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ORIGINAL PAPER

Emergent occupational injuries presenting to hospital during increasing and extreme heat days in Illinois (USA)

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Abstract

The changing climate and rising occurrence of heat events may impact incidence and severity of occupational traumatic injuries. The objective of this research is to characterize the association between daily hospital presentations for work-related traumatic injuries and temperature in Illinois, USA. The Illinois outpatient and inpatient hospital databases were used to identify work-related traumatic injuries treated in Illinois hospitals during the summer months from May to September between 2017 to 2023. National weather service data was used to assess temperature metrics in Illinois. We used generalized linear mixed models to examine the association between daily hospital presentations for work-related traumatic injuries and two temperature related events: (1) extreme heat days and (2) days with increasing temperatures above 76°F(24.4 °C) as workers begin to acclimate to increasing ambient temperatures. Models were stratified by worker demographics, cause and nature of injury. Over the study period there were 95,038 hospital presentations for work-related traumatic injuries.. We observed a significant daily increase in traumatic injuries of 1.52% (95%CI: 0.19%, 2.87%, $p < 0.05$) during days with sequentially increasing temperatures above 76°F(24.4 °C). Workers aged 16–19 years, Hispanic workers, and workers presenting with open wound injuries and injuries caused by contact with or against objects also showed significant increase in injuries. An increase on extreme heat days in the adjusted models was seen in traumatic brain injuries (22.74%, 95%CI: 2.57, 46.86%, $p < 0.05$). Results indicate differences in susceptibility to traumatic injuries by demographic characteristics and mechanisms of injury during both periods of acclimatization to heat and extreme heat days.

Keywords Occupational health surveillance · Heat stress · Extreme heat · Heat acclimatization · Work related Injury and Illness · Emergency service—hospital

Introduction

Heat waves and rising temperatures are a growing public health problem (Gasparrini et al. 2011, Bobb et al. 2014, Kaltsatou et al. 2018) and concerns over climate change have generated interest in heat-related injuries and illnesses (HRII) in the workforce (Amoadu et al. 2023). In 2022, the United States (U.S.) recorded the third warmest summer (June–August) (NOAA, 2022). Extreme heat events, elevated temperatures and acclimating temperatures may differentially impact workers and can present different risk profiles for HRII. A prior study identified that heat related injuries (HRI) in the general Illinois population was associated with increasing temperatures above 76°Fahrenheit (24.4° Celsius) of the daily maximum temperature (Friedman et al. 2020). As the climate warms, besides increasing the frequency of extreme weather events, there have been greater than 4% more summer days with maximum temperatures over 76°F (24.4 °C) in Illinois during the past decade (2010–2019) when compared to the prior four decades (1970–2009) (NOAA, 2020a).

Exposure to heat in workers can result in HRII including heat rash, heat cramps and heat exhaustion that can lead to heat stroke or occur independently (Becker and Stewart 2011). Risk factors for HRII include age, male gender, certain prescription medication (Glazer 2005), and comorbid conditions (Becker and Stewart 2011) particularly cardiorespiratory, mental disorders, obesity and mechanisms that impact a workers ability to increase cardiovascular output, volume depletion, and acclimate to heat (Adelakun 1999).

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Occupational risk factors for HRII include precarious work conditions, working in urban areas where the built environment creates heat spots/islands (CDC, 2019a), high physical exertion, inadequate PPE (Kim et al. 2019), acclimatization plans, engineering (Morris et al. 2020), and administrative controls including training, education, frequent breaks and work scheduling (Tustin et al 2018a; Bodin et al 2016). Valid and reliable methods to measure and assess heat exposure including early warning systems have also been linked to reducing HRII in the occupational context (Gao et al 2018). Fatalities resulting from occupational HRII have been disproportionately reported among men, Hispanic/Latino workers (Gubernot et al 2015) and those working in outdoor environments (Tustin et al 2018b). Differential rates of HRII have also been reported by industry and occupation (Department of Labor 2021), particularly in construction and agriculture (Gubernot et al 2015). Heat related deaths have disproportionally impacted those unacclimated to higher ambient temperatures (Arbury et al 2014). A subset of HRII enforcement investigations conducted by the Occupational Safety and Health Administration (OSHA) from 2011–2016 found 45% of fatalities occurring in workers on their first day on the job and over 70% in the first week on the job (Tustin et al 2018b).In the same study 28 HRIs at outdoor worksites were identified with a median air temperature at the time of the incidents of 88°F (31.1 °C) (range, 83°F-102°F (28.3 °C-38.9 °C)), and a median heat index of 92°F (range, 83°F-110°F (28.3 °C-43.3 °C)) (Tustin et al 2018b).

HRII can also contribute to traumatic work-related injuries (WRI). From 2011 to 2020 there were 33,920 (mean/year = 3392) recorded HRII cases in U.S. workers that required days away from work, and 1240 HRII cases (mean/year = 124) in Illinois workers over the same period(Department of Labor, 2023). Heat can impair cognitive function, heightening the risk of errors and accidents (Mazloumi et al 2014; Rastegar et al 2021) which could lead to unintentional injuries that may not otherwise be reported as heat related. Injuries related to motor vehicle crashes, assaults, falls and penetrating objects have been shown to increase in the general population with extreme heat (Chen et al 2023) but is not well characterized in workers. Using Australian workers compensation data, researchers found that occupational burns, wounds, lacerations, and amputations as well as heat illnesses were significantly associated with heatwaves, as well as injuries caused by moving objects and contact with chemicals (Xiang et al 2014). There is however, a dearth of studies conducted in the U.S. workforce.

Not only are extreme heat waves a concern for workers, but it can also take a worker as long as 5 or more days to acclimate to ambient heat even in the absence of a heat wave (Khalaf et al 2017). Illinois represents a unique geographical region to examine the relationship between WRI and ambient temperature change since workers must reacclimate throughout the summer months due to seasonal weather variations and temperature fluctuations, for example in July which is the middle of the North American Summer we saw daily maximum temperatures range from 68–96°F (20–35.6 °C) in northern Illinois, with even more fluctuation seen in the shoulder summer months (see range of daily maximum temperature by region and month in Fig. 1).

Given the risk of traumatic injuries resulting from heat related fatigue, loss of muscle coordination and dehydration, studies are needed to examine the relationship between traumatic WRI's and both extreme heat events and days with an increasing max temperature at or above 76°F (24.4 °C) selected as a cutoff for acclimating temperatures. The aim of this paper is to examine the association between daily hospital presentations in Illinois, U.S.A within summer months during 2017–2023 for acute traumatic WRI's and two temperature related events: (1) extreme heat days and (2) days with increasing temperatures above 76°F (24.4 °C) which workers need to physically acclimate to increasing ambient temperatures.

Methods

Data sources

The Illinois outpatient and inpatient hospital databases were used to identify injuries, based on injury diagnostic codes (ICD-10-AM 'S','T') in the principal diagnosis field. We include traumatic injury cases that were treated in Illinois hospitals for the summer months from May to September between 2017 to 2023. These summer months were chosen as almost all heat-related deaths in the Illinois occur during this 5-month period (Friedman et al 2020; CDC, 2019a). The outpatient database includes all patients treated in EDs for less than 24 h who were not admitted to the hospital. The inpatient or hospital discharge database includes all patients treated for 24 h or more in Illinois hospitals for any medical reason. Both datasets include information on patient demographics (age, race, and sex), clinical outcomes (diagnoses, hospital procedures, and discharge status), and economic outcomes (hospital charges and payer source). The barell matrix is a standardized method of defining injury by body region and nature of injury (CDC, 2019b). Traumatic brain injuries are defined from the barell matrix include fractures to the skull or nerve damage (including injuries to the optic chiasm pathway and visual cortex) or internal injuries involving the brain. Internal injuries are also defined from the barell matrix, including injuries to an internal organ. Based on the annual state audit of hospitals, the hospitals included in the datasets used for this analysis comprise 96.5% of all inpatient admissions state-wide (IDPH, 2013; Lale et al 2017).

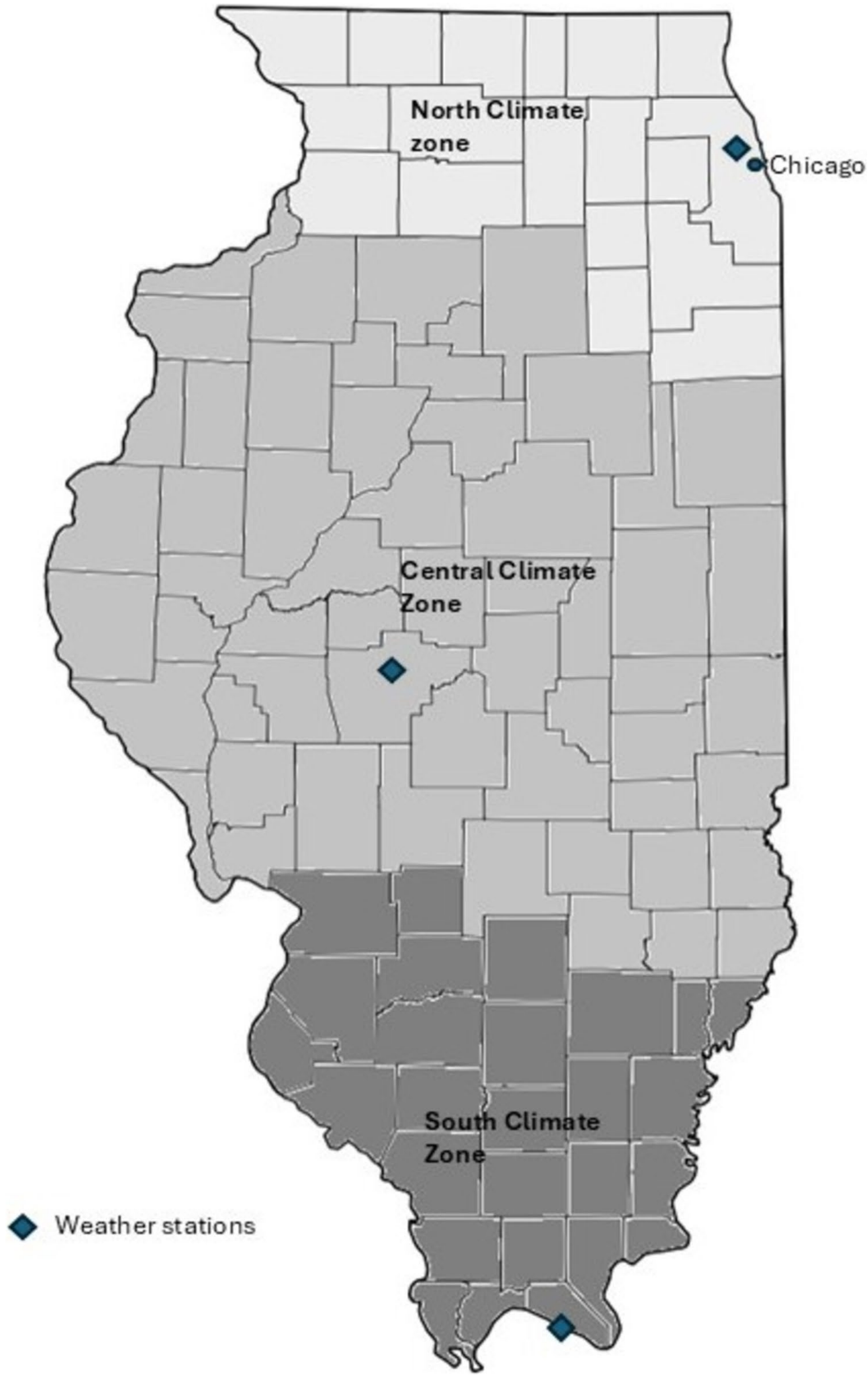

Fig. 1 Map of Illinois Climate zones with weather station locations

Inclusion and exclusion criteria

The inclusion criteria for this analysis comprised patients 16 and older, reporting workers' compensation payer, emergent presentation to hospital and presenting to the hospital emergency room (ER) with an acute injury (ICD-10-AM 'S','T'). For the purposes of this analysis, emergent cases included all patients with an admission type of "emergent", "urgent", or "trauma center"; patients with elective treatment were excluded. Elective cases primarily include those requiring imaging, other diagnostic procedures, and ambulatory and non-ambulatory surgical procedures that have been scheduled to present to the hospital.

Cases over 95 years were excluded, due to age coding errors. Cases caused by medical error (Y60-Y95), with an unknown hospital location, and cases that were recorded as sequelae of a previous injury were also excluded. Specific types of injuries that did not represent traumatic injuries at work including medical injuries (T80-T93), temperature related (S15, S25, T33-T34, T67-T69), poisoning (T51-T65), other external causes (T66-T78) and suicide attempts (T1491) were also excluded. Out of all workers compensation cases over the study period we found that 531 cases were reported as temperature related, which would account for less than 1% of all acute traumatic injuries that met the inclusion criteria.

Weather data and illinois state regions

Because daily temperatures vary across Illinois, we used locations of national weather service forecast offices to divide Illinois into three climate regions (see Fig. 1) (NOAA, 2020b). Based on treating hospital location, cases were assigned to the corresponding region of the state and weather station. Weather data was collected, including daily minimum and maximum temperatures, monthly average temperature from the National Oceanic and Atmospheric Administration database (NOAA, 2020b). Daily temperature data from the national weather service for the following weather stations were used: southern climate zone (Paducah Barkley Regional airport), central climate zone (Springfield Abraham Lincoln capital airport) and northern climate zone (Chicago O'Hare international airport weather station) (see Fig. 1). Extreme heat days can be defined in a number of ways; using daily minimum, mean or maximum temperatures (Gosling et al 2009). The 95th percentile is a commonly used cutoff (Anderson and Bell 2011) and because we were interested in daytime exposures to heat in the workplace we used the 95th percentile of the daily maximum temperature by month during the summer and region to account for spatial differences within the state (see Table 1). In 2023 the Department of Labor released a background document overviewing several options that OSHA is considering for a standard to protect outdoor and indoor workers from hazardous heat. In this document the control measures considered for the future standard include 76°F (24.4 °C) heat index as a cut-off as a 'initial heat trigger' for workplaces. Prior research relating to all heat related injuries from 2011 to 2018 in Illinois that presented to hospital also identified 76°F (24.4 °C) as the lowest daily maximum temperature in which heat related injuries occurred (Friedman et al 2020). Based on these findings indicating HRI can occur in Illinois

Table 1 Mean (range) and 95th Percentile of Maximum daily temperature in Fahrenheit and Celsius by Illinois Region and Month

Month	Region					
	North Maximum Daily temperature		Central Maximum Daily temperature		South Maximum Daily temperature	
	Mean (range)	95th % (Extreme heat)	Mean (range)	95th % (Extreme heat)	Mean (range)	95th % (Extreme heat)
May	70.9°F (46–97°F)	89°F	76.4°F (50–98°F)	90°F	79.5°F (56–93°F)	90°F
	21.6 °C (7.8–36.1 °C)	31.7 °C	24.6 °C (10.0–36.7 °C)	32.2 °C	26.4 °C (13.3–33.9 °C)	32.2 °C
June	81.8°F (60–99°F)	93°F	85.9°F (72–99°F)	94°F	87.6°F (67–101°F)	96°F
	27.7 °C (15.6–37.2 °C)	33.9 °C	29.9 °C (22.2–37.2 °C)	34.4 °C	30.9 °C (19.4–38.3 °C)	35.6 °C
July	84.8°F (68–96°F)	94°F	86.8°F (68–97°F)	94°F	90.3°F (77–100°F)	96°F
	29.3 °C (20–35.6 °C)	34.4 °C	30.5 °C (20–36.1 °C)	34.4 °C	32.4 °C (25–37.8 °C)	35.6 °C
August	83.7°F (68–100°F)	94°F	84.7°F (71–99°F)	93°F	87.9°F (75–99°F)	95°F
	28.7 °C (20–37.8 °C)	34.4 °C	29.3 °C (21.7–37.2 °C)	33.9 °C	31.1 °C (23.9–37.2 °C)	35 °C
September	77.5°F (60–95°F)	92°F	81.7°F (59–97°F)	94°F	85.1°F (67–101°F)	95°F
	25.3 °C (15.6–35 °C)	33.3 °C	27.6 °C (15–36.1 °C)	34.4 °C	29.5 °C (19.4–38.3)	35 °C

when daily maximum temperatures reach 76 °F (24.4 °C), we used this as a cutoff for acclimating temperatures. We evaluated five temperature groups as follows 1) Days below 76°F (24.4 °C) of the daily maximum temperature, (2) Days with equal to or greater than 76°F (24.4 °C) of the daily maximum temperature and increase in maximum temperature from the previous day, (3) Days with equal to or greater than 76°F (24.4 °C) of the daily maximum temperature and no change or decrease in the maximum temperature from the previous day, (4) Extreme heat days defined as equal to or greater than 95th percentile of the daily maximum temperature, and (5) Non Extreme heat days defined as less than 95th percentile of the daily maximum temperature. The 95th percentile values for maximum temperature by region and month can be found in Table 1. This was required due to wide variation in maximum temperature throughout the summer months and between regions in Illinois (see range of maximum temperatures in Table 1). Temperature group 2 (Days with sequentially increasing temperatures above 76°F (24.4 °C)) was used in our analysis because this was the lowest daily max temperature from a prior Illinois study[6] associated with heat related injuries in the general Illinois population. This measure evaluates the hypothesis that workers were most susceptible to heat fatigue and injury during the initial days of increased temperatures above 76°F (24.4 °C) before they acclimate. Temperature group 4 examined the hypothesis that traumatic WRIs increase on extreme heat days.

Covariates

Demographic characteristics included in this study are age, sex, race/ethnicity (Non-Hispanic whites (NHW), Non-Hispanic blacks, Hispanic/Latino, Non-Hispanic Asian and Pacific Islander, American Indian/Alaskan native). Information on industry and occupation of patients were not available in this dataset hence these covariates could not be utilized in this analysis to determine rates. Inpatient admission outcomes were characterized based on Illinois hospital discharge data and includes all patients treated for 24 h or more in hospital. Patients who were admitted to Intensive care units, received surgical care or died at hospital were also examined.

Statistical analysis

All statistical analyses were conducted using SAS software (v9.4; SAS Institute Inc., Cary, NC). Descriptive analysis of participant characteristics by region was conducted. We used generalized linear mixed models (SAS procedure GLIMMIX) to evaluate the relationship of increasing temperatures above 76°F (24.4 °C) and extreme heat days with change in daily traumatic injuries among subgroups of workers accounting for both serial correlation (AR1) and random effect of month given expected changes in monthly traumatic WRIs given fluctuant employment over the summer months. We calculated crude models and adjusted unmarginalized mixed models for the relationship of increasing temperatures above 76°F (24.4 °C) and extreme heat days with change in daily traumatic injuries controlling for weekends and year. We present all models with percent change (with 95% confidence intervals) in daily traumatic injuries including stratified models by sex, age group, race-ethnicity and cause of injury (see Table 6). The confidence interval signifies with 95% probability that the true population parameter lies within the calculated change in daily traumatic injuries based on our sample data. Linear mixed model results with cells where n = < 20 was restricted from the results due to unstable estimates.

Results

In this study, 95,038 patients presented with acute WRI's to Illinois hospitals between May and September of 2017–2023 (3213 days). Over 135 days (4.2%) that met our criteria for extreme heat Illinois had 6273 (6.6%) acute WRIIs present to hospital. The breakdown of total summer days and proportions of injuries for acclimating temperatures can also be seen in Table 2. Table 3 shows demographic characteristics of injuries by daily temperature group. Males were disproportionately involved in work-related injuries, and over 60% of all injuries occurred in workers aged 25 to 54 years. Race/ethnicity of injured workers showed injuries were predominantly in NHW workers, and there were higher proportions of NHW (61.6% vs 59.8%) and Non-Hispanic black (13.7% vs 13.4%) workers presenting to the hospital with traumatic injuries on extreme heat days compared to non-extreme heat days. This coincided with a drop in the proportion of Hispanic work injuries on extreme heat days vs non-extreme heat days (extreme heat; 17.3% vs non-extreme heat; 19%).

Table 4 shows work injuries by month and day of the week. Over 75% of work injuries during temperatures under 76°F (24.4 °C) occurred in the summer months of May and September, however outside of August these months also saw the highest proportion of injuries on extreme heat days. The highest proportion of injuries at lower temperatures (< 76°F (24.4 °C)) was seen on Fridays which may be a result of fatigue at the end of the working week or distractions related to the weekend. There was no increase in proportion of inpatient cases, intensive care unit admissions or deaths with increasing temperatures.

Table 5 presents data on type and mechanism of injury by daily temperature group. The case mix of injuries presenting to hospital differed on acclimating temperatures (days with increasing temperatures at or above 76°F (24.4 °C)), with a

Table 2 Proportion total summer days and traumatic work related injuries Treated In Illinois Hospitals; Inpatient And Emergency Department Database (Illinois): 2017–2023 by acclimating and extreme heat temperature categories during Summer Months (May – September)

Temperature groups	Proportion (%) total summer days (n = 3213 days)	Proportion (%) total traumatic work-related injuries (*n* = 95,038 injuries)
Acclimating temperatures		
Days below 76°F (24.4 °C) of the daily maximum temperature	16.8	21.1
Days = > 76°F (24.4 °C) of the daily maximum temperature and increase in max temperature from the previous day. [b]	45.1	44.3
Days = > 76°F (24.4 °C) of the daily maximum temperature and no change or decrease in max temperature from the previous day	38.1	34.6
Extreme heat temperatures		
Non-Extreme heat day (days with < 95th percentile of the daily maximum temperature)	95.8	93.4
Extreme heat days (days with = > 95th percentile of the daily maximum temperature)	4.2	6.6

higher proportion of burns and internal injuries, and injuries more commonly seen from struck by / caught between and cutting/piercing mechanisms. On extreme heat days there was a higher proportion of fractures, traumatic brain injuries, open wounds and contusions compared to non-extreme heat days. Cut-pierce injuries, injuries from machinery and transport injuries were mechanisms that showed an increase in proportion of all injuries on extreme heat days with all other mechanisms declining compared to non-extreme heat days.

Multivariable models: days of increasing temperatures above 76°F (24.4°C)

In multivariable models (Table 6) evaluating the overall trend of daily traumatic injuries in workers there was a significant daily average increase in both unadjusted and adjusted models, with an increase of 1.64% (95%CI: 0.32, 2.98%, $p < 0.05$) during days of increasing temperatures above 76°F (24.4 °C) in our adjusted model.

In adjusted modes by age group, the most significant increase in daily traumatic injuries during the first days of increasing temperatures above 76°F (24.4 °C) was in workers aged 16–19 years (7.47%, 95%CI: 1.91, 13.31, $p < 0.01$). There was a borderline non-significant increase in WRI on extreme heat days in workers aged 45 to 54 years (2.94%, 95%CI: −0.16, 6.14, $p = 0.0634$). Hispanic workers also showed a significant increase in traumatic injuries during the first days of increasing temperatures above 76°F (24.4 °C) (3.33%, 95%CI: 0.26, 6.5, $p < 0.05$). Open wounds were the only primary diagnosis that showed a significant increase in traumatic injuries during the first days of increasing temperatures above 76°F (24.4 °C) (3.22%, 95%CI: 0.85, 5.65, $p < 0.01$) and injuries caused by contact with or struck by or against objects was the only mechanism that showed a significant increase (3.05%, 95%CI: 0.21, 5.98, $p < 0.05$).

Multivariable models: extreme heat days

On extreme heat days, there was a significant daily increase of 22.67% (95%CI 2.73, 46.48, $p = 0.024$) in traumatic brain injuries. There was also a significant decrease in crush injuries on extreme heat days (−38.6%, 95%CI −55.81, −14.7, $p < 0.01$) and borderline non-significant increase in WRI on extreme heat days in workers aged 55 to 64 years (7.04%, 95%CI: −0.91, 15.62, $p = 0.0838$). Cutting/piercing injuries (8.86%, 95%CI: 1.05, 17.28, $p = 0.0255$) and transport related injuries (13.05%, 95%CI: 0.85, 30.45, $p = 0.0367$) both had significant increases on extreme heat days in our adjusted models. Traumatic injuries involving fractures and superficial contusions had non-significant increases ($p > 0.05$) on extreme heat days.

Discussion

Extreme temperatures and acclimatization to heat are a growing public health problem in the twenty-first century. Illinois can expect to see rising temperatures, with projected increases in average daily temperatures by the end of the century from low end estimates of 4—9°F (2.2–5 °C) to high-end estimates of 8—14°F (4.4–7.8 °C) increase based on varying scenarios of greenhouse gas emissions (University of Illinois, 2021).

Days of increasing temperatures above 76°F (24.4°C)

This analysis indicated that traumatic injuries in workers presenting to hospital occur significantly more frequently overall in periods of acclimating temperatures which may be linked to acclimatization to heat. Workers aged 16–19 years middle-aged workers (45–54 years) and Hispanic workers also demonstrated higher traumatic injuries. Open

Table 3 General Characteristics of Emergent Traumatic Work Related Injuries Treated In Illinois Hospitals; Inpatient And Emergency Department Database (Illinois): 2017–2023 by Daily Temperature during Summer Months (May – September)

	[a] < 76°F(24.4 °C) (n = 20,064)	[b] = > 76°F (24.4 °C) and inclining (n = 42,137)	[c] = > 76°F (24.4 °C) and declining or stable (n = 32,837)	[d] Non Extreme Heat days (n = 88,720)	[e] Extreme Heat Days (n = 6318)
Gender [f]	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
Male	12,706 (63.3)	26,933 (63.9)	20,992 (63.9)	56,570 (63.8)	4061 (64.3)
Female	7355 (36.7)	15,201 (36.1)	11,840 (36.1)	32,141 (36.2)	2255 (35.7)
Age					
16 to 19 yrs	1022 (5.1)	2642 (6.3)	2019 (6.1)	5308 (6.0)	375 (5.9)
20 to 24 yrs	2508 (12.5)	5368 (12.7)	4171 (12.7)	11,235 (12.7)	812 (12.9)
25 to 34 yrs	4878 (24.3)	10,115 (24.0)	8015 (24.4)	21,483 (24.2)	1525 (24.1)
35 to 44 yrs	3919 (19.5)	8147 (19.3)	6290 (19.2)	17,122 (19.3)	1234 (19.5)
45 to 54 yrs	3793 (18.9)	7606 (18.1)	5785 (17.6)	16,041 (18.1)	1143 (18.1)
55 to 64 yrs	2969 (14.8)	6098 (14.5)	4872 (14.8)	13,014 (14.7)	925 (14.6)
65 to 74 yrs	734 (3.7)	1571 (3.7)	1247 (3.8)	3328 (3.8)	224 (3.5)
75 yrs and older	241 (1.2)	590 (1.4)	438 (1.3)	1189 (1.3)	80 (1.3)
Mean Age (SD)	40.0 (sd = 14.8)	39.7 (sd = 15.1)	39.7 (sd = 15.1)	39.8 (sd = 15.1)	39.7 (sd = 15.0)
Race/Ethnicity					
White, Non-Hispanic	10,977 (54.7)	25,546 (60.6)	20,440 (62.2)	53,072 (59.8)	3891 (61.6)
Hispanic	4453 (22.2)	7843 (18.6)	5685 (17.3)	16,885 (19)	1096 (17.3)
Non-Hispanic blacks	2833 (14.1)	5601 (13.3)	4288 (13.1)	11,855 (13.4)	867 (13.7)
Asian/Pacific Islander	479 (2.4)	815 (1.9)	597 (1.8)	1772 (2.0)	119 (1.9)
American Indian/Alaska Native	38 (0.2)	81 (0.2)	56 (0.2)	165 (0.2)	10 (0.2)
Other / Unspecified	1336 (6.7)	2303 (5.5)	1823 (5.6)	5023 (5.7)	387 (6.1)
Region					
North	16,230 (80.9)	25,737 (61.1)	18,516 (56.4)	56,834 (64.1)	3649 (57.8)
Central	2871 (14.3)	10,572 (25.1)	8738 (26.6)	20,416 (23)	1765 (27.9)
South	963 (4.8)	5828 (13.8)	5583 (17)	11,470 (12.9)	904 (14.3)

SD = standard deviation

[a]Days with below 76°F (24.4°C) daily maximum temperature by region of the state

[b] Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature increased from the previous day

[c]Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature stable or decreased from the previous day

[d]Non Extreme heat days are days with maximum temperature < 95th percentile of the daily maximum temperature by month and region of the state

[e]Extreme heat day is days with = > 95th percentile of the daily maximum temperature by month and region of the state. Non Extreme heat days are days with maximum temperature < 95th percentile of the daily maximum temperature by month and region of the state

[f]Gender was not recorded in 11 hospital presentations

wounds and injuries caused by struck by or contact with objects were diagnoses and mechanisms that demonstrated significant increases in daily hospital presentations during acclimating temperatures while transport incidents and cutting-piercing mechanisms demonstrated borderline non-significant increases. These are mechanisms of injuries that can be related to attention, psychomotor function and memory, all of which can be impaired with as low as 2% dehydration (Adan 2012). Young and new workers with less than one-month experience in the job are known to be vulnerable to heat conditions, particularly in manual occupations (Institute for Work and Health, 2013). With a 7.47% increase in hospital presentations on days with inclining temperatures at or above 76°F (24.4 °C) in workers 16–19 years in Illinois, our results suggest this is a vulnerable group, possibly related to several factors including; (1) inadequate acclimatization to working conditions, (2) inappropriate education and awareness, (3) work rate and (4) personal risk factors including hydration status and being de-conditioned. Research from Canada found that workers 15–18 years reported more accidents, less safety compliance and higher safety neglect than workers aged 19–22 (Turner et al 2015). Acclimating temperatures and extreme temperatures require safety education and compliance includingwritten

Table 4 Emergent traumatic work related injuries Treated In Hospital by Year, Month and Weekday; Inpatient And Emergency Department Database (Illinois): 2017–2023 by Daily Temperature during Summer Months (May – September)

	[a] < 76°F (24.4 °C) (20,064)	[b] = > 76°F (24.4 °C) and inclining (42,137)	[c] = > 76°F (24.4 °C) and declining or stable (32,837)	[d] Non Extreme Heat days (88,720)	[d] Extreme Heat Days (6318)
Year					
2017	3737 (18.6)	6220 (14.8)	5266 (16.0)	14,163 (16.0)	1060 (16.8)
2018	2742 (13.7)	7287 (17.3)	5852 (17.8)	14,251 (16.1)	1630 (25.8)
2019	3994 (19.9)	6649 (15.8)	4794 (14.6)	15,002 (16.9)	435 (6.9)
2020	2143 (10.7)	4629 (11.0)	3599 (11.0)	9710 (10.9)	661 (10.5)
2021	2371 (11.8)	5330 (12.6)	4201 (12.8)	11,456 (12.9)	446 (7.1)
2022	2526 (12.6)	5843 (13.9)	4771 (14.5)	11,794 (13.3)	1346 (21.3)
2023	2551 (12.7)	6179 (14.7)	4354 (13.3)	12,344 (13.9)	740 (11.7)
Month					
May	9410 (46.9)	5357 (12.7)	3232 (9.8)	16,977 (19.1)	1405 (22.2)
June	2767 (13.8)	9730 (23.1)	6284 (19.1)	17,772 (20.0)	1518 (24)
July	851 (4.2)	9600 (22.8)	9085 (27.7)	19,143 (21.6)	1118 (17.7)
August	1130 (5.6)	10,140 (24.1)	8921 (27.2)	19,734 (22.2)	1223 (19.4)
September	5906 (29.4)	7310 (17.3)	5315 (16.2)	17,715 (20.0)	1362 (21.6)
Day					
Sunday	1859 (9.3)	3330 (7.9)	3156 (9.6)	8012 (9.0)	544 (8.6)
Monday	3266 (16.3)	6119 (14.5)	4972 (15.1)	13,568 (15.3)	1226 (19.4)
Tuesday	2670 (13.3)	7782 (18.5)	4774 (14.5)	14,426 (16.3)	1285 (20.3)
Wednesday	2936 (14.6)	6752 (16.0)	5980 (18.2)	15,157 (17.1)	1017 (16.1)
Thursday	3290 (16.4)	7040 (16.7)	5428 (16.5)	15,296 (17.2)	989 (15.7)
Friday	3715 (18.5)	5858 (13.9)	5184 (15.8)	14,365 (16.2)	886 (14.0)
Saturday	2328 (11.6)	5256 (12.5)	3343 (10.2)	10,517 (11.9)	679 (10.7)

[a]Days with below 76°F (24.4°C) daily maximum temperature by region of the state

[b]Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature increased from the previous day

[c]Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature stable or decreased from the previous day

[d]Extreme heat day is days with = > 95th percentile of the daily maximum temperature by month and region of the state. Non Extreme heat days are days with maximum temperature < 95th percentile of the daily maximum temperature by month and region of the state

and verbal instructions, encouragement of hydration, education on awareness of HRII symptoms and acclimatization programs to mitigate some of the risk of HRII. These factors are required to protect all workers from injuries related to heat, however, young workers are known to be more inclined to feel rushed and unable to meet the demands of their work which may deter safety compliance and increase their risk for work accidents (Breslin et al 2005). These psychosocial factors combined with hard physical work can lead to fatigue and errors in warmer temperatures for younger workers.

In 2016, the National Institute of Occupational Safety and Health (NIOSH) published its third revision of the Criteria for a Recommended Standard, Occupational Exposure to Heat and Hot Environments which outlines training, medical monitoring, and research on worker populations exposed to heat (Department of Labor, 2016). An important component of the new standard was the development of an acclimatization program for new workers, as well as workers returning from illness or absent for sequential days during the summer. Historically, it has been thought that HRII is highest during the first 2 to 4 weeks of a workers heat stress exposure. The physiological adaptations during acclimatization include sweating efficiency, cardiometabolic function, reduced core body temperature (Périard et al 2015) which can impact physical and cognitive functioning. These adaptations are going to differ in individual workers based of physical fitness, gender, age, comorbid conditions, specific medication use and hydration status.

Climate change presents a unique risk for heat acclimatization in workers located in regions such as the Midwest, particularly for outdoor occupations and seasonal workers. The region has a fluctuating seasonal climate, with predicted increases in average temperatures and extreme heat days, along with cool days between these in the summer months.

There is a need for a variety of future studies that examine acclimating and elevated temperatures relationship to work injuries to evaluate different aspects of heat exposure in more detail. An Italian study that used hospital admissions

Table 5 Emergent Injury Workers Compensation Cases Treated In Hospital by Primary diagnosis and mechanism of Injury; Inpatient And Emergency Department Database (Illinois): 2017–2023 by Daily Temperature during Summer Months (May – September)

	[a] < 76°F (24.4 °C) (20,064)	[b] = > 76°F (24.4 °C) and inclining (42,137)	[c] = > 76°F (24.4 °C) and declining or stable (32,837)	[d] Non Extreme Heat days (88,720)	[d] Extreme Heat Days (6318)
Primary Diagnosis					
Amputation	219 (1.1)	379 (0.9)	280 (0.9)	832 (0.9)	46 (0.7)
Blood vessels	963 (4.8)	1895 (4.5)	1421 (4.3)	3992 (4.5)	287 (4.5)
Burns	588 (2.9)	1374 (3.3)	1062 (3.2)	2843 (3.2)	181 (2.9)
Crush	265 (1.3)	545 (1.3)	461 (1.4)	1209 (1.4)	62 (1.0)
Dislocation	258 (1.3)	452 (1.1)	330 (1.0)	982 (1.1)	58 (0.9)
Eye / orbit injury	53 (0.3)	88 (0.2)	73 (0.2)	200 (0.2)	14 (0.2)
Foreign Body	156 (0.8)	335 (0.8)	281 (0.9)	737 (0.8)	35 (0.6)
Fracture	2424 (12.1)	5075 (12.0)	3888 (11.8)	10,614 (12)	773 (12.2)
Internal injuries	64 (0.3)	120 (0.3)	95 (0.3)	259 (0.3)	20 (0.3)
Open Wound	6275 (31.3)	13,400 (31.8)	10,232 (31.2)	27,907 (31.5)	2000 (31.7)
Sprain / Strain	3411 (17.0)	7397 (17.6)	5852 (17.8)	15,547 (17.5)	1113 (17.6)
Superficial Contusion	3673 (18.3)	7584 (18)	6131 (18.7)	16,204 (18.3)	1184 (18.7)
Traumatic Brain Injury	564 (2.8)	1074 (2.5)	801 (2.4)	2259 (2.5)	180 (2.8)
Other diagnosis	1059 (5.3)	2269 (5.4)	1812 (5.5)	4798 (5.4)	342 (5.4)
Unspecified injury	92 (0.5)	150 (0.4)	118 (0.4)	337 (0.4)	23 (0.4)
Mechanism of Injury					
Fall injury	3570 (17.8)	7417 (17.6)	5951 (18.1)	15,812 (17.8)	1126 (17.8)
Machinery	1055 (5.3)	2229 (5.3)	1743 (5.3)	4686 (5.3)	341 (5.4)
Struck by / caught between	4355 (21.7)	9236 (21.9)	7080 (21.6)	19,272 (21.7)	1399 (22.1)
Cut pierce injuries	3108 (15.5)	6556 (15.6)	5012 (15.3)	13,653 (15.4)	1023 (16.2)
Overexertion injury	1729 (8.6)	3667 (8.7)	2970 (9.0)	7817 (8.8)	549 (8.7)
Other	3038 (15.1)	6632 (15.7)	5065 (15.4)	13,814 (15.6)	921 (14.6)
Transport incident	1135 (5.7)	2727 (6.5)	2129 (6.5)	5567 (6.3)	424 (6.7)
Unspecified mechanism	2074 (10.3)	3673 (8.7)	2887 (8.8)	8099 (9.1)	535 (8.5)

[a]Days with below 76°F (24.4°C) daily maximum temperature by region of the state

[b]Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature increased from the previous day

[c]Days with = > 76°F (24.4°C) daily maximum temperature by region of the state and max temperature stable or decreased from the previous day

[d]Extreme heat day is days with = > 95th percentile of the daily maximum temperature by month and region of the state. Non Extreme heat days are days with maximum temperature < 95th percentile of the daily maximum temperature by month and region of the state

data found evidence of differences in work-related accidents over four temperature quartiles, with the peak of work-related accidents occurring in days characterized by high but not extreme temperatures (max temperature 83.48–89.06°F (28.6–31.7 °C), average temperature 76.82–82.94°F (24.9–28.3 °C)). The authors state this may be explained by change in worker behaviors during periods of extreme temperatures with use of preventive measures that may not be occurring in temperatures within the 3rd quartile despite an increase in heat stress (Morabito et al 2006).

Extreme heat days

Older workers (55 to 64 years) showed the most marked increase in hospital presentations during extreme heat days. Elderly people have several physiological changes that contribute to decreased thermoregulation (Kenny et al 2010) that make them more prone to reduced heat tolerance and generally disproportionately impacted in general hospital admissions during extreme heat (Semenza et al 1999). Older workers over 55 in the US are known to have higher rates of falls on the same level, fractures, and hip injuries compared with younger workers (CDC, 2009) and our findings suggest that this is an age group to target awareness efforts for injury prevention during heat waves.

Injuries by mechanism showed varying changes related to extreme heat days, with transport incidents showing the most marked increase. The significant decrease seen in crush injuries presenting to hospital on extreme heat days may be related to specific industries avoiding work or specific tasks on extreme heat days. Primary metal manufacturing, construction and wood product manufacturing are known

Table 6 Generalized linear mixed models assessing percentage change in Traumatic Work-Related Injuries Presenting to Illinois Hospital during Summer Months on Days with Increasing Temperatures above 76°F and Extreme heat days; overall and stratified by subgroups; Inpatient And Emergency Department Database (Illinois): 2017–2023 during Summer Months (May – September)

	Unadjusted % models [a]		**Adjusted % models** [a b]	
	= > 76°F (24.4 °C) and inclining % Change (95% CI)	**Extreme Heat Days % Change** (95% CI)	**= > 76°F (24.4 °C) and inclining % Change (95% CI)**	**Extreme Heat Days % Change** (95% CI)
All Injuries	1.35 (0.04, 2.68)*	1.78 (−1.23, 4.89)	1.64 (0.32, 2.98)*	2.34 (−0.69, 5.46)
Gender				
Female	1.36 (−0.81, 3.58)	−0.43 (−5.31, 4.71)	1.65 (−0.53, 3.88)	−0.06 (−4.96, 5.09)
Male	1.42 (−0.22, 3.09)	3.05 (−0.74, 6.98)	1.7 (0.06, 3.38)	3.71 (−0.1, 7.67)
Race/Ethnicity				
White, Non-Hispanic	1.25 (−0.44, 2.96)	2.58 (−1.54, 6.88)	1.55 (−0.15, 3.27)	3.28 (−0.87, 7.61)
Hispanic	3.21 (0.14, 6.37)*	−2.05 (−8.12, 4.43)	3.33 (0.26, 6.50)*	−1.64 (−7.74, 4.87)
Non-Hispanic blacks	1.62 (−1.95, 5.31)	5.61 (−2.20, 14.04)	1.95 (−1.63, 5.66)	5.98 (−1.86, 14.45)
Asian/Pacific Islander	0.42 (−9.16, 11)	5.84 (−13.68, 29.76)	0.82 (−8.81, 11.47)	5.7 (−13.79, 29.59)
AIAN	5.22 (−22.23, 42.35)	[c]	5.76 (−21.85, 43.12)	[c]
Other race	−2.8 (−7.96, 2.65)	2.41 (−8.82, 15.03)	−2.41 (−7.59, 3.06)	2.91 (−8.38, 15.59)
Age Group				
16 to 19 years	7.36 (1.81, 13.20)**	1.5 (−10.64, 15.29)	7.47 (1.91, 13.31)**	1.58 (−10.57, 15.38)
20 to 24 years	0.91 (−2.71, 4.67)	0.5 (−7.74, 9.47)	1.11 (−2.53, 4.88)	0.98 (−7.3, 10)
25 to 34 years	0.42 (−2.22, 3.12)	1.59 (−4.40, 7.95)	0.69 (−1.95, 3.41)	2 (−4.01, 8.39)
35 to 44 years	1.96 (−1.02, 5.03)	2.43 (−4.25, 9.57)	2.35 (−0.65, 5.43)	3.06 (−3.66, 10.24)
45 to 54 years	2.39 (−0.70, 5.57)	−0.66 (−7.41, 6.58)	2.94 (−0.16, 6.14)	0.17 (−6.64, 7.47)
55 to 64 years	−0.95 (−4.27, 2.47)	6.27 (−1.61, 14.79)	−0.61 (−3.93, 2.84)	7.04 (−0.91, 15.62)
65 to74 years	1.73 (−4.8, 8.71)	−0.07 (−14.89, 17.33)	1.52 (−5.00, 8.48)	−0.34 (−15.13, 17.01)
75 and over	8.61 (−2.76, 21.29)	−5.51 (−31.35, 30.06)	8.36 (−2.98, 21.01)	−5.57 (−31.39, 29.97)
Nature of Primary Injury				
Amputation	−1.04 (−13.53, 13.25)	−18.93 (−42.60, 14.49)	−0.65 (−13.19, 13.71)	−18.18 (−42.07, 15.57)
Blood vessel	3.35 (−2.71, 9.78)	−0.04 (−13.21, 15.14)	3.28 (−2.78, 9.71)	0.06 (−13.13, 15.25)
Burns	6 (−1.46, 14.03)	−7.1 (−22.03, 10.69)	6.36 (−1.13, 14.42)	−6.75 (−21.74, 11.1)
Crush Injury	−4.17 (−14.26, 7.10)	−39.01 (−56.09, −15.26)**	−3.8 (−13.93, 7.52)	−38.6 (−55.81, −14.70)**
Dislocation	−0.44 (−11.94, 12.57)	−21.23 (−42.68, 8.25)	−0.21 (−11.74, 12.83)	−20.9 (−42.44, 8.71)
Eye / Orbit injury	−10.10 (−31.55, 18.08)	[c]	−10.13 (−31.58, 18.05)	[c]
Foreign Body	−2.64 (−15.57, 12.28)	−15.35 (−42.56, 24.72)	−1.94 (−14.96, 13.09)	−14.27 (−41.82, 26.33)
Fracture	2.61 (−1.18, 6.54)	7.50 (−1.32, 17.10)	2.66 (−1.13, 6.60)	7.83 (−1.02, 17.47)
Internal	−2.86 (−23.38, 23.17)	[c]	−3.00 (−23.50, 22.99)	[c]
Open Wounds	2.95 (0.59, 5.37)*	1.84 (−3.47, 7.44)	3.22 (0.85, 5.65)**	2.45 (−2.89, 8.09)
Sprain Strain	1.60 (−1.52, 4.81)	−0.31 (−7.20, 7.08)	2.13 (−1.00, 5.37)	0.57 (−6.38, 8.03)
Superficial contusion	−1.59 (−4.55, 1.46)	4.12 (−2.84, 11.58)	−1.31 (−4.28, 1.75)	4.60 (−2.39, 12.10)
Traumatic Brain Injury	1.08 (−6.70, 9.50)	22.46 (2.56, 46.23)*	1.13 (−6.65, 9.56)	22.67 (2.73, 46.48)*
Severity of Injury				
Inpatient admission	6.09 (−1.8, 14.63)	−1.58 (−18.17, 18.38)	6.44 (−1.49, 14.99)	−1.06 (−17.74, 18.99)
Intensive Care Unit admission	7.30 (−6.87, 23.61)	13.92 (−17.72, 57.73)	7.83 (−6.41, 24.23)	14.59 (−17.23, 58.66)
Died	16.24 (−30.32, 93.92)		16.04 (−30.44, 93.60)	
Mechanism of Injury				
Struck by or against injury	2.82 (−0.01, 5.74)	2.27 (−4.1, 9.06)	3.05 (0.21, 5.98)*	2.68 (−3.71, 9.50)
Fall injury	−0.70 (−3.72, 2.41)	1.09 (−5.86, 8.56)	−0.44 (−3.47, 2.68)	1.61 (−5.38, 9.11)
Cut pierce injuries	3.04 (−0.33, 6.51)	8.31 (0.54, 16.68)*	3.33 (−0.04, 6.82)	8.86 (1.05, 17.28)*
Machinery	0.58 (−4.95, 6.44)	−4.46 (−16.81, 9.74)	1.09 (−4.48, 6.98)	−3.19 (−15.73, 11.2)
Overexertion injury	−0.89 (−5.16, 3.56)	−1.63 (−11.2, 8.98)	−0.70 (−4.97, 3.77)	−1.32 (−10.93, 9.31)
Transport incident	4.74 (−0.59, 10.36)	14.25 (0.46, 29.93)*	4.95 (−0.39, 10.57)	14.69 (0.85, 30.45)*

**** = < 0.0001 ** = < 0.01, * = < 0.05*

[a]Each model controls for serial correlation (AR1) and random effects for changes by month to account for variability in both temperature and employment over summer months

[b]adjusted models account for weekends and year

Table 6 (continued)

[c]Estimate restricted due to small sample size ($n = < 20$)

to have disproportionately higher rates of crush injuries in workers (Kica and Rosenman 2017).

Traumatic brain injuries, fractures and superficial contusions were the three mechanisms with the largest increase in hospital presentations on extreme heat days. Heat stress can decrease cerebral perfusion, increases heart rate and cardiac output, and redistribute blood flow throughout the body (Wilson 2018), all of which have the potential to impair alertness and balance in workers making them more susceptible to traumatic injuries. This aligns with our result of a significant increase in traumatic brain injuries on extreme heat days. Furthermore, the role of fluid balance in recovery of certain severe injuries including traumatic brain injuries is well cited, however the role of dehydration and mild heat stress in recovery post mild to moderate traumatic injuries including fractures and contusions is not well understood. As heat waves and elevated temperature events become more frequent in the latter half of the twenty-first century (Meehl and Tebaldi 2004), along with worsening chronic disease and obesity (National Institute of Health, 2018) surveillance of all occupational injuries to monitor trends and personal risk factors may yield important information for occupational health and safety planning. The relationship between acute traumatic injuries, heat and comorbidities will be assessed in a future Illinois study using hospital data.

Limitations

The primary limitation of this study is that it does not account for work related injuries that do not come through the emergency room (e.g. doctor's offices). However, emergency room outpatient and inpatient data capture the most severe cases which tend to be the priority of public health policies. Additionally, our analysis does not account for work-related deaths that occurred prior to arriving at a hospital, however Illinois only recorded 4 deaths in workers related to exposure to environmental heat in 2022 and a total of 177 worker deaths from traumatic injuries (U.S. Bureau of Labor Statistics 2024). A further limitation of this study is that weather data available for this project did not include relative humidity. For this reason, our estimates of heat related temperature exposure are conservative. The effects of heat are often exacerbated by humidity as evaporative cooling is decreased and thermal load is increased. Accurate estimates of work-related HRII by industry/occupation are difficult to obtain as occupation is not listed on hospital records and HRII relies on diagnostic clarification in hospital data systems that are prone to misclassification (CDC, 1984).

Conclusion

An analysis of outpatient and inpatient cases treated in hospitals from 2017 to 2023 for work related injuries identified higher injury incidence on days with temperatures above 76°F and among Hispanic workers, workers 16–19 years and workers with open wounds and injuries caused by contact with or struck by/against objects. On extreme heat days, there was a significant daily increase in traumatic brain injuries, cutting/piercing injuries and transport related injuries. Considering the changing climate and the potential for heat related weather extremes, improved awareness and education are needed regarding temperature related injuries for employers and employees, as well as healthcare professionals. Public health messages regarding temperature related injuries should be tailored to different temperature zones, including an understanding of acclimatization to heat at temperatures lower than extreme heat events and mechanisms impacting personal and environmental risk for dehydration. Future efforts should focus on inclusion of occupational information in hospital records, including industry, occupation, work-relatedness of a hospital visit, and workers' compensation payer source. Incorporating occupational information into clinical encounters will allow for more holistic patient care, allowing for consideration of occupation and workplace exposures in injuries, illnesses and general health encounters.

Authors contribution BS was involved in the conception and design, analysis, literature review, interpretation of data, drafting and revisions of the manuscript, and approval of the final version. CA was involved in the drafting and revisions of the manuscript, and approval of the final version. LF was involved in the conception and design, analysis, literature review, interpretation of data, drafting and revisions of the manuscript, and approval of the final version.

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Data availability Weather data is publically available from National Oceanic and Atmospheric Association (NOAA) at https://www.ncdc.noaa.gov/cdo-web/. Access to Illinois hospital data is restricted access. Aggregated data can be provided upon request.

Code availability SAS code can be provided upon request.

Declarations

Ethics approval The University of Illinois at Chicago (UIC) IRB has approved this work (#2012–0116).

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Consent for publication Not applicable.

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