The Effects of High Heat on Emergency Department Visits for Accidental Injuries

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2015

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology
2021

Abstract

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Introduction: Climate change has resulted in an increase of the global mean temperature and increase in the frequency of high heat events. The effects of high heat have been examined for mortality and specific morbidity conditions, but few studies have examined the effects of high heat and the risk of injury or injury causes. The aim of this study is to estimate the effects of high heat on the risk of emergency department visits for accidental injuries, including an assessment of injury causes, in Los Angeles, California during the warm season, May-September, 2005 – 2015.

Methods: Over-dispersed Poisson log-linear time-series models were run to estimate associations of current day (lag day 0) daily maximum temperature and ED visit counts for thirteen accidental injury categories. Models controlled for mean dew point temperature, day of the week, holidays, hospital-specific indicators, and long-term time trends. The estimates for the nonlinear relationship were calculated for the 1^{st} to the 99^{th} percentile of maximum daily temperature, using the 25^{th} percentile temperature (25 °C) as the reference temperature. Secondary analyses considered models stratified by age group, and the assessment of lag structures up to lag day 3. Sensitivity analyses were conducted to control for the presence of precipitation, high amounts of precipitation, and air pollution.

Results: Significant nonlinear associations between daily maximum temperature and injury ED visits were observed for seven of the thirteen injury categories: natural and environmental factors, cuts/pierce, drownings, machinery, injuries struck by or against, falls, and bicycle injuries. Most of the seven injury outcomes had the strongest nonlinear relationship on lag day 0. Overall, for most injury categories, associations with temperature were similar across age groups. Controlling for the presence of rain and high amounts of rain did not substantially change the nonlinear relationships observed between temperature at the various accidental injury outcomes. However, pollution did affect the observed associations for all of the seven accidental injury outcomes

Conclusion: These findings expand the literature on the effects of high temperatures on human health, and specifically illustrate the impacts of heat on healthcare utilization for accidental injuries.

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Introduction

Climate change has resulted in an increase of the global mean temperature, with a concomitant increase in frequency and severity of heat waves (Balbus et al. 2016 & Bell et al., 2018 &). Previous studies have shown a short-term increase in morbidity and mortality during high heat periods (Bell et al., 2018). The relationship between heat and morbidity and mortality has been examined across the U.S. with the highest sensitivity being found among the elderly, working, or young populations. (Sheffield et al, 2018). Studies have shown a broad range of impacts including heat-related illnesses, kidney disease, and cardiorespiratory disease effects, through strong observed associations with cause-specific hospitalizations and emergency department (ED) visits (Kim et al., 2018 & Winquist et al., 2016). Biological mechanisms for these impacts are highly plausible through dehydration and related pathways. It is also possible that heat may have more far reaching impacts on health care utilization, by influencing the onset of accidental injuries that result in need for emergency care.

Unintentional injuries are the fifth leading cause of death among all age groups in the U.S. (Johns Hopkins Health, 2020) and in 2017, 1 in 5 ED visits involved an injury, with the most common cause of injury being unintentional falls for all age groups, except ages 10-24 whose most common cause of injury was struck by or against objects (Weiss et al., 2020). The existing literature on the topic of heat and injuries, use “traumatic injury” visits to the ED to examine the effects for specific occupational groups (Calkins et al., 2019 & Spector et al., 2016) and intentional injuries, like assault (Michel et al., 2016). However, the relationships of heat and accidental injuries, specifically, has only been examined for young children in pediatric emergency departments. For example, Christoffel et al. observed that season impacted the prevalence of disease and injury among pediatric ED visits; weather also affected ED use, but was not a factor in a family’s decision to seek care (Christoffel et al., 1985). Macgregor et al. found that, on average, attendance in a pediatric ED was 30% higher in the summer months (April- September) compared to winter months. In addition, attendance for trauma incidents was higher on drier, sunnier weather days compared to other days (Macgregor et al., 2003). In the most specific study focused on heat, Sheffield et al. found that children age 0-4 had an increased risk of ED visits corresponding with an increase in maximum daily temperature. When examining injury diagnostic codes, the authors observed a 5.1% (95% CI: (3.8- 6.4)) increased risk of injury related ED visits for every 13 °F increase in daily maximum temperature. This novel finding of an increased risk of injury diagnosis among children during warm temperatures did not examine the external causes of injuries (Sheffield et al., 2018).

Identifying causes of injuries that are associated with high heat can be an important step in further understanding of potential mechanisms of heat effects and may inform targeted prevention efforts. To address this, the objective of this study was to estimate the effects of high heat on the risk of emergency department visits for accidental injuries, with assessment of accident causes, in Los Angles, California. Analyses included the consideration of heat effects by age group, nonlinear and lagged effects.

Methods

Data Sources

Daily maximum and minimum temperature data for the years 2005 to 2016 were obtained from Daymet (https://daymet.ornl.gov/), a publicly available website that produces meteorological measurements for 1km gridded areas. Daymet has been found to provide accurate ambient temperature estimates for the U.S. when compared to data measured at an airport monitoring station (Spangler et al. 2019 & Thomas et al. n.d.).

Patient-level ED records were obtained from the California Health and Human Services Agency, Office of Statewide Planning and Development, for the years 2005 to 2016. The study was then restricted to dates prior to October 1, 2015 in order to focus on the period in which International Classification of Disease (ICD) 9th revision diagnosis codes were in effect. The ED visits records were collapsed by date and categorized by ICD 9 external cause of injury code (E-code) The thirteen outcomes of interest included ED visits for bicycle accidents (E826), burns

(E924, E895-E897), cut or pierce injuries (E920), drowning (E910, E830, E832), accidental falls (E880- E886), foreign bodies (E914, E915), machinery (E918, E919, E846), non-traffic motor vehicle accidents (E822- E825), traffic motor vehicle accidents (E810– E819), injuries caused by natural and environmental factors (E900- E909), poisoning (E850- E869), suffocation (E911- E913) and struck by or against objects (E916- E917).

Precipitation and air pollution levels were considered as potential confounders. Precipitation data were pulled from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information online data portal (https://www.ncdc.noaa.gov/cdo-web/search). Data for air pollution were obtained from CMAQ (Community Multiscale Air Quality) model simulations conducted by the United States Environmental Protection Agency (USEPA) (Senthilkumar et al., 2019). Specifically, for this study, we pulled daily data for three pollutants, nitrogen dioxide (NO_2), ozone (O_3), and fine particulate matter ($PM_{2.5}$). The CMAQ simulation output hourly concentrations which were then converted to 1-hr max averages for NO_2, 8-hr max averages for O_3, and 24-h averages for $PM_{2.5}$. These data were available for the years 2005-2014.

Statistical Analysis

This analysis was restricted to the five warmest moths of the year, May through September. Time-series plots were made of each accidental category by age (00 or Unknown, 1-14, 15-24, 25-44, 45-59, 60-74, 75+) to assess the stability of ED visit counts over time. For the warm season, the poisoning outcome had an average of 32.1 ED visits (SD= 10.9) per day, with a maximum daily visit count of 218, which was observed in the last month of the study period. This high daily visit count was observed as part of a spike in visits leading up to the transition from the ICD 9th revision to the 10th revision in October 2015. As there were no mass poisoning events that we are aware of for this period, we attribute the trend to potential coding changes affecting the daily observed visit number for poisonings during this period. As such, the month of September was dropped and the last date for poisoning counts in this analysis was

August 30th, 2015. Without the month of September, during the warm season, the average number of ED visits for poisoning was 31.5 (SD=7.2) and a maximum count of 55. The other accidental injury categories had stable counts throughout the study period.

Over-dispersed Poisson log-linear time-series models were run to examine the relationship between daily maximum temperature and ED visit counts for each accidental injury category, controlling for time and other factors. A basic form of the model was as follows:

$$\ln(\lambda) = \alpha + \beta_1 MAX + \beta_2 MAX_{SQ} + \beta_3 MAX_{CU} + \gamma_1 DEW + \gamma_2 DEW_{sq} + \gamma_3 DEW_{cu} + \gamma_4 YEAR + \gamma_5 t + \gamma_6 tyr + \gamma_7 WEEKDAY_H + \gamma_8 HOLIDAY_{FO} + \gamma_9 HOLIDAY_{WI} + \gamma_{10-37} FACILLITY + \gamma_{38} PRCP + \gamma_{39} PRCP_{HIGH} + \gamma_{40} NO2 + \gamma_{41} O3 + \gamma_{42} PM25 \quad \text{(Eq. 1)}$$

Where:

- λ represents the count of emergency department visits for a given accidental injury category per day
- α represents the true y- intercept
- $\beta_1 MAX$ represents the true slope associated with a 1-degree change in daily maximum temperature; for lag models, β_1 is the lag day X temperature (X= 1,2,3)
- $\beta_2 MAX_{SQ}$ represents the true slope associated with a 1-degree change in daily maximum temperature squared
- $\beta_3 MAX_{CU}$ represents the true slope associated with a 1-degree change in daily maximum temperature cubed
- $\gamma_1 DEW$ represents the main effect of daily mean dew point temperature
- $\gamma_2 DEW_{sq}$ represents the main effect of daily mean dew point temperature squared
- $\gamma_3 DEW_{cu}$ represents the main effect of daily mean dew point temperature cubed
- $\gamma_4 YEAR$ represents the main effect of the indicator variable for year 2005- 2015 (ex. 1 if year is 2005, 0 if else)
- $\gamma_5 t$ represents the monthly knots

- $\gamma_6 tyr$ represents the monthly knots included inside each year, used to control for long term time trends
- $\gamma_7 WEEKDAY\_H$ represents the main effect of the indicator variable for day of the week and holiday days
- $\gamma_8 HOLIDAY_{FO}$ represents the main effect for the indicator variable representing the day a federal holiday is observed (0 if actual holiday date falls on a weekend, 1 if else)
- $\gamma_9 HOLIDAY_{WI}$ represents the main effect of the indicator variable for Independence Day observance (1 if Independence Day is different than the federal holiday, 0 if else)
- $\gamma_{10-37} FACILLITY$ represents the main effect of the indicator variables for each hospital providing data, indicating if the hospital was open and receiving patients on the respective day
- $\gamma_{38} PRCP$ represents the main effect of the indicator variable for precipitation present (1 if amount of precipitation > than 0, 0 if else)
- $\gamma_{39} PRCP_{HIGH}$ represents the main effect of the indicator variable for high precipitation (1 if amount of precipitation greater than, or equal to, 0.11 inches, 0 if else)
- $\gamma_{40} NO2$ represents the main effect of nitrogen dioxide pollution
- $\gamma_{41} O3$ represents the main effect of ozone pollution
- $\gamma_{42} PM25$ represents the main effect of fine particulate matter pollution ($PM_{2.5}$)

As shown in Eq. 1, all models controlled for the mean dew point temperature, day of the week, holidays, and hospital-specific indicators, which indicated whether a hospital was open and receiving patients on any respective date. Long term time trends within the warm season for each year were also controlled for, using splines with monthly knots. The daily maximum temperature was modeled with linear, quadratic and cubic terms to examine nonlinear relationships. Evidence of nonlinear effects was assessed using a likelihood ratio test for the significance of the squared and cubic terms examined together. The results of the nonlinear models were graphed for the 1st to the 99th percentile of daily maximum temperature, using the 25th percentile temperature (25°C) as the reference temperature**.** Results from linear models were expressed as rate ratios for a 5 °C change in temperature, based on the interquartile range (IQR) of the temperature distribution (IQR = 5.20 °C). In secondary analyses, linear models were stratified by age group to assess temperature-accidental injury associations by age, and the lag structure of the temperature-accidental injury associations were assessed for lag days 0-3. Sensitivity analyses were conducted to assess the stability of the results when changes were made to the model, including the addition of further covariates to the model. Additional models included controlling for air pollutant concentrations, the presence of precipitation (indicator variable for amount greater than 0), and high amounts of precipitation (indicator variable for amount greater than, or equal to, 0.11 inches).

Results

Descriptive Analysis

The average warm season daily maximum temperature during 2005 – 2015 in Los Angles was 27.8 °C (SD= 3.9 °C) (Table 1). The average amount of daily precipitation during the warm season was 0.004 inches, which fell between the 90th and 95th percentile for daily precipitation during the study period. The 99th percentile of daily precipitation, 0.11 inches, was used as the cut off for identifying ‘high precipitation’ days; 5.23% of days were classified as having high precipitation. Other meteorological and air pollution data for the study period in Los Angles, California are described in Table 1.

Table 1. Descriptive statistics for meteorological and air pollution parameters in Los Angeles, May-September, 2005-2015.

Metrologic measure	# of Days	Mean	SD	IQR	Min.	25th percentile	50th percentile	75th percentile	Max.
Maximum daily temperature (°C)	1,683	27.8	3.9	5.2	15.9	25.1	27.8	30.3	42.7
Minimum daily temperature (°C)	1,683	16.3	2.6	3.5	8.5	14.6	16.2	18.1	24.1
Precipitation (Inches)	1,683	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.80
NO_2 (µg/m^3)	1,530	27.4	9.1	11.5	6.8	20.8	26.1	32.3	65.6
O_3 (µg/m^3)	1,530	51.1	9.1	11.4	22.4	45.3	50.5	56.7	85.9
$PM_{2.5}$ (µg/m^3)	1,530	11.1	3.2	3.6	3.9	9.0	10.7	12.6	30.5

In Los Angles, there were 2,253,292 ED visits for accidental injuries during the warm seasons of 2005 through 2015, with a daily average of 1,339 ED visits for accidental injuries (Table 2). Drowning and suffocation had the lowest average accidental injury visits per day, with less than 3 visits per day, while falls had the largest average accidental injury visits per day (410.1 visits per day). Table 3 presents a summary of the daily average visit counts for each accidental injury category, by age group.

Table 2. Descriptive statistics for accidental injury ED visits by external cause, May-September 2005 – 2015

Injury Category	Abbreviation	ICD-9 code(s)	# of Days	Total # of Injury Visits	Average # of Injury Visits per Day
All injuries	ALL	ALL	1,683	2,253,292	1,339
Bicycles	BIKE	E826	1,683	65,319	38.8
Burns	BURN	E924, E895-E897	1,683	39,868	23.7
Cut/Pierce	CUT	E920	1,683	256,841	152.6
Drowning	DROWN	E910, E830, E832	1,683	2,824	1.7
Falls	FALL	E880- E886	1,683	690,195	410.1
Foreign Bodies	FB	E914, E915	1,683	76,934	45.7
Machinery	MACH	E918, E919, E846	1,683	57,781	34.3
Motor Vehicle Accident: Non-Traffic	MVANT	E822- E825	1,683	9,971	5.9
Motor Vehicle Accident: Traffic	MVAT	E810– E819	1,683	372,959	221.6
Natural & Environmental Factors	NAT	E900- E909	1,683	180,613	107.3
Poisoning	POIS	E850- E869	1,653	54,107	31.5
Suffocation	SUF	E911- E913	1,683	4,345	2.6
Struck by or against	STRUCK	E916- E917	1,683	441,535	262.3

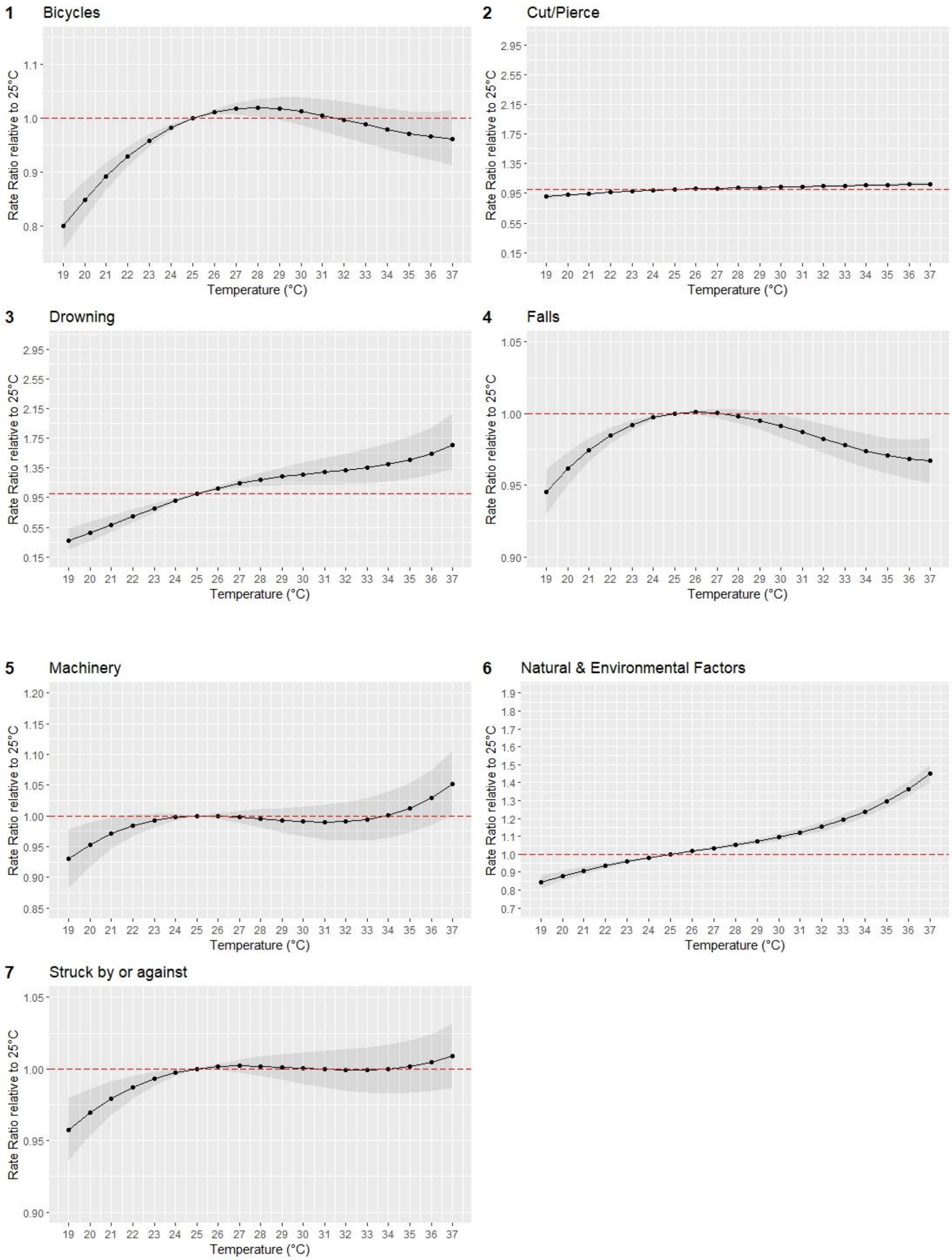
Table 3. Total and average number of ED visits per day for accidental injuries in Los Angles, May- September 2005 – 2015

Injury Category	Age 00 or Unknown (# per day)	Age 01-14 (# per day)	Age 15-24 (# per day)	Age 25-44 (# per day)	Age 45-59 (# per day)	Age 60- 74 (# per day)	Age 75+ (# per day)
Bicycles	20 (0.0)	21,307 (12.7)	13,302 (7.9)	15,988 (9.5)	10,515 (6.2)	3,412 (2.0)	775 (0.5)
Burns	1,193 (0.7)	11,264 (6.7)	6,124 (3.6)	10,853 (6.4)	6,395 (3.8)	2,746 (1.6)	1,293 (0.8)
Cut/Pierce	871 (0.5)	45,669 (27.1)	51,217 (30.4)	89,359 (53.1)	43,127 (25.6)	18,663 (11.1)	7,935 (4.7)
Drowning	101 (0.1)	1,624 (1.0)	351 (0.2)	390 (0.2)	199 (0.1)	93 (0.1)	66 (0.0)
Falls	18,410 (10.9)	193,323 (114.9)	62,123 (36.9)	97,688 (58.0)	95,463 (56.7)	87,864 (52.2)	135,324 (80.4)
Foreign Bodies	2,526 (1.5)	30,506 (18.1)	8,326 (4.9)	16,838 (10.0)	9,731 (5.8)	4,940 (2.9)	4,067 (2.4)
Machinery	469 (0.3)	18,895 (11.2)	8,550 (5.1)	15,327 (9.1)	8,851 (5.3)	3,771 (2.2)	1,918 (1.1)
Motor Vehicle Accident: Non-Traffic	56 (0.0)	1,575 (0.9)	1,925 (1.1)	2,763 (1.6)	1,662 (1.0)	978 (0.6)	1,012 (0.6)
Motor Vehicle Accident: Traffic	1,712 (1.0)	31,590 (18.8)	94,041 (55.9)	132,738 (78.9)	70,096 (41.6)	30,064 (17.9)	12,718 (7.6)
Natural & Environmental Factors	1,498 (0.9)	61,071 (36.3)	28,438 (16.9)	41,440 (24.6)	26,881 (16.0)	13,939 (8.3)	7,346 (4.4)
Poisoning	1,008 (0.6)	10,567 (6.4)	7,434 (4.5)	12,066 (7.3)	10,120 (6.1)	6,385 (3.9)	4,450 (2.7)
Suffocation	407 (0.2)	772 (0.5)	137 (0.1)	339 (0.2)	541 (0.3)	791 (0.5)	1,358 (0.8)
Struck by or against	3,895 (2.3)	158,930 (94.4)	94,591 (56.2)	100,525 (59.7)	48,450 (28.8)	20,841 (12.4)	14,303 (8.5)

Model Results

Significant nonlinear relationships were found between warm season daily maximum temperature and seven of the thirteen accidental injury outcomes: bicycles, cut/pierce, drowning, falls, machinery, natural & environmental factors, struck by or against. The six other accidental injury categories (burns, foreign bodies, motor vehicle accidents: non-traffic, motor vehicle accidents: traffic, poisoning, suffocation) showed no linear or nonlinear effects with temperature (results not shown). The estimates for the nonlinear change in temperature were plotted for from 19 °C to 37 °C, the 1st to the 99th percentile for maximum daily temperature, using 25 °C as the reference temperature (Figure 1). Injuries caused by natural and environmental factors, cuts, drownings, machinery injuries, and injuries caused by being struck by or against objects showed the rate of injuries increased at high temperatures compared to 25 °C. Bike injuries and accidental falls had a negative relationship with higher temperatures; as the temperature approached the extreme high end of the temperature distribution the rate of these injuries decreased.

Figure 1. Estimated rate ratios for the effects of daily maximum temperature, relative to the 25th percentile temperature (25 °C), for accidental injury ED visits, by external cause, at lag 0, for all ages.



[1]

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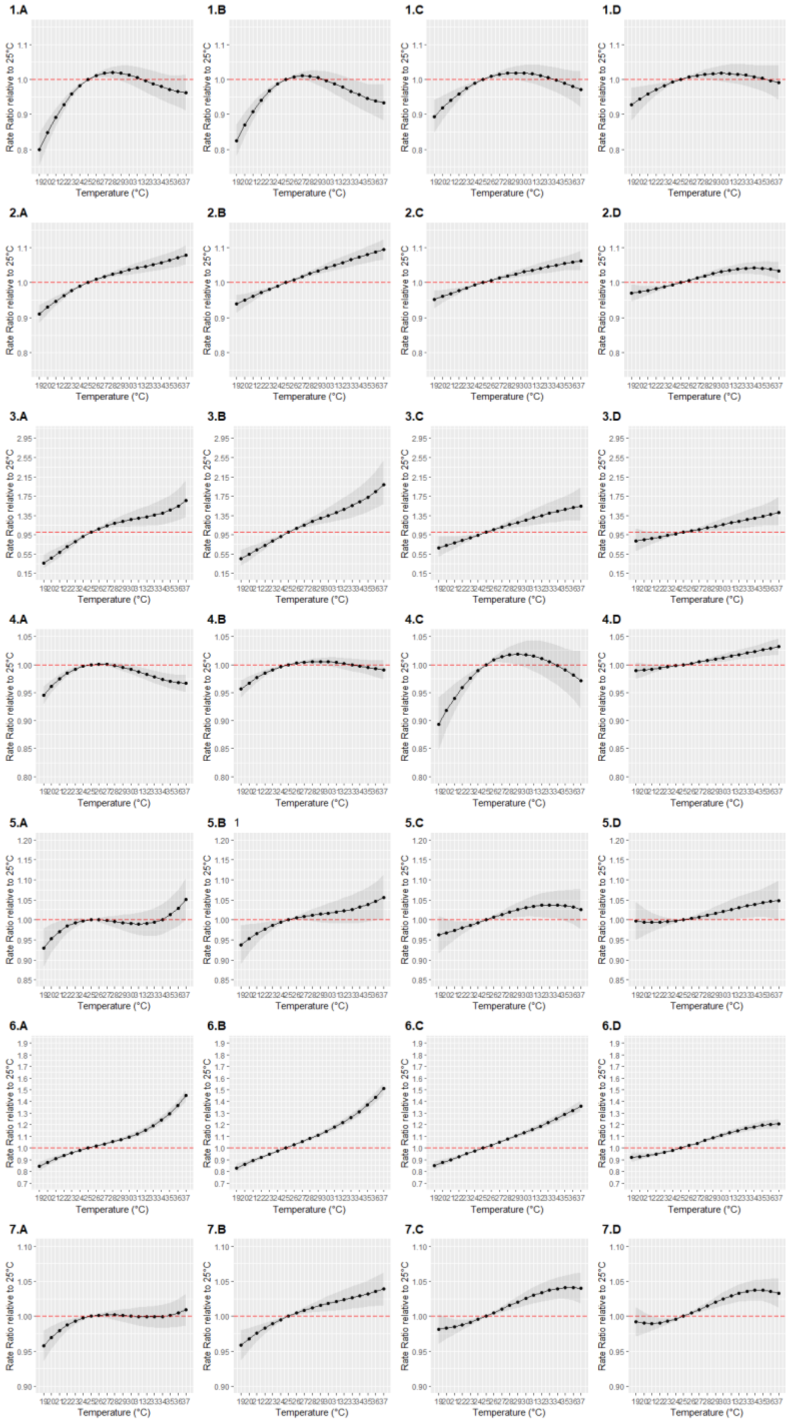
[1] 1-7 represents the injury category, where 1 is bicycles, 2 is cut/pierce, 3 is falls, 4 is drowning, 5 is machinery, 6 is natural & environmental factors, and 7 is struck by or against.

Most of the seven injury outcomes had the strongest nonlinear relationship on lag day 0 (Figure 2). The daily maximum temperature at lag day 3 had a stronger nonlinear relationship for the outcome of cuts and struck by or against injuries. Falls had a stronger nonlinear relationship on lag day 2. The same seven injuries also had significant linear rate ratios which were also strongest on lag day 0.

Figure 2. Estimated rate ratios for the effects of daily maximum temperature, relative to the 25th percentile temperature (25°C), for accidental injury ED visits, by external cause, at lag 0-3.



[2,1]

[2] A-D represent the maximum daily temperature single-day lag, where A is lag 0, B is Lag 1, C is lag 2, and D is lag 3

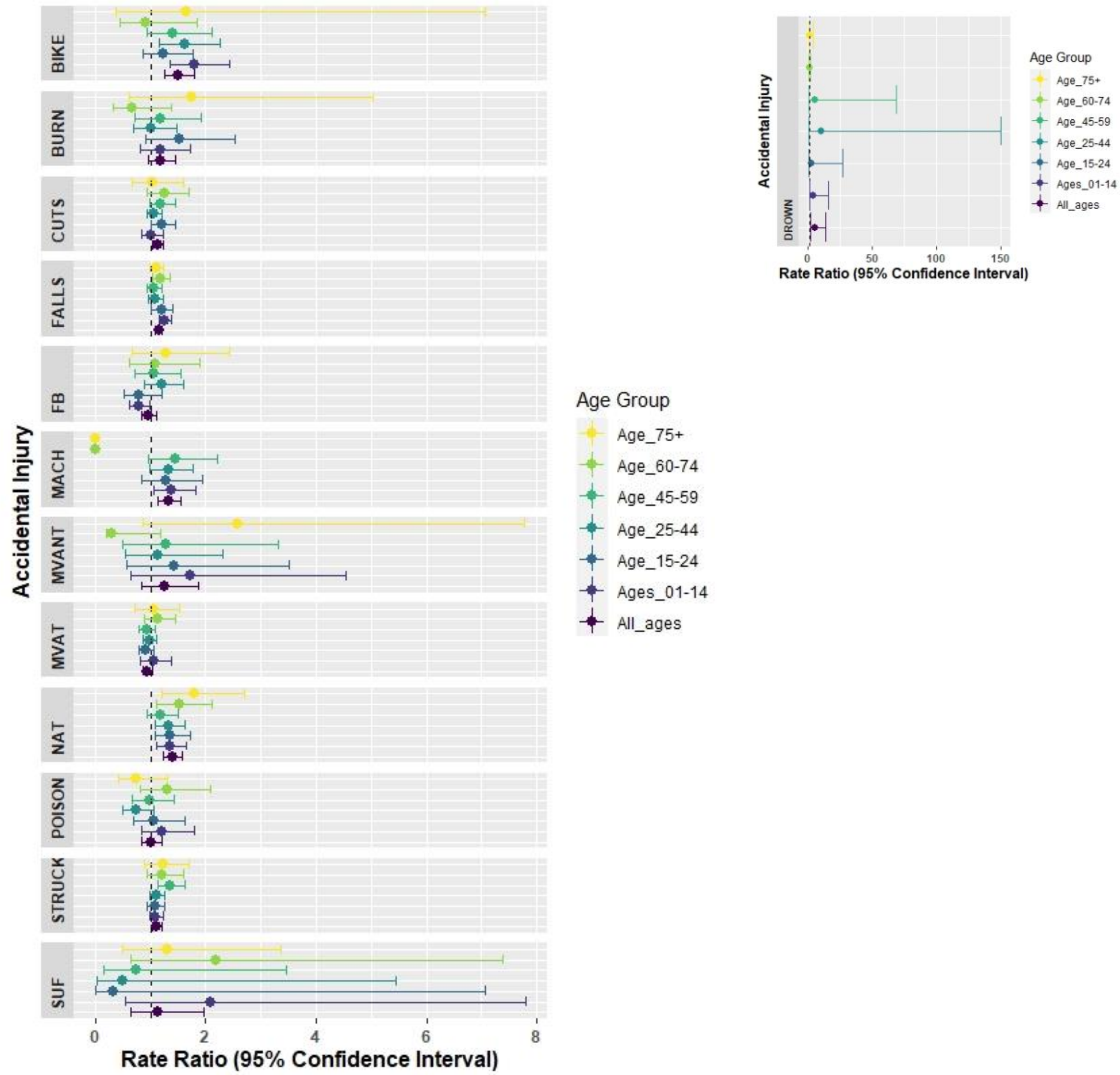
[1] 1-7 represents the injury category, where 1 is bicycles, 2 is cut/pierce, 3 is falls, 4 is drowning, 5 is machinery, 6 is natural & environmental factors, and 7 is struck by or against.

Age-Stratified Results

Overall, the linear models, by external cause of injury, showed most accidental injury categories had similar rate ratios across different age groups, especially the categories of cuts, falls, machinery, and traffic motor vehicle accidents (Figure 3). Accidental injury categories for which associations with temperature were stronger for certain age groups included non-traffic motor vehicle accidents, poisoning, and burns. Particularly strong associations with temperature were observed for: injuries caused by being struck by or against objects (ages 45-59 years), and injuries cause by natural and environmental factors (ages 60-74 and 75+ years). Bike injuries (ages 1-14 and 25-44 years), suffocation (ages 15-24, 24-44, and 45-59 years), traffic motor vehicle accidents (ages 15-24, 24-44, and 45-59 years), and foreign body injuries (ages 1-14 and 15-24 years) appeared to have lower rates (i.e., protective effects) in relation to high daily temperatures.

Machinery injuries for ages 60-84 and 75+ years had low daily counts, so the temperature effects could not be estimated for this outcome and age groups. These results for these models were not reported in Figure 3. Models assessing associations of temperature on drowning injuries had convergence issues for all age groups, and those predicting suffocation injuries had convergence issues for ages 25-44 and 45-59 years.

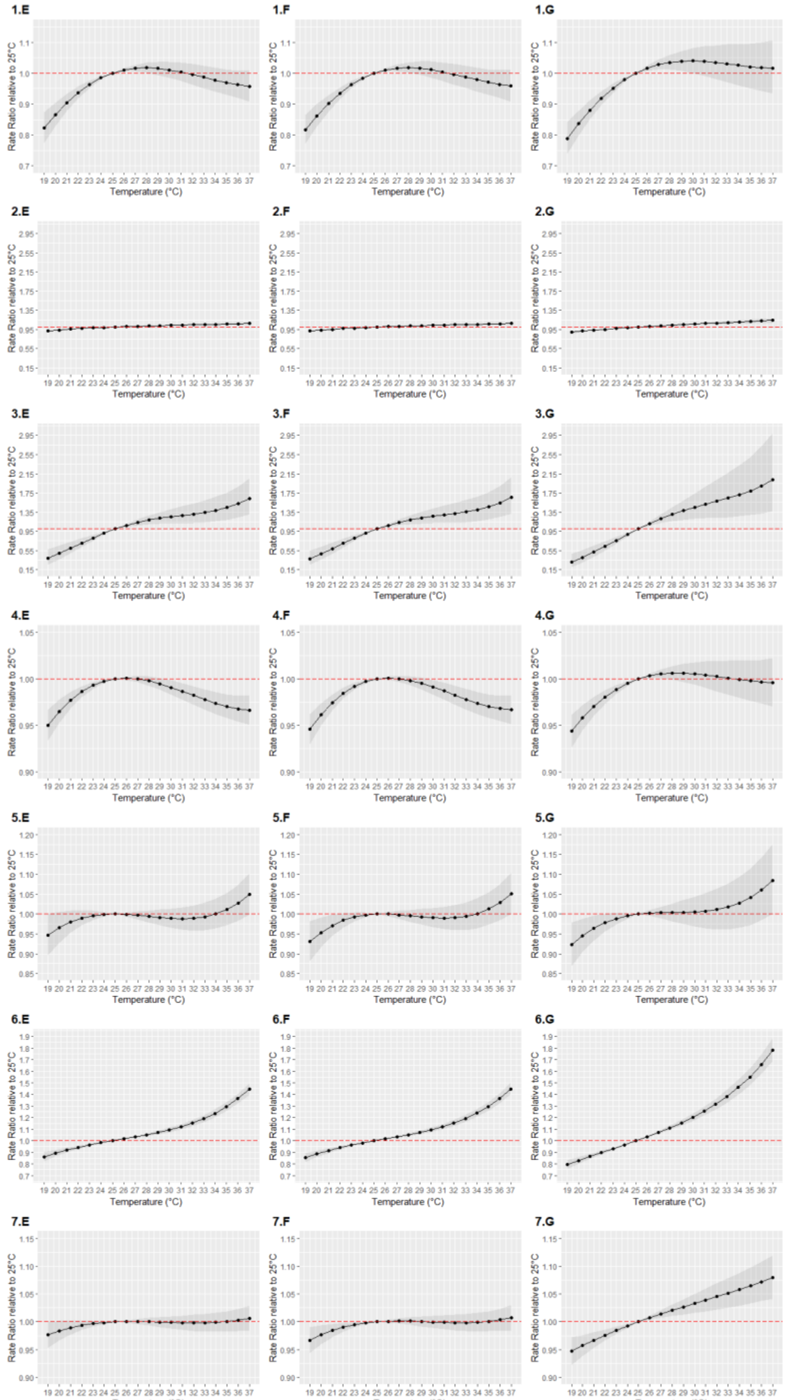
Figure 3. Estimated rate ratios for the linear relationship between accidental injury ED visits and a 5 °C change in daily maximum temperature, by external cause and age group, in Los Angeles, May-September, 2005-2015.



Sensitivity Analysis Results

Controlling for the presence of rain and high amounts of rain did not substantially change the nonlinear relationships observed between temperature at the various accidental injury outcomes (Figure 4). The addition of the three air pollutants to the model, however, did affect observed associations on all of the seven accidental injury outcomes (Figure 4). For the accidental injury categories with a positive nonlinear relationship (cut/pierce, drowning, machinery, natural & environmental factors, struck by or against) with daily maximum temperature, the addition of pollution into the model resulted in stronger exponential relationships. For these outcomes, a wider range of rate ratios were observed in the models controlling for pollution compared to the base models without pollution control. For the accidental injury outcomes with a negative nonlinear relationship (bicycles and falls) with daily maximum temperature, the addition of pollution into the model resulted in weaker effects, consistent with the null.

Figure 4. Estimated rate ratios for the effects of maximum daily temperature, relative to the 25th percentile temperature (25°C), for accidental injury ED visits, by external cause, for the sensitivity analysis models.



[3,1]

[3] E-G represent the models that included additional variables for the sensitivity analyses, where E is a model that controlled for the presence of precipitation, F controlled for high amounts of precipitation and G controlled for pollution.

[1] 1-7 represents the injury category, where 1 is bicycles, 2 is cut/pierce, 3 is falls, 4 is drowning, 5 is machinery, 6 is natural & environmental factors, and 7 is struck by or against

Discussion

To examine the causes of accidental injuries resulting in emergency care associated with high temperatures, in this study we estimated associations of warm season daily maximum temperature and accidental injury ED visits over a 10-year period in Los Angles, California. Statistically significant nonlinear associations were observed between daily maximum temperature and ED visits for injuries caused by natural and environmental factors, cuts, drownings, machinery injuries, injuries caused by being struck by or against objects, accidental falls, and bicycle injuries.

To our knowledge, nonlinear relationships for injury emergency department visits, categorized by a variety of E-codes, and temperature have been described in only one previous study. Lipman et al. (2015) assessed injury ED visits and mean daily temperatures in North Carolina, where mean daily temperatures ranged from 40 to 90 °F (4.4- 32.2 °C). The injury categories with the strongest positive associations with temperature were bites and stings, drowning, excessive heat, cutting/piercing instruments, and unspecified mechanisms. In this previous study, the incidence of bites and stings increased with increasing daily mean temperature, but the rate decreased at extreme temperatures. The comparable category to bites and stings in the current analysis is the category of natural & environmental injuries, which included other injuries caused by extreme weather conditions, like lightning. In the current analysis, a decrease in rate ratios at high temperatures was not observed; in fact, as the maximum daily temperature reached the extremes, the rate ratio for natural/ environmental injuries increased exponentially. The inclusion of injuries caused by extreme weather conditions, like lightning, in our natural & environmental injuries category may explain the observed differences in results compared to Lipman et al. (2015). Struck by or against objects and cut injuries were both observed having a negative relationship as mean daily temperature increased toward the extremes, increasing and peaking between 70°F and 80°F (Lipman et al., 2015).In our analysis both struck by or against objects and cuts were observed to have a weak positive relationship with high maximum daily temperatures.

To date, we have not explored age-stratified nonlinear models. The Lipman study found some differences in interpretation where stratifying by age and comparing linear vs. nonlinear effects; this will be worth exploring in our data in the future. For example, Lipman et al. (2015) observed that drownings increased exponentially with an increase in temperature for ages 0-9 years and increased slightly for ages 20-44 years. Drowning for ages 10-19 years followed a similar negative relationship at higher temperatures like the previously mentioned injuries (Lipman et al., 2015). In our analysis, the linear relationship for drownings and a 5°C change in temperature are relatively similar across all age groups, but ages 25-44 have a slightly stronger association than the other age groups.

Accidental falls is an injury outcome that has been studied more extensively, for cold weather conditions, including a focus on more specific diagnostic codes for different bone fractures (Hughes et al., 2014 & Yeung et al., 2020). Injury rates, adjusted for weather, show falls are strongly associated with older adults (Hulland et al. 2017). In our study, there was a large number of total falls and falls per day for people ages 60-74 and ages 75+, but the largest number of ED visits for falls occurred in ages 1-14, who had about 115 falls per day during the study period. A negative relationship for temperature and falls has been described previously (Lipman et al., 2015). During North Carolina' s warm season, April-October for the period 2008-2013, the rate of emergency department visits for unintentional fall injuries remained steady for mean daily temperatures of 40-70 °F and then dropped at higher temperatures. The oldest age group, age 75- 99 years, had the highest rate of fall injuries in this study, while the pediatric age group, ages 10-19 years, had the strongest negative association with temperature. These findings could suggest that in cold weather, older adults are the most at risk for falls, but in warmer weather children could be most at risk because of their activity and behavioral patterns.

The pediatric ED visit studies that assessed outcomes defined as total number of ED visits (Christoffel et al., 1985) and injuries defined by diagnostic codes for fractures and lacerations (e.g., ICD-9 diagnostic code 800-804 represents "fracture of skull") (Macgregor et al., 2003 & Sheffield et al, 2018) examined the effects of weather. Because of the different outcomes and age stratifications, it is difficult to compare the results of these studies. In our analysis, the youngest age group was ages 1-14 and the only strong linear rate ratio for pediatrics observed was bike injuries. A previous study using E-codes to examine injury rates and different demographic characteristics for adults in Atlanta, controlling for weather, found that the rates of motor vehicle accidents, being struck by objects, and burns were strongly associated with younger age groups, with the strongest association for adults age 18-29 (Hulland et al., 2017). Our analysis used different cut points for age groups, but younger people, under the age of 45, were observed to have a larger number of injuries per day for the injury causes: burns, struck by or against objects and both traffic and non-traffic motor vehicle accidents (Table 3).

Pollution has been considered as a confounder in a previous study using time-series models for daily maximum temperature and injury ED visits in in New York City (Sheffield et al., 2018). Two of the pollutants considered in this analysis, $PM_{2.5}$ and O_3, were included in a sensitivity analysis and found that the addition of the pollutants led to a lower magnitude of linear temperature-ED visit associations, but significance was retained (Sheffield et al, 2018). In our analysis of nonlinear temperature models, the magnitude of the rate ratios increased for five accidental injury categories (cut/pierce, drowning, machinery, natural & environmental factors, struck by or against) when pollution variables were added to the models. The confidence intervals were also much wider when pollution was included in the models. Air pollution has commonly been considered a confounder in previous temperature studies but has recently fallen under scrutiny because air pollution can sometimes be considered as a part of the causal pathway of temperature effects (Buckley et al., 2014). Our findings and previous findings show that pollution is a complex, potential confounder in temperature-injury studies, but requires further consideration, specific to temperature-injury studies, to determine if pollution is an appropriate confounder.

The five causes of injury, cut/pierce, drowning, machinery, natural & environmental factors, struck by or against, were found to have a significant, positive association with daily maximum temperature. The causes cut/pierce, machinery and struck by or against likely share biological mechanisms similar to occupational or athletic injuries, which have been studied in more detail. The Centers for Disease Control and Prevention states that heat can increase the risk of injury for workers due to sweat and dizziness (Centers for Disease Control and Prevention, 2020). Drownings are likely caused by biologic mechanisms related to heat exhaustion and/ or alcohol consumption in young adults. An increase in natural and environmental factors, which includes insect bites and stings, may be explained by rising temperatures impacting vector ecology through changes in activity and density. Identifying causes of injuries that are associated with high heat is an important step in further understanding of the potential mechanisms of heat effects to inform targeted prevention efforts. Injury prevention recommendations have been created to prevent occupational injuries and similar recommendations may need to be applied to everyday life as the global mean temperature continues to rise.

The main limitation of this study is the assessment of only one city, this limiting the generalizability of results from this study to the whole U.S. population. Low event counts for some injuries and age groups also impacted our ability to measure their association with daily maximum temperature. Other limitations include potential residual confounding by unmeasured temporal factors; also, “undetermined and late effects” accident codes were excluded from this analysis, so some relevant ED visits may have been missed. While we did consider age-stratified models, this analysis did not consider stratification by socioeconomic status, sex, race or other demographic characteristics. These factors may be important effect modifiers to consider in injury analyses because previous studies have found significant relationships between demographic characteristics and injury categories, when controlling for weather (Hulland et al., 2017). For Atlanta adults, using data from 10 Atlanta hospitals from 2010-2013, non-fatal injuries were most common among males, whites and people of younger ages. Patients living in areas with a higher household income were more at risk for motor vehicle accidents, falls, and being struck by objects. Whites were overall, were less at risk for injury, except for motor vehicle accidents. Male gender was found to be associated with motor vehicle accidents, burns, and being struck by objects, while females were at a higher risk for falls (Hulland et al., 2017). In the one previous study of temperature and accidental injury categories, the effects of high daily temperature were similar for males and females (Lipman et al., 2015). Future research should consider potential differences in the association of temperature and accidental injury categories by socioeconomic status, sex, race or other demographic characteristics to help create public health recommendations.

Conclusion

Associations between maximum daily temperature and ED visits for several injury categories, including bicycles, cut/pierce, drowning, falls, machinery, natural & environmental factors, struck by or against. These associations were seen across all age categories, with some ages having a stronger relationship. These findings illustrate the potential effect that temperature extremes, brought on by climate change, have on human health and healthcare utilization and can inform targeted prevention efforts**.**

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