# Risk Factors for Heat-Related Illness in U.S. Workers

## An OSHA Case Series

*Aaron W. Tustin, MD, MPH, Dawn L. Cannon, MD, MS, Sheila B. Arbury, RN, MPH, Richard J. Thomas, MD, MPH, and Michael J. Hodgson, MD, MPH*

**Objective:** The aim of this study was to describe risk factors for heat-related illness (HRI) in U.S. workers. **Methods:** We reviewed a subset of HRI enforcement investigations conducted by the Occupational Safety and Health Administration (OSHA) from 2011 through 2016. We assessed characteristics of the workers, employers, and events. We stratified cases by severity to assess whether risk factors were more prevalent in fatal HRIs. **Results:** We analyzed 38 investigations involving 66 HRIs. Many workers had predisposing medical conditions or used predisposing medications. Comorbidities were more prevalent in workers who died. Most (73%) fatal HRIs occurred during the first week on the job. Common clinical findings in heat stroke cases included multiorgan failure, muscle breakdown, and systemic inflammation. **Conclusion:** Severe HRI is more likely when personal susceptibilities coexist with work-related and environmental risk factors. Almost all HRIs occur when employers do not adhere to preventive guidelines.

**Keywords:** heat, heat stroke, heat-related illness, OSHA, prevention

Occupational heat-related illness (HRI) is a well-known consequence of work in hot environments. Clinical outcomes range from mild effects (eg, heat cramps or heat rash) to severe effects such as heat stroke, with multiorgan failure and death. In 2015 in the U.S., 2830 cases of occupational HRI resulted in at least one day of lost work,[1] with 214 hospitalizations[2] and 37 fatalities. The Occupational Safety and Health Administration (OSHA) addresses heat hazards under section 5(a)(1) of the Occupational Safety and Health Act of 1970 (29 U.S.C. Ch. 15). This ''general duty clause'' states that employers must provide a workplace free of recognized hazards causing or likely to cause serious harm or death.

Previous OSHA reports have described serious deficiencies in employer HRI prevention programs. In one case report, a landscaping worker died of heat stroke after his first day on the job, and OSHA cited the employer for failing to provide effective engineering controls, work practice modifications, or training to prevent HRI.[3] Similar circumstances were common in a larger case series of 84 OSHA heat enforcement actions from 2012 and 2013, which found that 74% of heat-related deaths occurred during the first three days on the job.[4] A primary finding of that study was the frequent lack of one or more recommended elements of a comprehensive HRI prevention program at employers inspected by OSHA following reports of HRIs. Almost all (99%) of those employers failed to acclimatize new workers, most failed to monitor environmental conditions or enforce mandatory rest breaks during hot work, and there were large gaps in shade provision and fluid replacement strategies.[4,5]

The aim of this paper was to expand on prior OSHA reports by assessing the clinical characteristics of affected workers and their HRIs. To do so, we reviewed all HRI enforcement consultations undertaken by the Office of Occupational Medicine and Nursing (OOMN), an office of Federal OSHA, between 2011 and 2016. OOMN had access to the victims' medical records, which allowed us to explore worker characteristics, in addition to employer program elements and incident characteristics. These OOMN consultations represent a subset of all OSHA heat enforcement cases during those years.

## METHODS

### Cases Analyzed

OOMN receives consultation requests from OSHA Area Offices to address questions of work-relatedness, illness severity, and adherence to standards of care. We searched a master list of OOMN consultations to identify all available HRI consultations from 2011 through 2016.

### Data Coding Process

Available medical records included ambulance reports, inpatient and emergency department (ED) hospital records, and postmortem reports from coroners or medical examiners. The type and completeness of the available medical records varied among cases. Other sources of data for this study included written OOMN consultation reports, employer information from OSHA's Information System (OIS), and archived weather data from a nearby National Oceanic and Atmospheric Administration (NOAA) observation station.[6]

We excluded consults in which, in OOMN's opinion, the worker did not experience HRI. For each of the remaining cases, we coded over 70 variables in an Excel spreadsheet (for details, see the Table in Supplemental Digital Content 1, http://links.lww.com/JOM/A451). Briefly, we coded the following: employer characteristics including industry [classified by two-digit North American Industry Classification System (NAICS) sector code], number of employees, and HRI prevention efforts; job-related attributes such as clothing and workload (light, moderate, heavy, or very heavy, according to published guidelines[7]); local weather conditions (air temperature and Heat Index) at the time of the incident; worker demographics, job tenure, and medical conditions that could predispose to HRI; and clinical findings including HRI type and severity, laboratory test results, and related diagnoses (eg, rhabdomyolysis, organ failure). Weather was only assessed for outdoor worksites with no nearby occupational heat sources (eg, fires or hot tar). Heat Index combines temperature and relative humidity to quantify how hot the weather ''feels'' to members of the general public.[8] The coded predisposing medical conditions were hypertension, diabetes, multiple sclerosis, cardiac disease, and obesity

From the Office of Occupational Medicine and Nursing, Directorate of Technical Support and Emergency Management, Occupational Safety and Health Administration, Washington, District of Columbia.

The views expressed in this article are the personal views of the authors and do not purport to reflect official views of OSHA or the U.S. Department of Labor.

No outside funding was obtained for this work.
The authors have no conflicts of interest.
Supplemental digital contents are available for this article. Direct URL citation appears in the printed text and is provided in the HTML and PDF versions of this article on the journal's Web site (www.joem.org).

Address correspondence to: Aaron W. Tustin, MD, MPH, Office of Occupational Medicine and Nursing, Department of Labor – OSHA, 200 Constitution Ave NW, Mailstop N3653, Washington, DC 20210 (tustin.aaron.w@dol.gov).



DOI: 10.1097/JOM.0000000000001365

**TABLE 1.** Demographics and Personal Health Characteristics of Workers With Occupational Heat-Related Illnesses

| Characteristic | Overall Study Population | Workers Who Died | Workers With Nonfatal Heat-Related Illness Only |
|---|---|---|---|
| Total number, *n* | 64 | 24 | 40 |
| Sex, *n* (%)* | | | |
| Male | 38 (66.7) | 24 (100.0) | 14 (42.4) |
| Female | 19 (33.3) | 0 (0.0) | 19 (57.6) |
| Unknown, *n* | 7 | 0 | 7 |
| Age in years, median (range)* | 38 (15–71) | 44 (18–67) | 33 (15–71) |
| Body mass index (BMI) category, *n* (%)† | | | |
| Underweight | 3 (8.1) | 0 (0) | 3 (15.0) |
| Normal | 12 (32.4) | 4 (23.5) | 8 (40.0) |
| Overweight | 8 (21.6) | 4 (23.5) | 4 (20.0) |
| Obese | 14 (37.8) | 9 (52.9) | 5 (25.0) |
| Unknown, n | 27 | 7 | 20 |
| Diabetes, *n* (%) | | | |
| No | 27 (90.0) | 8 (80.0) | 19 (95.0) |
| Yes | 3 (10.0) | 2 (20.0) | 1 (5.0) |
| Unknown, *n* | 34 | 14 | 20 |
| Hypertension, *n* (%) | | | |
| No | 23 (74.2) | 6 (54.5) | 17 (85.0) |
| Yes | 8 (25.8) | 5 (45.5) | 3 (15.0) |
| Unknown, *n* | 33 | 13 | 20 |
| Cardiac disease, n (%)* | | | |
| No | 30 (83.3) | 10 (62.5) | 20 (100.0) |
| Yes‡ | 6 (16.7) | 6 (37.5) | 0 (0.0) |
| Unknown, *n* | 28 | 8 | 20 |
| Number of recorded predisposing medical conditions, n (%)*,§ | | | |
| 0 | 19 (47.5) | 5 (26.3) | 14 (66.7) |
| 1 | 15 (37.5) | 9 (47.4) | 6 (28.6) |
| 2 | 3 (7.5) | 3 (15.8) | 0 (0.0) |
| 3 | 3 (7.5) | 2 (10.5) | 1 (4.8) |
| 4 | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| Unknown, *n* | 24 | 5 | 19 |

Note: All percentages are column percentages after excluding workers with unknown data.
*This symbol indicates a statistically significant difference between fatal and nonfatal illnesses.
†BMI category definitions: underweight, BMI < 18.5 kg/m$^2$; normal, 18.5 kg/m$^2$ $\leq$ BMI < 25 kg/m$^2$; overweight, 25 kg/m$^2$ $\leq$ BMI < 30 kg/m$^2$; obese, BMI $\geq$ 30 kg/m$^2$.
‡Cardiac disease totals include cases in which significant preexisting heart disease was discovered at autopsy.
§The predisposing medical conditions were obesity, diabetes, hypertension, and cardiac disease. This variable was considered ''unknown'' only if there was no information about any of these four conditions.

(defined as body mass index $\geq$30 kg/m$^2$). We considered workers to have rhabdomyolysis if their serum creatine kinase (CK) concentration was higher than 1000 U/L.[9] In addition to the coded variables, we used free text format to store other past medical history, outpatient medications, and pertinent social history.

## Statistical Analysis

We used descriptive statistics to summarize characteristics of each case. To assess whether risk factors differed for more severe HRIs, we stratified incidents by severity (fatal vs nonfatal) and compared selected characteristics between strata. Categorical and continuous variables were compared using Fisher exact test and Student *t* test, respectively. For hypothesis testing, we considered *P* values less than 0.05 to be statistically significant. All analyses were conducted in R version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria).

# RESULTS

## Study Population

From 2011 through 2016, OOMN consulted on 47 heat investigations. After excluding cases that did not represent occupational HRI ($n = 3$) and cases for which medical records were no longer available ($n = 6$), our study sample consisted of 38 investigations. Six investigations involved HRI clusters in which multiple workers at the same company were affected (range, 2 to 10 workers per company). For this reason, our sample included 64 workers who experienced 66 total episodes of HRI. There were 24 fatalities. Two workers became ill twice, including a worker who was hospitalized overnight for heat exhaustion and dehydration after his first day at a new job. After taking 2 days off, he died of heat stroke after his third day of work (ie, 5 days after his initial HRI).

## Worker Demographics and Predisposing Medical Conditions

Most (67%) affected workers were male and the median age was 38 years (range, 15 to 71 years; Table 1). Compared with workers with nonfatal HRI, workers who died were significantly more likely to be male (100% of fatalities vs 42% of nonfatal cases) and older (median age, 44 vs 33 years).

Among workers for whom information was available, 38% were obese, 26% had hypertension, 10% had diabetes, and 17% had cardiac disease (either previously diagnosed or discovered at autopsy). Fifty-eight percent of the assessed workers had at least one of these four conditions. Workers who died were significantly more likely to have at least one predisposing medical condition than workers with nonfatal HRI (74% vs 33%). The prevalence of each condition was higher in deceased workers (eg, 53% of decedents were obese vs 25% of workers with nonfatal HRI), but most of the observed differences were not statistically significant (Table 1).

**TABLE 2.** Number and Type of Outpatient Medications Used by Workers Who Suffered Heat-Related Illnesses

| Characteristic | Number (%) of Workers |
|---|---|
| Sample size: Workers for whom medication information was available | 24 (100.0) |
| Count of total outpatient medications (prescription and nonprescription), per worker | |
| 0 | 15 (62.5) |
| 1–3 | 6 (25.0) |
| 4–6 | 0 (0.0) |
| 7–9 | 2 (8.3) |
| 10 or more | 1 (4.2) |
| Count of outpatient medications linked to increased susceptibility to heat-related illness, per worker | |
| 0 | 17 (70.8) |
| 1–3 | 4 (16.7) |
| 4–6 | 3 (12.5) |
| 7–9 | 0 (0.0) |
| 10 or more | 0 (0.0) |
| Anticholinergics or sympathomimetics | 1 (4.2) |
| Anticonvulsants | 3 (12.5) |
| Antidepressants | 3 (12.5) |
| Antiplatelet agents including aspirin | 2 (8.3) |
| Antipsychotics | 0 (0.0) |
| Benzodiazepines | 1 (4.2) |
| Diuretics | 2 (8.3) |
| Nondiuretic antihypertensives [eg, angiotensin-converting enzyme (ACE) inhibitor or angiotensin receptor blocker] | 3 (12.5) |
| Opiates and opioids | 2 (8.3) |
| Oral hypoglycemics | 1 (4.2) |

**TABLE 3.** Clinical Characteristics of Occupational Heat Stroke Cases

| Characteristic | Value |
|---|---|
| Total cases, *n* | 27 |
| Fatal, *n* (%) | |
| Yes | 23 (85.2) |
| No | 4 (14.8) |
| Acute kidney failure, *n* (%) | |
| Yes | 15 (83.3) |
| No | 3 (16.7) |
| Unknown, *n* | 9 |
| Rhabdomyolysis, *n* (%) | |
| Yes | 5 (71.4) |
| No | 2 (28.6) |
| Unknown, *n* | 20 |
| Respiratory failure, *n* (%) | |
| Yes | 11 (61.1) |
| No | 7 (38.9) |
| Unknown, n | 9 |
| Liver failure, *n* (%) | |
| Yes | 9 (60.0) |
| No | 6 (40.0) |
| Unknown, n | 12 |
| Diffuse intravascular coagulation [DIC], *n* (%) | |
| Yes | 7 (38.9) |
| No | 11 (61.1) |
| Unknown, *n* | 9 |
| Seizure, *n* (%) | |
| Yes | 4 (19.0) |
| No | 17 (81.0) |
| Unknown, *n* | 6 |

Note: For each characteristic, the percentages are column percentages after excluding cases with unknown data.

Information about outpatient medications was available for 24 workers (Table 2). Seven workers (29%) took at least one medication that predisposes patients to HRI[10,11] (range, one to six such medications per worker). An additional worker was prescribed medications for hypertension and diabetes but had been unable to fill those prescriptions recently. Eight different classes of HRI-associated medications were represented in our sample. The most common of these were antidepressants, anticonvulsants, and antihypertensives (Table 2).

## Alcohol and Illicit Drugs

Four workers who died of heat stroke had a documented history of alcohol abuse or high-risk drinking. In three other heat stroke fatalities, methamphetamine was detected in postmortem toxicology tests. However, most records in this study did not include information about alcohol or illicit drugs. These data were more likely to be present in fatal cases. Because of the high frequency of missing data, which was at least partially due to sampling bias, we did not attempt to compute rates of alcohol abuse or methamphetamine use among the workers in this study.

## Clinical Characteristics of Occupational HRI

The most common HRIs were heat exhaustion (44%) and heat stroke (41%). Only 12% of cases involved less severe HRIs such as heat syncope, heat cramps, or heat rash.

Table 3 summarizes clinical findings of the 27 heat stroke cases. Most (85%) heat stroke cases were fatal, and multiorgan failure was common. The majority of heat stroke victims experienced acute kidney failure (83%), respiratory failure (61%), or liver failure (60%). Diffuse intravascular coagulation (DIC) was present in 39% of heat stroke cases.

Serum CK was measured in 10 cases (heat stroke = 7, heat exhaustion = 1, heat cramps = 2). The CK concentration was elevated (> 200 U/L) in all 10 cases. Rhabdomyolysis (CK > 1000 U/L) was present in five cases of heat stroke and one case of heat cramps. The highest measured CK concentration was 55,940 U/L.

## Job Tenure

After excluding cases with missing job tenure information, almost half of heat-related fatalities (10 of 22; 45%) resulted from incidents that occurred on the first day on the job or a worker's first day back after an extended absence (Table 4). Altogether, 73% of fatal incidents (16 of 22) happened in the first week on the job. Fatal HRIs were significantly more likely to occur during the first week of work than nonfatal HRIs. The latter predominantly affected established workers.

## Employer Characteristics

The 38 investigations involved 37 unique employers (one employer was investigated by OSHA twice for HRIs, in consecutive years) in 19 U.S. states and the District of Columbia (Fig. 1). OOMN investigated occupational HRIs, which occurred in both southern and northern regions. The geographic distribution of these cases was partially determined by the fact that OOMN rarely receives consultation requests from OSHA-approved State Plans.[12]

Table 5 summarizes selected employer characteristics. The most frequently investigated industry sectors were Construction (NAICS 23), Administration and Support and Waste Management and Remediation Services (NAICS 56), and Transportation and Warehousing (NAICS 48–49). These three sectors comprised almost two-thirds (65%) of workplaces in our study. Ninety-two percent of the establishments had fewer than 250 employees,

**TABLE 4.** Job Tenure, Stratified by Severity of the Heat-Related Illness

| Days on Job | Fatal Heat-Related Illnesses, *n* (%)* | Nonfatal Heat-Related Illnesses, *n* (%)* |
|---|---|---|
| First day | 10 (45.5) | 1 (3.1) |
| 2–7 days | 6 (27.3) | 5 (15.6) |
| 8–14 days | 1 (4.5) | 1 (3.1) |
| More than 14 days | 5 (22.7) | 25 (78.1) |
| Unknown, *n* | 2 | 10 |
| | $P < 0.001$ | |
| Totals | 24 (100.0) | 42 (100.0) |

When computing percentages and *P* value, we excluded cases with missing information about job tenure. For new workers, "days on job" was the number of work days since hire. For existing employees who had been reassigned recently to a job with higher heat stress, it was the number of days since reassignment. For existing workers who had returned recently from an absence of 1 week or more, it was the number of days worked since returning.

*Percentages are column percentages after excluding cases with unknown job tenure.

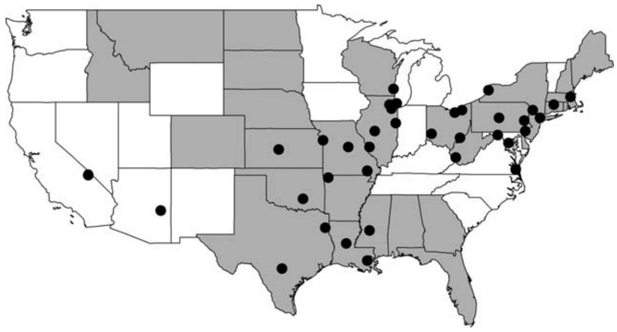

**FIGURE 1.** Worksite locations (black circles) for the 38 OSHA HRI investigations described in this report. Grey shading indicates states where Federal OSHA has jurisdiction over most private-sector employers. In the other states, private employers are regulated by OSHA-approved State Plans, but Federal OSHA has jurisdiction over federal government agencies.

**TABLE 5.** Employer Characteristics: Industry, Establishment Size, and Efforts to Prevent Heat-Related Illness

| Characteristic | | Number (%) of Employers* |
|---|---|---|
| Industry sector [NAICS code] | | |
| Construction [23] | | 12 (32.4) |
| Administrative and Support and Waste Management and Remediation Services [56] | | 7 (18.9) |
| Transportation and Warehousing [48–49] | | 5 (13.5) |
| Manufacturing [31–33] | | 4 (10.8) |
| Mining, Quarrying, and Oil and Gas Extraction [21] | | 2 (5.4) |
| Arts, Entertainment, and Recreation [71] | | 2 (5.4) |
| Agriculture, Forestry, Fishing, and Hunting [11] | | 1 (2.7) |
| Retail Trade [44–45] | | 1 (2.7) |
| Information [51] | | 1 (2.7) |
| Real Estate and Rental and Leasing [53] | | 1 (2.7) |
| Other services [81] | | 1 (2.7) |
| Number of employees | | |
| 1–4 | | 3 (8.1) |
| 5–9 | | 6 (16.2) |
| 10–19 | | 2 (5.4) |
| 20–49 | | 9 (24.3) |
| 50–99 | | 2 (5.4) |
| 100–249 | | 12 (32.4) |
| 250–499 | | 0 (0.0) |
| 500–999 | | 0 (0.0) |
| 1,000 or more | | 3 (8.1) |
| Components of heat-related illness prevention programs | | |
| Acclimatization program | Yes | 0 (0.0) |
| | No | 30 (100.0) |
| | Unknown/missing, n | 7 |
| Mandatory rest breaks triggered by high levels of heat stress | Yes | 0 (0.0) |
| | No | 33 (100.0) |
| | Unknown/missing, n | 4 |
| Onsite environmental heat monitoring | Yes | 3 (10.0) |
| | No | 27 (90.0) |
| | Unknown/missing, n | 7 |
| Training about heat-related illness | Yes | 12 (36.4) |
| | No | 21 (63.6) |
| | Unknown/missing, n | 4 |
| Readily accessible drinking water | Yes | 28 (84.8) |
| | No | 5 (15.2) |
| | Unknown/missing, n | 4 |

NAICS, North American Industry Classification System.

*For each characteristic, the percentages are column percentages after excluding employers with unknown/missing data.

**TABLE 6.** Characteristics of Work Being Performed at the Time of Heat-Related Illness

| Characteristic | Entire Study Population, *n* (%)* | Fatalities, *n* (%)* | Nonfatal Heat-Related Illnesses, *n* (%)* |
|---|---|---|---|
| Work location | | | |
| Outdoor | 34 (52.3) | 19 (79.2) | 15 (36.6) |
| Indoor | 29 (44.6) | 4 (16.7) | 25 (61.0) |
| Mixed indoor/outdoor | 2 (3.1) | 1 (4.2) | 1 (2.4) |
| Unknown, *n* | 1 | 0 | 1 |
| Work near an artificial heat source | | | |
| No | 47 (72.3) | 18 (75.0) | 29 (70.7) |
| Yes | 18 (27.7) | 6 (25.0) | 12 (29.3) |
| Unknown, *n* | 1 | 0 | 1 |
| Estimated work load | | | |
| Light | 5 (9.8) | 1 (4.8) | 4 (13.3) |
| Moderate | 10 (19.6) | 6 (28.6) | 4 (13.3) |
| Heavy | 32 (62.7) | 10 (47.6) | 22 (73.3) |
| Very heavy | 4 (7.8) | 4 (19.0) | 0 (0.0) |
| Unknown, *n* | 15 | 3 | 12 |
| Clothing | | | |
| Regular work clothes | 39 (83.0) | 13 (76.5) | 26 (86.7) |
| Double layer of protective clothing | 3 (6.4) | 3 (17.6) | 0 (0.0) |
| Chemical protective suit | 3 (6.4) | 1 (5.9) | 2 (6.7) |
| Character costume | 2 (4.3) | 0 (0.0) | 2 (6.7) |
| Unknown, *n* | 19 | 7 | 12 |
| Total heat-related illnesses | 66 (100.0) | 24 (100.0) | 42 (100.0) |

*For each characteristic, the percentages are column percentages after excluding cases with unknown data.

although several small firms were subsidiaries of much larger national corporations.

Table 5 also provides data about the employers' HRI prevention programs. Because OSHA did not collect these data in a standardized manner during the study period, this information was occasionally missing or incomplete. Of the employers for which data were available, none (0 of 31) had a formal plan to allow new or returning workers to obtain heat acclimatization gradually, and none (0 of 34) enforced mandatory rest breaks when the combination of workload and environmental heat was above recommended heat stress exposure limits. Only 10% (3 of 30) of assessed employers had the ability to monitor onsite environmental heat; in these three cases, the monitoring was minimal (eg, a thermometer connected to an indoor HVAC system) and was not used effectively to protect workers. Just over one-third (12 of 21, 36%) of assessed employers provided training about occupational HRI, and drinking water was almost always (28 of 33, 85%) readily accessible.

## Characteristics of the Work Being Performed

Most (19 of 24; 79%) heat-related fatalities were associated with outdoor work, while 61% (25 of 41) of nonfatal HRIs occurred during or after indoor work (Table 6). Overall, 28% of HRIs (18 of 65 with available data) were associated with work near an artificial heat source such as a fire, oven, sauna, or grill. The level of physical exertion was generally high. Among HRIs with available workload data, 71% (36 of 51) of workers were performing heavy or very heavy work. Most [83% (39 of 47 for whom data were available)] workers were wearing normal work clothing, and eight workers (17%) were wearing protective gear or costumes that impeded heat dissipation.

There were 28 HRIs at outdoor worksites with no nearby heat source. Periods of direct sunlight were present in almost all cases; none of these incidents occurred on an overcast day, and only one worker was known to be working in the shade. The median ambient air temperature at the time of the incidents was 88°F (range, 83°F to 102°F). The median Heat Index was 92°F (range, 83°F to 110°F).

## DISCUSSION

Because OSHA often obtains worker medical records to support its investigations, the agency is well-positioned to study the epidemiology of occupational HRI in the U.S. We were able to assess personal risk factors and clinical characteristics of both fatal and nonfatal HRI. The 24 deaths in the present study comprise one of the largest published samples of civilian U.S. occupational heat-related fatalities for which extensive medical information was available. A study of the burden of HRI in Florida found that cardiovascular disease was the most common comorbidity in the 23 work-related HRI deaths.[13] Other large fatality studies lacked detailed worker medical information[14,15] or included only military personnel.[16,17]

The current study expands upon a 2016 OSHA case series whose primary findings were that most (74%) heat-related fatalities occurred during the first 3 days of work and most employers did not provide important HRI prevention elements such as acclimatization programs, work/rest cycles, and training.[4] We confirmed those findings in a different set of OSHA heat investigations (there was some overlap, as 12 of 38 inspections in our sample were also included in the prior paper). We expanded on the prior report by including detailed information from medical records (both fatal and nonfatal cases), workload assessments, and environmental heat estimates. This additional information allowed us to analyze personal risk factors (eg, medication use), clinical features, and heat stress measures that were not assessed in the prior study.

We found a high prevalence of obesity, diabetes, hypertension, and cardiac disease in workers who died of HRI in this study. Epidemiologic studies have shown that these conditions increase the risk of HRI through mechanisms such as decreased thermoregulatory ability, disordered skin vasodilation, impaired sweating response, dehydration, and inability to increase cardiac output.[18] However, much of the evidence for these risk factors comes from general population studies.[19–21] There is less published information about preexisting medical conditions in workers with HRI. Some studies of occupational HRI did not evaluate workers' comorbid medical conditions.[4,5,22] Among those that did, an analysis of

Washington State workers' compensation claims found that medication use or a medical condition may have contributed to 22% of work-related HRIs, but the frequency of individual conditions was not reported.[23] A case series of occupational HRI in the southeastern U.S. found that 67% of hospitalized workers had at least one medical condition that increases HRI risk, compared with only 17% of workers who were treated in the ED.[24] This result supports our finding that predisposing medical conditions may increase the severity of occupational HRI.

Of the workers in this study for whom data were available, 29% (7 of 24) took medications associated with HRI. In addition, at least seven heat stroke victims had a history of heavy alcohol use or recent methamphetamine use. Alcohol and methamphetamine increase HRI risk,[25,26] as do medications such as antidepressants, anticonvulsants, antipsychotics, anticholinergics, diuretics and other antihypertensives, benzodiazepines, opioids, antiplatelet agents, and oral hypoglycemic drugs.[10,11,27] Ours is one of the first studies to document the prevalence of these risk factors in work-related HRIs. In Washington State, some workers with HRI used diuretics, beta-blockers, antihistamines, and psychiatric medications, but the report did not specify the percentage of workers taking each class of medication.[23]

Heat stroke victims in this study often had multiorgan failure and inflammatory changes such as coagulopathy (ie, DIC) and rhabdomyolysis. Similar findings have been described in prior reports. In Florida, work-related HRI hospitalizations were commonly associated with comorbid diagnoses involving the cardiovascular, cerebrovascular, respiratory, and renal systems.[13] Heat stroke hospitalizations in the U.S. Army were associated with rhabdomyolysis (25%) and acute kidney failure (13%).[17] The reason for these observations is that in addition to hyperthermia, heat stroke produces physiologic derangements, including reduced splanchnic blood flow, platelet aggregation, endothelial damage, and cytokine release.[28,29] Heat stroke often meets systemic inflammatory response syndrome (SIRS) diagnostic criteria (ie, two or more of abnormal body temperature, heart rate, respiratory rate, or white blood count).[30] Aggressive cooling, the preferred treatment for heat stroke, may be delayed if clinicians mistake heat stroke for other causes of SIRS (eg, sepsis). For example, one heat stroke decedent in this study did not receive therapeutic cooling in the ED. Infectious SIRS etiologies apparently were considered more likely, and initial treatments included empiric antibiotics. Diagnosis of work-related heat stroke can be aided by considering the occupational history and obtaining a rectal temperature, as peripheral temperature measurements may mask severe hyperthermia by underestimating core body temperature.[31] Nonetheless, the complexity of the clinical manifestations and the lack of perfectly effective treatments underscore the importance of preventing, rather than diagnosing and treating, heat stroke.[29]

Of the cases for which the worker's job tenure was available, over 70% of heat-related fatalities occurred during the first week on the job. Newly hired workers are at a higher risk of severe HRIs because of physiological factors and/or insufficient heat-related knowledge and training. For example, in one case report, a landscaper who developed heat stroke during his first day on the job did not know where to obtain water at the worksite.[32] New workers should receive training about prevention and recognition of HRI before they begin work in a hot environment.[25] Beneficial physiological adaptations, sometimes termed "acclimatization," can be acquired with gradual exposure to hot work. Such adaptations include higher plasma volume, lower heart rate, improved core temperature regulation, and increased sweating efficiency.[25,33] None of the employers in our study were identified as having implemented heat acclimatization schedules for new workers. The National Institute for Occupational Safety and Health (NIOSH) recommends limiting new workers to 20% of the usual duration of work in the hot environment during their first day.[25] Exposure time can increase over the next 7 to 14 days until the worker is completely acclimatized to heat. Unfortunately, our findings demonstrate that many employers fail to acclimatize workers, despite decades of recognition among the scientific community that new workers are at high risk of heat stroke.[4,16,24,32] Public health authorities and occupational safety professionals must do a better job of communicating the importance of formal heat acclimatization procedures.

This work identified other opportunities to improve the quality of heat-related enforcement and program management. For example, one worker developed hyponatremia and heat cramps while sweating excessively and consuming a large quantity of water. We discovered that when investigating HRIs, our office did not routinely assess whether employers provided electrolyte-containing beverages for workers. National military, athletic, and occupational guidelines stress the need for electrolyte replacement during prolonged periods of physical activity.[25,34,35]

In contrast to "classic" (nonexertional) heat stroke that is typically caused by high environmental temperature,[28] occupational HRI is an exertional disease that predominantly affects workers who engage in strenuous job tasks.[5,22,25,28] Of the workers in this study for whom workload information was available, over 70% became ill while performing heavy or very heavy physical activity. In many cases, environmental conditions were not excessively hot. Outdoor workers in this study developed HRI when the Heat Index was as low as 83°F. Employers who monitor the Heat Index should recognize that certain workers (eg, new workers, those who work in direct sunlight, those who perform strenuous physical activity, and those who wear heavy or nonbreathable clothing) can experience HRI even when the Heat Index is less than 90°F.[36]

Wet bulb globe temperature (WBGT) is the preferred workplace environmental heat metric[7,25] because WBGT, unlike Heat Index, automatically incorporates the effects of radiant heat and air movement. Associations of WBGT with 25 outdoor HRIs from the current study have been reported separately.[37] Workers' total heat stress was compared with WBGT-based occupational exposure limits (OELs) published by NIOSH and ACGIH® (American Conference of Governmental Industrial Hygienists). The OELs had 100% sensitivity for detecting fatal heat stress. This result was one of the first real-world validations of the heat OELs.

This study had several limitations. Selection bias and OSHA enforcement exemptions may have reduced this study's generalizability for two reasons. First, OSHA field offices consulted OOMN only 47 times during more than 200 OSHA HRI investigations from 2011 to 2016. Some characteristics of the OOMN consults may have differed from those of OSHA HRI investigations overall. For example, field offices may be more likely to consult OOMN when there is a suspected 5(a)(1) violation. This bias could have caused over-representation of serious health outcomes and deficient employer HRI prevention programs in our sample of investigations. Second, although many occupational HRIs occur at farms,[14,15,22] agricultural workers had a low probability of inclusion in our sample because small farms are exempt from OSHA investigations.[38] Another limitation of this study was the lack of a comparison group. We could not compute measures of association (eg, odds ratios) for risk factors between sick and healthy workers. We attempted to ameliorate this problem by stratifying by disease severity; this analysis essentially created an internal comparison group of workers with nonfatal HRI. Finally, we may have misclassified some exposures and risk factors due to the variable quality of the available records. Medical records of workers who died were often more extensive than those of workers with nonfatal HRI.

## CONCLUSION

This study of OSHA heat stress investigations provided important evidence about the epidemiology of occupational HRI.

 

Many workers have comorbid medical conditions and use medications that may exacerbate heat stress. Workplace safety managers and clinicians who oversee medical surveillance programs should consider the interplay of environmental, job-related, and personal risk factors when designing protocols that protect all workers. New workers are particularly susceptible to severe HRI. Government regulators and public health authorities should increase efforts to educate employers about the need to adopt a comprehensive HRI prevention program that includes a plan to acclimatize workers to heat.

## REFERENCES

1. Bureau of Labor Statistics. Occupational Injuries/Illnesses and Fatal Injury Profiles. Available at: https://data.bls.gov/gqt/InitialPage. Accessed May 9, 2017.
2. Occupational Safety and Health Administration. Data & Statistics: Severe Injury Reports. Available at: https://www.osha.gov/severeinjury/index.html. Accessed March 17, 2017.
3. Nevarez J. OSHA compliance issues: OSHA heat stress fatality investigation of a Latino landscaping worker. *J Occup Environ Hyg*. 2013;10:D67–D70.
4. Arbury S, Lindsley M, Hodgson M. A critical review of OSHA heat enforcement cases: lessons learned. *J Occup Environ Med*. 2016;58:359–363.
5. Arbury S, Jacklitsch B, Farquah O, et al. Heat illness and death among workers: United States, 2012–2013. *MMWR Morb Mortal Wkly Rep*. 2014;63:661–665.
6. National Centers for Environmental Information. Data Tools: Local Climatological Data. Available at: https://www.ncdc.noaa.gov/cdo-web/datatools/lcd. Accessed July 27, 2017.
7. ACGIH. TLVs: Heat Stress and Strain. Cincinnati, OH: ACGIH; 2017.
8. National Weather Service. NWS Heat Index. Available at: http://www.nws.noaa.gov/om/heat/heat_index.shtml. Accessed May 9, 2017.
9. Cervellin G, Comelli I, Lippi G. Rhabdomyolysis: historical background, clinical, diagnostic and therapeutic features. *Clin Chem Lab Med*. 2010; 48:749–756.
10. Westaway K, Frank O, Husband A, et al. Medicines can affect thermoregulation and accentuate the risk of dehydration and heat-related illness during hot weather. *J Clin Pharm Ther*. 2015;40:363–367.
11. Bruning RS, Dahmus JD, Kenney WL, Alexander LM. Aspirin and clopidogrel alter core temperature and skin blood flow during heat stress. *Med Sci Sports Exerc*. 2013;45:674–682.
12. Occupational Safety and Health Administration. Directorate of Cooperative and State Programs: State Plans. Available at: https://www.osha.gov/dcsp/osp/. Accessed May 9, 2017.
13. Harduar Morano L, Watkins S, Kintziger K. A comprehensive evaluation of the burden of heat-related illness and death within the Florida population. *Int J Environ Res Public Health*. 2016;13:pii: E551.
14. Centers for Disease Control and Prevention (CDC). Heat-related deaths among crop workers: United States, 1992–2006. *MMWR Morb Mortal Wkly Rep*. 2008;57:649–653.
15. Mirabelli MC, Richardson DB. Heat-related fatalities in North Carolina. *Am J Public Health*. 2005;95:635–637.
16. Schickele E. Environment and fatal heat stroke; an analysis of 157 cases occurring in the Army in the U.S. during World War II. *Mil Surg*. 1947;100:235–256.
17. Carter 3rd R, Cheuvront SN, Williams JO, et al. Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc*. 2005;37:1338–1344.
18. Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O. Heat stress in older individuals and patients with common chronic diseases. *CMAJ*. 2010; 182:1053–1060.
19. Henschel A, Burton LL, Margolies L, Smith JE. An analysis of the heat deaths in St. Louis during July, 1966. *Am J Public Health Nations Health*. 1969;59:2232–2242.
20. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. *Arch Intern Med*. 2007;167:2170–2176.
21. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev*. 2002; 24:190–202.
22. Prudhomme JC, Neidhardt A. State of California Memorandum: Cal/OSHA Investigations of Heat Related Illnesses. Available at: https://www.dir.ca.gov/dosh/heatillnessinvestigations-2005.pdf. Accessed May 9, 2017.
23. Bonauto D, Anderson R, Rauser E, Burke B. Occupational heat illness in Washington State, 1995–2005. *Am J Ind Med*. 2007;50:940–950.
24. Harduar Morano L, Bunn TL, Lackovic M, et al. Occupational heat-related illness emergency department visits and inpatient hospitalizations in the southeast region, 2007–2011. *Am J Ind Med*. 2015;58:1114–1125.
25. National Institute for Occupational Safety and Health. Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. Available at: https://www.cdc.gov/niosh/docs/2016-106/. Accessed August 25, 2017.
26. Kiyatkin EA, Sharma HS. Acute methamphetamine intoxication: brain hyperthermia, blood-brain barrier, brain edema, and morphological cell abnormalities. *Int Rev Neurobiol*. 2009;88:65–100.
27. Kilbourne EM, Choi K, Jones TS, Thacker SB. Risk factors for heatstroke. A case-control study. *JAMA*. 1982;247:3332–3336.
28. Bouchama A, Knochel JP. Heat stroke. *N Engl J Med*. 2002;346:1978–1988.
29. Leon LR, Helwig BG. Heat stroke: role of the systemic inflammatory response. *J Appl Physiol (1985)*. 2010;109:1980–1988.
30. Bone RC, Balk RA, Cerra FB, et al. Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. The ACCP/SCCM Consensus Conference Committee. American College of Chest Physicians/Society of Critical Care Medicine. *Chest*. 1992;101: 1644–1655.
31. Mazerolle SM, Ganio MS, Casa DJ, Vingren J, Klau J. Is oral temperature an accurate measurement of deep body temperature? A systematic review. *J Athl Train*. 2011;46:566–573.
32. Adelakun A, Schwartz E, Blais L. Occupational heat exposure. *Appl Occup Environ Hyg*. 1999;14:153–154.
33. Ashley CD, Ferron J, Bernard TE. Loss of heat acclimation and time to re-establish acclimation. *J Occup Environ Hyg*. 2015;12:302–308.
34. American College of Sports Medicine, Sawka MN, Burke LM, Eichner ER, et al. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377–390.
35. Institute of Medicine. Fluid Replacement and Heat Stress. Available at: https://www.ncbi.nlm.nih.gov/books/NBK231130/. Accessed June 9, 2017.
36. Occupational Safety and Health Administration. Using the Heat Index: A Guide for Employers. Available at: https://www.osha.gov/SLTC/heatillness/heat_index/index.html. Accessed November 30, 2016.
37. Tustin AW, Lamson GE, Jacklitsch BL, et al. Evaluation of occupational exposure limits for heat stress in outdoor workers: United States, 2011–2016. *MMWR Morb Mortal Wkly Rep*. 2018. In press.
38. Occupational Safety and Health Administration. Directive CPL 02-00-051: Enforcement Exemptions and Limitations under the Appropriations Act. Available at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id=1519. Accessed May 18, 2017.

 