and 3.3 °C (32.3–29 °C) for locations in Category 2 and 1 respectively. Thus, athletes in Category 3 would be limited to 2 h of practice, have certain restrictions on equipment, and have four rest breaks for WBGTs 30.6–32.2 °C while those in the cooler Category 1 region would have these same limitations at WBGTs of 27.3–28.9 °C.

Discussion and conclusions

Heat acclimatization is not uniform across the country due to differential exposures and thus susceptibility to an EHI may vary geographically. Our study identifies three heat category regions with associated activity guidelines that are adjusted based on local climatology. Some states completely fall within a particular heat safety region (e.g. North Dakota in Category 1, Iowa in Category 2, and Georgia in Category 3) and could implement the appropriate regional heat safety guidelines statewide. Other states such as California and Oregon have more diverse climates with areas that fall within different heat-safety categories. In these cases, the governing body for interscholastic sports might designate different guidelines by sections. The California Interscholastic Federation (CIF), for instance, divides that state into 10 sections (Fig. 3). The CIF might assign the Northern, Sacramento–Joaquin, and Central sections to Category 3; the North Coast, San Francisco, Oakland, Los Angeles, and San Diego sections to Category 1; and use a population or school density-based weighting to assign the Central Coast section to Category 1 or 2. The southern section, however, covers a vast area of Southern California stretching from the coast (Category 1) into the Mojave desert (Category 3). Here, some additional partitioning may be needed based on heat safety zones.

Implementing the new categories will have some impact upon when practices are held in Category 1 and 2 areas due to the lower WBGT thresholds. Many schools within these regions may not have had to frequently cancel or adjust practices and thus might lack experience in how to handle such situations. Revised heat safety policies should therefore include details on how decisions on adjustments or cancelations should be made (e.g. by the athletic director or athletic trainer for practices or event management staff for games) and on how alternative activities can be incorporated into training (e.g. training in climate controlled facilities, video review of game/training performances, etc.).

Finally, the revised heat safety activity guidelines were developed with the assumption that the athletes are at least acclimatized to local conditions. It is well established that athletes who undergo the

Table 2
Regional heat safety guidelines for low-risk acclimatized individuals based on American College of Sports Medicine guidelines. Values are wet-bulb globe temperatures (°C).

Cat 3	Cat 2	Cat 1	Activitiy guidelines
≤10.0	≤8.7	≤6.7	Normal activity
10.1–18.3	8.8–17.0	6.8–15.0	Normal activity
18.4–22.2	17.1–20.9	15.1–18.9	Normal activity
22.3–25.6	21.0–24.3	19.0–22.3	Normal activity, monitor fluids
25.7–27.8	24.4–26.5	22.4–24.5	Normal activity, monitor fluids
27.9–30.0	26.6–28.7	24.6–26.7	Plan intense or prolonged exercise with discretion
30.1–32.2	28.8–30.9	26.8–28.9	Limit intense exercise and total daily exposure to heat and humidity
>32.3	>31.0	>29.0	Cancel exercise

Table 3
Regional heat safety activity guidelines based on the Georgia High School Association policy. Values are wet-bulb globe temperatures (°C).

Cat 3	Cat 2	Cat 1	Activity guidelines
<27.8	<26.5	<24.5	Normal Activities - Provide at least three separate rest breaks each hour with a minimum duration of 3 min each during the workout.
27.9–30.5	26.6–29.2	24.6–27.2	Use discretion for intense or prolonged exercise; watch at-risk players carefully. Provide at least three separate rest breaks each hour with a minimum duration of 4 min each.
30.6–32.2	29.3–30.9	27.3–28.9	Maximum practice time is 2 h. For Football: players are restricted to helmet, shoulder pads, and shorts during practice. If the WBGT rises to this level during practice, players may continue to work out wearing football pants without changing to shorts. For All Sports: Provide at least four separate rest breaks each hour with a minimum duration of 4 min each.
32.3–33.3	31.0–32.0	29.0–30.0	Maximum practice time is 1 h. For Football: no protective equipment may be worn during practice, and there may be no conditioning activities. For All Sports: There must be 20 min of rest breaks distributed throughout the hour of practice.
≥33.4	≥32.1	≥30.1	No outdoor workouts. Delay practice until a cooler WBGT level is reached.

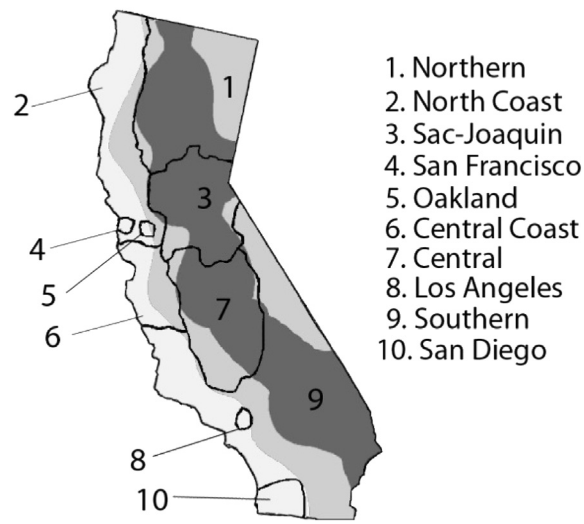

Fig. 3. California Interscholastic Federation sections overlayed with heat safety regions. The dark gray indicates Category 3, medium gray Category 2, and light gray Category 1.

heat acclimatization process (e.g. gradual adjustments in duration and intensity of activity along with amounts of protective equipment) enhance their heat tolerance and greatly reduce their risk for exertional heat illnesses (Nadel et al. 1974; Wenger 1988; Armstrong & Maresh, 1991; Bergeron et al. 2005; Binkley et al., 2002; Department of the Army and Air Force 2003; Casa & Csillan, 2009). Thus, heat acclimatization policies should be implemented in conjunction with our suggested regional heat safety thresholds. The National Collegiate Athletic Association (NCAA), for instance, requires a 5 day acclimatization period at the beginning of each season with specific guidelines about length of practice and the use of protective equipment (NCAA 2002; Howe & Boden, 2007). A longer acclimatization period of at least 14 days is recommended for youth athletes due to their greater susceptibility to heat-related illnesses (Bergeron et al. 2005; Casa & Csillan, 2009).

While professional and collegiate level athletic programs have already adopted strong heat safety policies, there is considerable variations among high school interscholastic programs (Korey Stringer Institute – KSI, 2014). In 2014, only 13 states have heat policy guidelines for athletic participation that meet suggestions by the National Athletic Trainers Association (NATA) and the Korey Stringer Institute (Casa & Csillan, 2009; KSI 2014). However, many other states are actively working to improve their policies. We hope that our regional heat safety information may be of use in guiding and informing these heat safety policy decisions.

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