Journal of Athletic Training 2018;53(1):43–50
doi: 10.4085/1062-6050-445-16

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Fatal Exertional Heat Stroke and American Football Players: The Need for Regional Heat-Safety Guidelines

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Context: Weather-based activity modification in athletics is an important way to minimize heat illnesses. However, many commonly used heat-safety guidelines include a uniform set of heat-stress thresholds that do not account for geographic differences in acclimatization.

Objective: To determine if heat-related fatalities among American football players occurred on days with unusually stressful weather conditions based on the local climate and to assess the need for regional heat-safety guidelines.

Design: Cross-sectional study.

Setting: Data from incidents of fatal exertional heat stroke (EHS) in American football players were obtained from the National Center for Catastrophic Sport Injury Research and the Korey Stringer Institute.

Patients or Other Participants: Sixty-one American football players at all levels of competition with fatal EHSs from 1980 to 2014.

Main Outcome Measure(s): We used the wet bulb globe temperature (WBGT) and a *z*-score WBGT standardized to local climate conditions from 1991 to 2010 to assess the absolute and relative magnitudes of heat stress, respectively.

Results: We observed a poleward decrease in exposure WBGTs during fatal EHSs. In milder climates, 80% of cases occurred at above-average WBGTs, and 50% occurred at WBGTs greater than 1 standard deviation from the long-term mean; however, in hotter climates, half of the cases occurred at near average or below average WBGTs.

Conclusions: The combination of lower exposure WBGTs and frequent extreme climatic values in milder climates during fatal EHSs indicates the need for regional activity-modification guidelines with lower, climatically appropriate weather-based thresholds. Established activity-modification guidelines, such as those from the American College of Sports Medicine, work well in the hotter climates, such as the southern United States, where hot and humid weather conditions are common.

Key Words: exertional heat illness, wet bulb globe temperature, acclimatization

Key Points

- Fatal exertional heat-stroke events in American football players tended to occur at lower wet bulb globe temperatures (WBGTs) in northern regions of the United States relative to those in southern regions but under conditions that were unusually stressful based on the local climate.
- Uniform WBGT thresholds for guiding activity are problematic, as they do not account for locally extreme conditions.
- Region-based WBGT thresholds would align activity modification with how athletes in particular areas are acclimatized.

Exertional heat illnesses (EHIs) affect thousands of athletes each year and are among the top 3 causes of athlete deaths.[1,2] They can vary from mild, such as exercise-associated muscle (heat) cramps, to the potentially life-threatening heat stroke. American football players are especially at risk for EHIs due to a combination of the timing of the practice season in the summer, their protective equipment, and their anthropometric characteristics.[3–5] Indeed, Kerr et al[1] found that these athletes were 11 times more likely to sustain a heat-related illness than other athletes.

Exertional heat illnesses are complex conditions, and both intrinsic (eg, health, hydration, acclimatization) and extrinsic (eg, environment, equipment, work-to-rest ratios) factors can influence the risk.[6] Policies can be developed to mitigate risk from extrinsic factors, such as weather and the amount of protective equipment worn. The American College of Sports Medicine (ACSM) has developed a widely applied set of activity-modification guidelines that use the wet bulb globe temperature (WBGT) to account for meteorologic conditions.[7] The WBGT is computed as a weighted average of the wet bulb, globe, and dry bulb temperatures. It is designed to integrate the various meteorologic variables that can influence human heat balance via gains or losses of energy through evaporative cooling (wet bulb temperature), radiant heating (globe temperature), and convection of sensible heat (dry bulb temperature). The ACSM[7] guidelines provide a series of categories based on the WBGT in which activity modification is recommended. For instance, on days with WBGTs from 30.1°C to 32.2°C, the ACSM[7] recommends "limiting intense exercise and total daily exposure to heat and humidity" for fit and acclimatized individuals.

The ACSM activity-modification guidelines are universal and do not adjust for regional differences in environmental conditions. However, it is well known that the magnitude of heat acclimatization is highly dependent on the weather conditions in which athletes train.[8] For example, an athlete acclimatized to summer conditions in New England may not be optimally acclimatized to conditions in the Southeast. Carter et al[9] showed that soldiers from the northern United States had 1.69 times more heat-related illnesses than recruits from the southern United States, who were more likely acclimatized to hot conditions. Building on the ACSM categories, Grundstein et al[10] developed regional heat-safety guidelines based on local climate conditions. These guidelines have WBGT activity-modification recommendations suitable for regions with mild, moderate, and hot climates.

The incidence of EHIs increases when weather conditions become hotter or more humid (or both).[11–14] Cooper et al[11] and Grundstein et al[12] identified an elevated incidence of EHIs among football players with exposure to high temperatures and humidity, and Cooper et al[14] found that illnesses among collegiate football players increased markedly when WBGT was greater than 28°C. In a study of Florida football players, Tripp et al[13] reported that almost 3/4 of EHIs occurred on days characterized as either high or extreme risk for an EHI based on ACSM guidelines. Grundstein et al[12] also noted that many heat-related fatalities occurred on days with unusually high air and dew-point temperatures based on the local climate.

To our knowledge, no one has examined whether EHIs are more closely tied to absolute or relative WBGT thresholds based on the local climate because such data are not widely available. Therefore, in this study, we investigated the long-term WBGT climate using output from a physically based WBGT model. Using these data, we retrospectively examined 61 well-documented cases of fatal exertional heat strokes (EHSs) among American football players from 1980 to 2014. The purpose of our study was to determine if fatal EHS cases among American football players occurred more frequently on days with abnormally high WBGTs based on the local climate and to assess how regional activity-modification guidelines as proposed by Grundstein et al[10] would have altered activity recommendations on days with fatal EHSs compared with current ACSM guidelines.

METHODS

Exertional Heat-Stroke Data

The dataset of 61 EHS fatalities of American football players included all levels of competition (ie, youth, collegiate, and professional) and expanded on the data used in Grundstein et al[12] through 2014. Source data from 1980 to 2009 were acquired from the National Center for Catastrophic Sport Injury Research (n = 53),[15] with the remaining data provided by the Korey Stringer Institute (n = 8). The National Center for Catastrophic Sport Injury Research data were compiled from reports by coaches, athletic trainers, athletic directors, and officials from various state and national athletic organizations and Web-based news reports.[15] Fatality data from the Korey Stringer Institute were initially obtained from online news reports.

Using the list of fatal EHS cases from the National Center for Catastrophic Sport Injury Research and the Korey Stringer Institute, we searched media reports, lawsuit publications, and obituaries to obtain information on exposure date and location (ie, latitude and longitude) and time of day when the athlete was participating in football-related activities. In particular, the approximate time of heat exposure before the EHS was identified for all 61 cases, including 25 incidents in which such data were initially not identified in Grundstein et al.[12] This expanded dataset was consistent with the original findings by Grundstein et al[12] that most fatalities were among youth athletes less than 18 years of age (79%, n = 48 of 61) and those who played lineman positions (89%, n = 39 of 44).

Meteorologic Data

For each fatality, we reconstructed the meteorologic conditions (dry bulb temperature, dew-point temperature, and WBGT) during the approximate exposure period using data from the nearest weather-observing station (median distance = 15.15 km). The exact exposure time was generally not available from our data sources, but we identified whether the activity occurred in the morning or afternoon. Morning sessions were assumed to occur between 8 AM and 12 PM local daylight savings time, and afternoon sessions were assumed to occur between 2 PM and 6 PM local daylight savings time. Maximum and average values for each of these variables were used to characterize the exposure during the training session.

We used WBGT as a heat-stress metric to be consistent with ACSM guidelines. Given that these data were not available on the exposure day or climatologically, they were modeled. The local climate conditions for the date of exposure of each fatality were generated from a 20-year period (1991–2010) using the physically based model of Liljegren et al.[16] The model requires inputs of air temperature, wind speed, relative humidity, and solar radiation, which were acquired from the National Solar Radiation Database of the National Renewable Energy Laboratory.[17] It has outperformed other physically based WBGT models and been shown to be accurate to within 1°C at locations with diverse climates across the United States.[16,18]

On exposure days, the model of Liljegren et al[16] was used to determine WBGTs present for fatalities occurring from 1980 to 2010 when solar-radiation data were available. The WBGTs for cases occurring from 2011 to 2014, when solar-radiation data were not available, were computed using the Heat Stress Adviser (Zunis Foundation, Tulsa, OK[19]) software package. This algorithm uses meteorologic data (eg, air temperature, relative humidity, cloud cover) and time of day to determine the WBGT.[20]

Regional Activity-Modification Guidelines

We used regional heat-safety guidelines from Grundstein et al[10] as a comparison with 2007 ACSM guidelines. These regional activity-modification guidelines were based on local climate conditions for warm-season WBGTs. Three regions characterized by mild, moderate, and hot climates were Region 1 (Pacific Coast, New England, and northern tier of the United States), Region 2 (portions of the interior Northwest through Nevada and parts of the Midwest, Ohio Valley, and Northeast), and Region 3 (Southeast, portions of the Southwest, and the Central Valley of California),

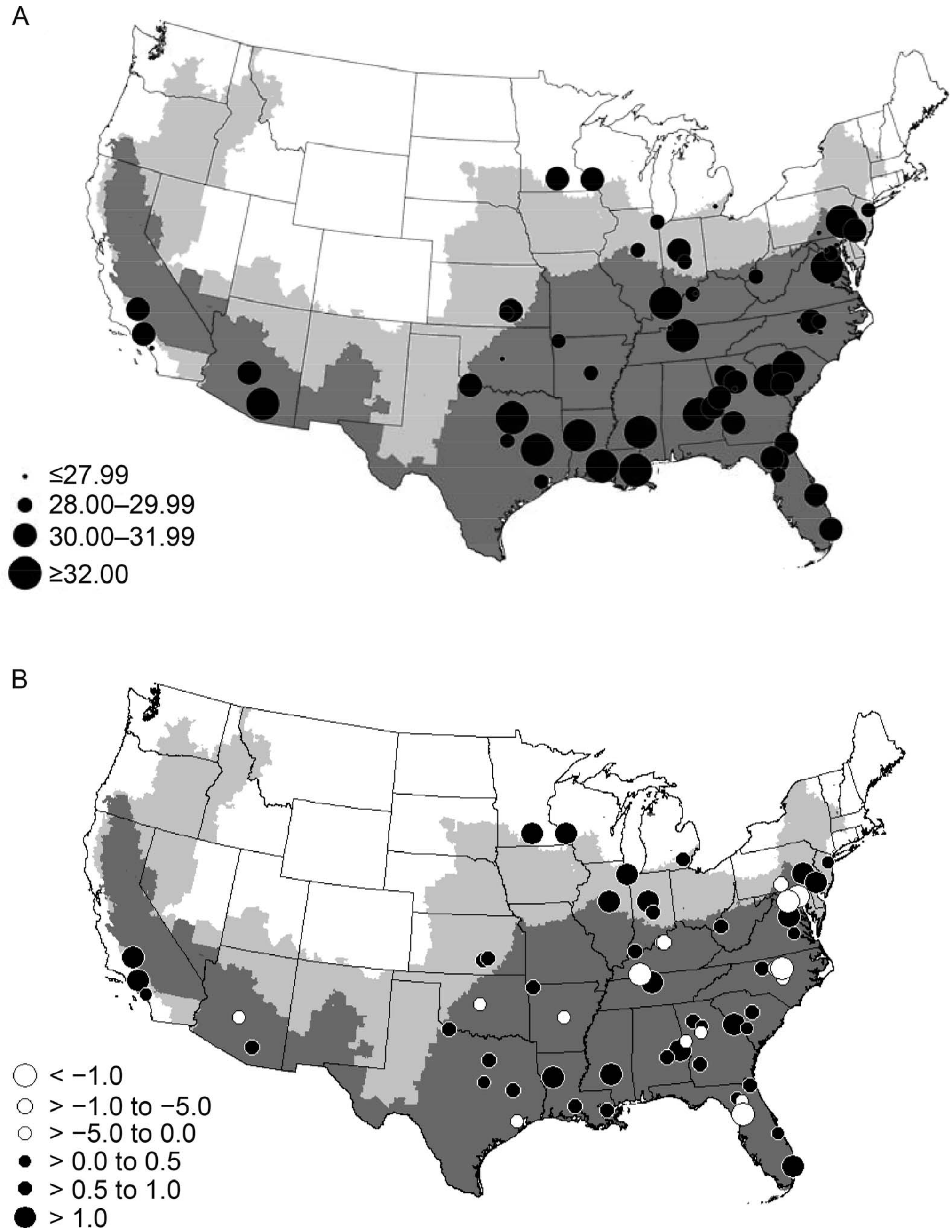

Figure 1. Maps of, A, maximum wet bulb globe temperature (°C) and, B, standardized maximum wet bulb globe temperature (*z* score) during exposure for fatal exertional heat-stroke cases. Background shading defines the heat-safety regions from Grundstein et al,[10] with white for Region 1, light gray for Region 2, and dark gray for Region 3.

respectively, and were identified with lower activity-modification thresholds for cooler climates (Figure 1). For instance, Grundstein et al[10] recommended that training cease at WBGTs of 29.0°C, 31.0°C, and 32.3°C, for Regions 1, 2, and 3, respectively. Our dataset included 4 fatalities in Region 1, 11 in Region 2, and 46 in Region 3.

Statistical Analyses

The relationship between latitude and maximum-exposure WBGT was determined using the Pearson product moment correlation coefficient (r). The WBGT z scores were computed from the exposure and climatic WBGTs to identify the degree of deviation from long-term mean conditions. We categorized z scores as *very above average* ($\geq$1.0), *above average* (0.5–0.99), and *near/below average* ($<$0.5) for analysis. A χ^2 test was used to determine the statistical significance of frequency differences in *above* (ie, *above* and *very above average* categories; z score $\geq$ 0.5) versus *near or below average* (z score $<$ 0.5) maximum WBGTs z scores for Regions 1 and 2 versus Region 3. We set the α level at .05. Graphical and statistical analyses were performed using SigmaPlot (version 12.5; Systat Software, Inc, San Jose, CA).

Table. Percentage of Fatal Exertional Heat Stroke Cases by Wet Bulb Globe Temperature Activity-Modification Category According to American College of Sports Medicine[7] and Regional[10] Guidelines

	Wet Bulb Globe Temperature Activity-Modification Category, % (n)			
Guidelines	Normal Activity	Plan Intense or Prolonged Exercise With Discretion	Limit Intense Exercise and Total Daily Exposure to Heat and Humidity	Cancel Exercise
American College of Sports Medicine				
Regions 1[a] and 2[b] (n = 15)	20 (3)	27 (4)	47 (7)	7 (1)
Region 3[c] (n = 46)	15 (7)	26 (12)	30 (14)	28 (13)
Regional				
Regions 1[a] and 2[b] (n = 15)	7 (1)	27 (4)	27 (4)	40 (6)
Region 3[c] (n = 46)	15 (7)	26 (12)	30 (14)	28 (13)

[a] Region 1 includes the Pacific Coast, New England, and the northern tier of the United States.
[b] Region 2 includes portions of the interior Northwest through Nevada and parts of the Midwest, Ohio Valley, and Northeast.
[c] Region 3 includes the Southeast, portions of the Southwest, and the Central Valley of California.

RESULTS

Meteorologic Conditions During EHS Cases

We observed that the athletes were exposed to a wide range of meteorologic conditions on the days they experienced EHS. However, the median conditions under which players sustained the EHSs were hot and humid, with maximum temperature of approximately 32°C, dew point of approximately 22°C, and WBGT greater than 30°C (Figure 2A). The tendency toward high absolute WBGTs is illustrated in Figure 2B: 82% (n = 50) of the fatalities occurred with maximum-exposure WBGTs greater than 27.9°C. When considered relative to local climatic conditions, the fatal EHSs tended to occur on warmer, more humid, and higher WBGT days (Figure 2B). The median *z* scores were 0.78 to 0.90 for temperature, 0.55 to 0.60 for dew-point temperature, and 0.67 to 0.73 for WBGT. We also observed that some fatalities occurred at average or below average conditions for given locations.

Geographic Patterns of EHS Cases

Geographically, we focused on maximum-exposure conditions, but the patterns were similar to average conditions (Figure 1). Most maximum WBGTs fell between 28°C and 32.0°C, with many of the greatest values exceeding 32°C located across the southern United States (Figure 1A). We noted a negative correlation between WBGT and latitude ($r = 0.30$, $P = .02$). For standardized WBGTs, the *z* scores were almost uniformly positive across the northern parts of the country but were a mix of positive and negative in more southern areas (Figure 1B). To investigate further, we aggregated the occurrence of very above average (*z* score ≥ 1.0), above average (*z* score = 0.5–0.99), and near or below average (*z* score < 0.5) maximum WBGTs across heat-safety regions (Figure 3). We combined Regions 1 and 2 due to the relatively small numbers of incidents in those areas. Within the milder Regions 1 and 2, 80% (n = 12) of the fatal EHSs occurred with above or very above average maximum WBGTs, and more than 50% (n = 8) had very above average *z* scores greater than 1 standard deviation from the mean. In contrast, half the cases (n = 23) occurred at near or below average WBGT in Region 3 (Figure 3). A χ^2 test showed a difference in the percentage of cases near or below average compared with above average (ie, above and very above average categories) between the hot Region 3 and the cooler Regions 1 and 2 ($\chi^2 = 19.79$, $P < .001$).

Activity Modification and Fatal EHSCases

Next, we categorized the maximum-exposure WBGTs based on the ACSM WBGT activity-modification guidelines and then grouped the results by heat-safety region (Table). In Regions 1 and 2, 80% (n = 12) of the fatal EHS cases would have occurred under some recommended activity modification, and 47% (n = 7) would have occurred when intense exercise and total daily exposure should be limited. However, only 7% (n = 1) of cases in these areas occurred when the threshold for canceling practice would have been reached, in part because 32.3°C is a very extreme WBGT in these cooler climates. This threshold occurs, on average, at greater than the 95th percentile in Region 2 and greater than the 99th percentile in Region 1 based on the WBGT data developed in Grundstein et al.[21] In Region 3, 85% (n = 39) of the cases would have occurred when activity modification would have been recommended, including 30% (n = 14) when limiting intense exercise and total daily exposure and 28% (n = 13) when cancellation of activities would have been recommended.

Using region-based activity modification led to several categorical shifts in Regions 1 and 2 but not in Region 3, where the ACSM thresholds were retained (Table). Some level of activity modification would have been required in 93% (n = 14) of cases, and 40% (n = 6) would have occurred under local environmental conditions severe enough to merit cancellation. In particular, the category would have shifted to *cancel activity* in 33.33% (n = 5) of cases, would have been increased to *limit intense exercise and total daily exposure to heat and humidity* in 13.33% (n = 2), and would have changed from no recommended activity modification to *plan intense or prolonged exercise with discretion* in 13.33% (n = 2). In total, 60% (n = 9) of the cases would have occurred when increased activity modification would have been recommended under the region-based guidelines.

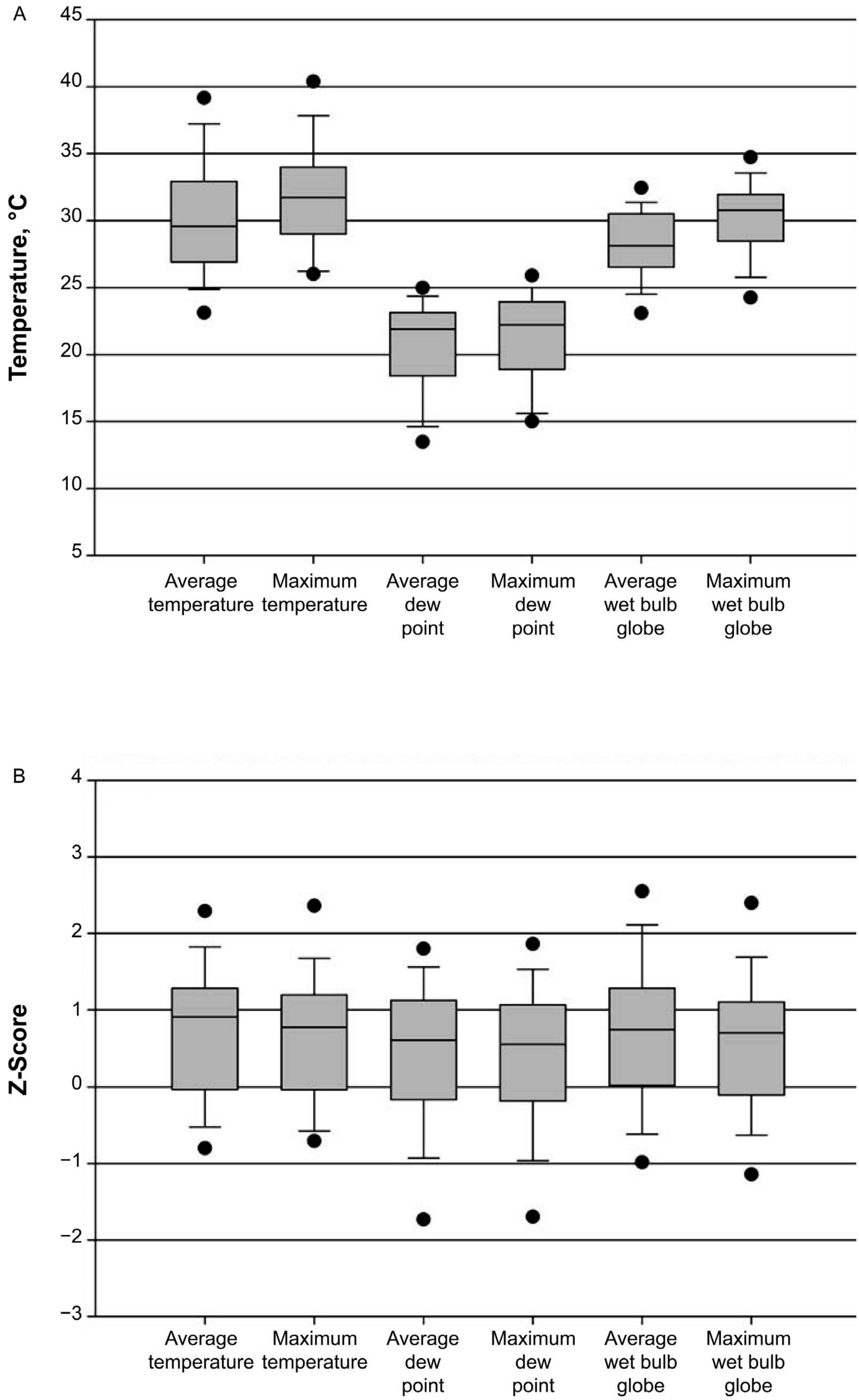

Figure 2. Box plots of, A, meteorologic observations and, B, standardized meteorologic observations (*z* scores). The boundaries of the box represent the 25th and 75th percentiles. The line within the box indicates the median. The whiskers are the 10th and 90th percentiles. The points above and below the whiskers are the 95th and 5th percentiles, respectively.

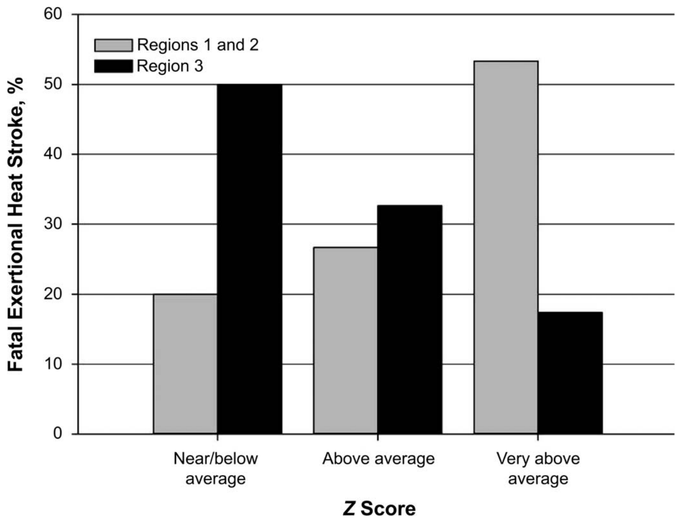

Figure 3. Percentage of fatal exertional heat stroke by heat-safety region. The *z* scores are <0.50 for *near or below average*, 0.50–0.99 for *above average*, and ≥1.0 for *very above average*.

DISCUSSION

At present, uniform WBGT activity-modification guidelines are used by many government agencies and professional organizations, such as the ACSM, the US military, and the Occupational Safety and Health Administration, regardless of the climate in the area.[7,22,23] For each of the aforementioned agencies or organizations, the same guidelines are recommended, for instance, in Massachusetts and Florida. For perspective, consider that a typical summer day in Boston has a daytime maximum WBGT of about 25°C, whereas in Miami, it is slightly greater than 31°C. The typical day in Miami, therefore, would be an unusually (>98th percentile) hot and humid day in Boston.

Heat acclimatization is a pillar of modern heat-safety policy and is designed to accustom athletes to local conditions.[7] We observed a poleward decrease in the magnitude of WBGTs on days with fatalities. Therefore, fatalities tended to occur at lower WBGT values in the North. This observation is consistent with studies[24–27] of heat-exposure–response relationships among the general population in which morbidity and mortality thresholds were lower in areas with cooler climates. Furthermore, we observed that most fatal EHSs in cooler climates (Regions 1 and 2) occurred on days with well-above locally normal WBGTs, but half the fatalities in warmer climates (Region 3) occurred on days with near or below average WBGTs. This pattern can be explained by the fact that conditions in cooler climates where WBGTs typically do not reach high levels would need to be extreme before they caused physiologic strain, whereas in hotter climates, typical conditions already reach these levels.

The implications are that fixed guidelines may not capture dangerous conditions in cooler climates, where lower WBGTs may be very stressful by local standards. To be sure, the ACSM guidelines recommended some form of activity modification in the cooler climates in which 80% (n = 12) of the fatalities occurred and, in almost half the cases, recommended the highest level of activity modification short of cancellation. However, 6 of the 7 deaths occurred on days with very above average maximum-exposure WBGTs exceeding 1 standard deviation from the mean, when ACSM would have recommended limiting intense exercise and total daily exposure to heat and humidity, and the WBGT during the seventh case was greater than 0.85 standard deviations from the mean. Athletes in these areas would not likely have acclimatized to these WBGTs, ranging from 30.3°C to 31.9°C, and would have found the conditions stressful. Indeed, even the current ACSM guidelines recommend canceling activities at a WBGT of 30.1°C for athletes who are not acclimatized. The region-based guidelines identify the severity of these conditions and advise that activities be cancelled.

On the other hand, the ACSM guidelines appeared to function well in warmer Region 3 climates. Most fatalities would have occurred either when limiting intense activity and total daily exposure to heat and humidity would have been recommended or when activity would have been cancelled. Only 15% (n = 7) of cases would have occurred when no activity modification was advised. In addition, many of the fatalities in this region occurred on days with near or below average WBGTs. In Region 3, the 50th percentile maximum daily WBGT was 29.9°C ± 1.1°C according to the data from Grundstein et al.[21] Authors of several studies in hot climates have documented increases in heat illnesses when WBGT was greater than 28°C, including Rav-Acha et al,[28] who reported that more than 80% of fatal EHS cases among Israeli Defense Force soldiers occurred when this threshold was exceeded, and Cooper et al,[11,14] who noted that EHI rates substantially increased among American collegiate football players. Therefore, even typical weather in Region 3 is sufficient to cause heat stress, particularly to athletes engaged in intense practice activities.

Our findings may have particular importance for youth athlete heat safety. Most fatal EHS events among American football players included in this study affected athletes aged 18 years or younger. Whereas overall heat-injury rates were lower for youth and high school football players than for collegiate-level players,[29] the large number of fatal EHS cases may be related to heat-management strategies. Indeed, EHS has been documented to be 100% survivable with proper identification and treatment.[30] Kerr et al[31] noted that EHS management strategies were more frequently implemented in states with state high school athletic association-mandated policies. As such, we highly recommend using region-based activity-modification guidelines as an important part of heat-safety policies in interscholastic and youth football.

Finally, we recognize a number of limitations in our study. First, we examined only a portion of all EHIs that occurred because fatal EHSs are more often reported. A key distinction between fatal and nonfatal EHSs is rapid identification and treatment. Second, onsite exposure data were not available for the cases, and data were collected from the nearest weather-observing station. Local variations in surface type or shelter could have affected environmental conditions by altering wind speeds or radiant heating. In addition, data on athlete activities were limited to the day of the EHS. Some researchers[32,33] have indicated that exposure to high WBGTs on a previous day may increase one's vulnerability to heat stress. Finally, our analysis was an ecological study designed to focus broadly on the role of environmental factors in local climate conditions. Exertional heat illnesses are complex, and a diverse set of intrinsic and extrinsic factors may contribute to an EHS in any particular patient.

CONCLUSIONS

We found strong geographic patterns related to environmental conditions under which heat-related fatalities in American football players occurred. Maximum-exposure WBGTs tended to occur at lower values with increasing latitude but under conditions that were highly unusual by local standards. In the southern portions of the United States, however, maximum-exposure WBGTs tended to be greater but were often not unusual based on the local climate. The ACSM standards would have recommended reduced training for the conditions under which most cases occurred. However, we found that, in cooler climates, very few of the activities would have been cancelled, although conditions were very extreme and athletes were unlikely to be acclimatized. Using region-based guidelines would have increased the number of days with more required restrictions and cancellations. Furthermore, given the high percentage of fatal EHS events among youth athletes, we highly encourage the state high school athletic associations that have not adopted comprehensive heat-safety policies (including regional WBGT activity-modification guidelines; heat acclimatization; cold-water immersion tubs; and cool-first, then transport) to do so as soon as possible to maximize the chance that protections are in place to prevent or reduce the occurrence of catastrophic events.

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