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Impact of Extreme Heat Events on Emergency Department Visits in North Carolina (2007–2011)

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Abstract Extreme heat is the leading cause of weather-related mortality in the U.S. Extreme heat also affects human health through heat stress and can exacerbate underlying medical conditions that lead to increased morbidity and mortality. In this study, data on emergency department (ED) visits for heat-related illness (HRI) and other selected diseases were analyzed during three heat events across North Carolina from 2007 to 2011. These heat events were identified based on the issuance and verification of heat products from local National Weather Service forecast offices (i.e. Heat Advisory, Heat Watch, and Excessive Heat Warning). The observed number of ED visits during these events were compared to the expected number of ED visits during several control periods to determine excess morbidity resulting from extreme heat. All recorded diagnoses were analyzed for each ED visit, thereby providing insight into the specific pathophysiological mechanisms and underlying health conditions associated with exposure to extreme heat. The most common form of HRI was heat exhaustion, while the percentage of visits with heat stroke was relatively low (<10 %). The elderly (>65 years of age) were at greatest risk for HRI during the early summer heat event (8.9 visits per 100,000), while young and middle age adults (18–44 years of age) were at greatest risk during the mid-summer event (6.3 visits per 100,000). Many of these visits were likely due to work-related exposure. The most vulnerable demographic during the late summer heat event was adolescents (15–17 years of age), which may relate to the timing of organized sports. This demographic also exhibited the highest visit rate for HRI among all three heat events (10.5 visits per 100,000). Significant increases ($p < 0.05$) in visits with cardiovascular and cerebrovascular diseases were noted during the three heat events (3–8 %). The greatest increases were found in visits with hypotension during the late summer event (23 %) and sequelae during the early summer event (30 %), while decreases were noted for visits with hemorrhagic stroke during the middle and late summer events (13–24 %) and for visits with aneurysm during the early summer event (15 %). Significant increases were also noted in visits with respiratory diseases (5–7 %). The greatest increases in this category were found in visits with pneumonia and influenza (16 %), bronchitis and emphysema (12 %), and COPD (14 %) during the early summer event. Significant increases in visits with nervous system disorders were also found during the early summer event (16 %), while increases in visits with diabetes were noted during the mid-summer event (10 %).

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Introduction

Extreme heat is the leading cause of weather-related mortality in the U.S. [1]. Direct deaths due to extreme heat (i.e. hyperthermia) have been estimated at approximately 700 annually [2]. However, that estimate more than doubles when including those deaths where exposure to extreme heat likely exacerbated a pre-existing health condition [3]. Numerous studies have examined the environmental and socioeconomic factors associated with heat-related mortality. These include inadequate housing conditions, lack of access to air conditioning, social isolation, chronic illness, as well as psychological and behavioral factors (see [4] for a review). Many of these factors are found disproportionately in urban areas, particularly among elderly, poor, and non-white individuals, though young children have also been found to be at somewhat higher risk [5].

Comparatively fewer studies have been conducted on heat-related morbidity; however, the health burden from heat-related illness (HRI) is not insignificant. From 2001 to 2004, HRI was the most frequent cause of environmental exposure-related injury treated in emergency departments (EDs) across the U.S. [6], while annual Medicare claims for hyperthermia treated in EDs have been estimated at over \$36 million [7]. HRI ranges in severity from mild cramps to heat exhaustion to heat stroke, and can quickly progress across this spectrum if treatment is not provided [8]. The fatality rate for heat stroke is around 15 % [4]; however, those that do survive often suffer impairments to the nervous, renal, or respiratory systems [9]. Individuals most at risk for non-fatal HRI include recreational athletes (both school-age and adult), those with high occupational exposure (e.g. construction workers, farm laborers, and military personnel), and those engaging in exertional activities such as yard work and home maintenance [4, 10].

Due to the considerable health burden associated with extreme heat, and the fact that heat-related mortality and morbidity are largely preventable, heat response plans and heat-health warning systems have been established (primarily in urban areas) to help protect the public during periods of extreme heat [11]. While these systems have been shown to save lives [12], most do not account for other non-fatal health outcomes associated with extreme heat and offer limited insight into the specific disease processes that contribute to HRI [13, 14]. This level of information is important, as exposure to extreme heat has been increasing over the past several decades [15] and will likely continue to increase due to a warming climate and growing population [16].

The objectives of this research are twofold: (1) to examine the specific forms of HRI (e.g. heat exhaustion, heat stroke) associated with periods of extreme heat in North Carolina, and (2) to characterize the underlying health conditions and disease processes associated with periods of extreme heat. To accomplish these objectives, we analyzed statewide ED visit data from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT), which has been used previously to study HRI in North Carolina [17–19]. This research complements those studies by focusing specifically on periods of extreme heat, examining the different forms of HRI, and exploring a broader range of health outcomes and diseases. The results of this research may provide health officials with better estimates of the public health burden of extreme heat, which can be used to inform efforts and strategies to prevent HRI and mitigate the associated health effects.

Data and Methods

Health Data

Daily records of ED visits across North Carolina for the period 2007–2011 were acquired from NC DETECT, a web-based, public health surveillance system developed and maintained by the Carolina Center for Health Informatics at the University of North Carolina at Chapel Hill, in collaboration with the North Carolina Department of Health and Human Services (www.ncdetect.org). For the first year of record (2007), approximately 92.5 % of ED visits in the state were captured by EDs reporting to NC DETECT; by 2008, over 99 % of ED visits in the state were captured [17]. For each ED visit, we obtained all recorded diagnoses (up to 11) using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes, as well as the age and county of residence of the patient. By examining all coded diagnoses (ICD-9-CM 001.0-999.9), we were able to account for any underlying, or pre-existing health conditions.

In addition to the various forms of HRI (ICD-9-CM 992.x), we focused our analysis on several different health outcomes (and disease sub-categories) that have been previously linked to increased mortality and morbidity during periods of extreme heat. These include cardiovascular diseases, cerebrovascular diseases, respiratory diseases, and other disorders of the endocrine, nervous, psychiatric, and renal systems [20–25]. Because the risk of

HRI has been shown to vary by age, we assembled all ED visits into 10 mutually exclusive age groups and used population estimates from the 2010 U.S. Census to calculate age-standardized rates of ED visits so that comparisons could be made across the different age groups.

Identifying Periods of Extreme Heat

In 2011, the North Carolina Division of Emergency Management drafted a statewide heat emergency response plan [26]. Like many other plans and systems across the U.S., it is to be activated when the National Weather Service (NWS) issues one of three heat products: "Heat Advisory", "Excessive Heat Watch", or "Excessive Heat Warning". Therefore, we identified periods of extreme heat based on the issuance and verification of these products by county from local NWS offices. A total of seven NWS offices cover all 100 counties in North Carolina and adopt the following criteria in issuing their heat products [27]:

- Heat Advisory: issued when the heat index is expected to reach between 105 and 109 °F for two or more hours, or between 102 and 105 °F for three or more consecutive days
- Excessive Heat Warning: issued when the heat index is expected to reach 110 °F for any duration
- Excessive Heat Watch: issued if warning conditions are expected in the next 24–48 h

While periods of extreme heat (often referred to as heat waves) can be defined in a number of different ways [14], the criteria developed by the NWS was based on the premise that absolute measures of apparent temperature (i.e. heat index) are the best indicators of the human physiological limits associated with extreme heat [28].

Since the proposed heat response plan is to be implemented at the state level, the focus of this study was on long-duration heat events that covered most of North Carolina. Specifically, heat events were identified using the following criteria: at least one heat product must have been issued and verified across four or more NWS county warning areas in North Carolina for five or more consecutive days. A heat event was terminated if there was a lapse in these conditions for at least 5 days. These criteria ensured that all heat events covered at least half of the geographic area of the state and were of sufficient duration where significant health effects would be expected to occur. It has been shown that mortality can increase tenfold during heat events lasting at least 5 days [11]. Heat events that meet these criteria also provide a more direct comparison to some of the major heat waves that have been examined in prior studies, such as the Midwest heat waves in July 1995 and 1999 [9, 20], the California heat wave in July and August of 2006 [21], and the January–February 2009 heat wave in southern Australia [24].

Using these criteria, we identified three heat events in North Carolina from 2007 to 2011: August 7–11, 2007; June 5–11, 2008; and July 20–26, 2011 (Fig. 1). The timing of these events was fortuitous, as it allowed us to examine the effects of seasonality (i.e. early, middle, and late season heat events). Maximum heat index values during the June 2008 event reached Heat Advisory status across parts of central and eastern North Carolina, while Excessive Heat Warnings verified over many of these same areas during the August 2007 and July 2010 heat events (Fig. 1).

Analysis of Health Effects

To determine the specific forms of HRI and most common health conditions associated with periods of extreme heat,

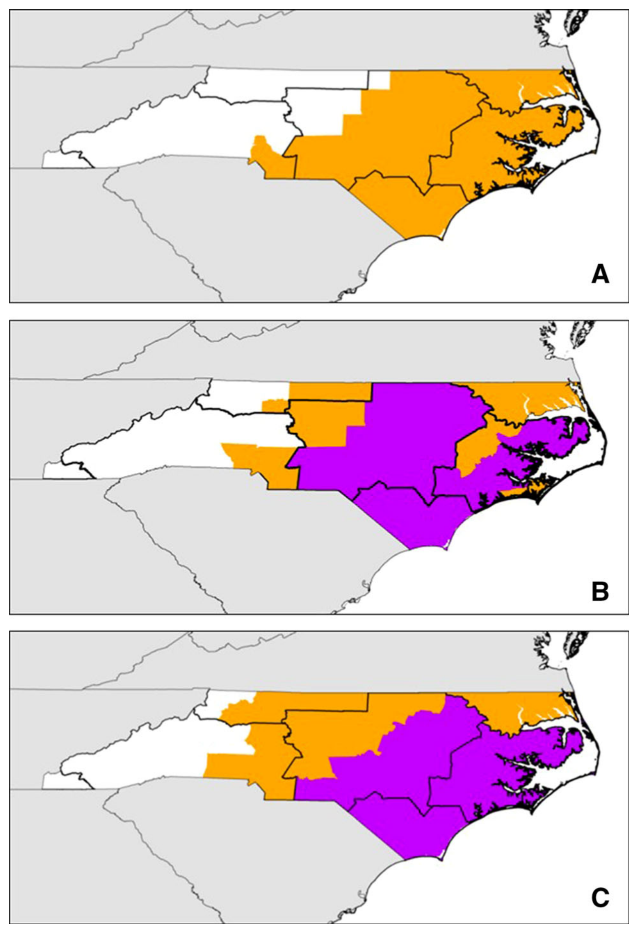

Fig. 1 Map of heat products issued and verified at the county level during the peak of each of the three heat waves: **a** June 7, 2008, **b** July 25, 2010, and **c** August 9, 2007. Counties *shaded in orange* were issued a Heat Advisory, while counties *shaded in purple* were issued an Excessive Heat Warning. *Dark black lines* demarcate NWS county warning areas in North Carolina (Color figure online)

we calculated the daily average number of ED visits for these illnesses during each of the three heat events (i.e. the observed number of visits) and during four control periods per heat event, which were averaged into a single control period, or baseline, for each event (i.e. the expected number of visits). This method has been used in previous studies to calculate excess and deficit morbidity associated with extreme heat [20, 21, 25]. While the effects of extreme heat on mortality can last for several days to weeks beyond the heat event, the effects on morbidity are often immediate, occurring within a day of exposure [4]. Therefore, the observed number of ED visits included the day following the last heat product issued and verified for the event. Only those ED visits where the patient's county of residence was issued a heat product during the event were included in our analysis. This eliminated much of the mountainous western part of North Carolina, where NWS heat product criteria are rarely met and ED visits for HRI are lowest (Fig. 2).

As in previous research [20, 21], we selected control periods that were of the same duration, same month, and same distribution of days as the corresponding heat event. By doing so, we accounted for systematic variations in ED visits by day of week (e.g. weekday versus weekend) and day in season (e.g. early summer versus late summer). Previous research on heat-related mortality found that as many as 60 % of the excess deaths during a heat event were actually displaced forward in time, resulting in lower than average death rates in the days and weeks following the event [29]. To account for a similar morbidity displacement effect, we did not select control periods beginning within 7 days following each heat event. In addition, the start and end dates of each control period could not occur within 5 days of the issuance or verification of any NWS heat product of any duration and spatial extent, ensuring that the control periods were not influenced by the occurrence of extreme heat. Dates for each control period are provided in the "Appendix".

By comparing the observed number of ED visits to the expected number of visits, we determined whether there was an excess or deficit number for each health outcome during the heat events. We calculated 95 % confidence intervals for the difference in observed and expected ED visits and assessed the statistical significance using a two-tailed Student's t test [20].

Results

Specific Forms of Heat-Related Illness

The observed number of ED visits for all forms of HRI during each of the heat events was substantially higher than their expected values (Table 1). The majority of ED visits for HRI, both expected and observed, were coded as heat exhaustion. The percentage of these visits was higher among the three heat events (>70 %) compared to their expected values (>60 %). Unspecified causes of HRI comprised between 8 and 14 % of all HRI visits, while all other forms of HRI, including heat stroke, generally comprised <10 % of the total number of visits for HRI. One exception was the percentage of expected visits coded as heat cramps associated with the July 2011 heat event (17.2 %). Interestingly, the percentage of visits coded as heat stroke increased by about 4 % during the June 2008 heat event, but decreased during the July 2011 and August 2007 events.

Heat-Related Illness by Age Group

Rates of ED visits for all forms of HRI by age group varied among the three heat events (Fig. 3). The highest rates

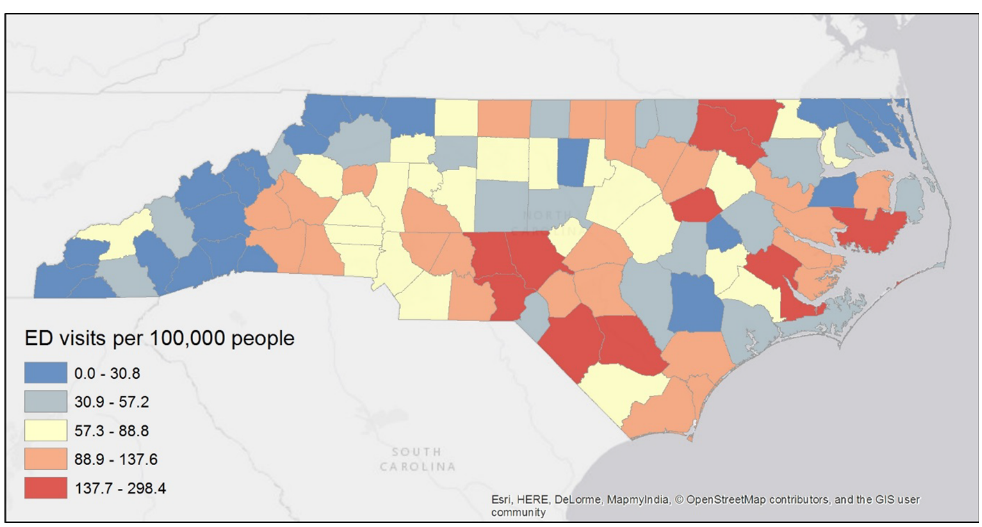

Fig. 2 Per capita rates of ED visits for HRI by county over the period January 1, 2007 to December 31, 2011

Table 1 Number of expected and observed ED visits for all forms heat-related illness (ICD-9-CM code 992.x) and percentage of these visits for each form of HRI among the three heat events

Diagnosis	ICD-9 codes	5–11 June 2008		20–26 July 2011		7–11 August 2007	
		Expected visits	Observed visits (Diff)	Expected visits	Observed visits (Diff)	Expected visits	Observed visits (Diff)
All heat	992.x	43	603 (560)	64	409 (345)	73	542 (469)
Heat stroke	992.0	2.3	5.8 (3.5)	7.8	4.4 (−3.4)	5.5	4.8 (−0.7)
Heat syncope	992.1	9.3	3.8 (−5.5)	3.1	5.9 (2.8)	5.5	2.2 (−3.3)
Heat cramps	992.2	4.7	5.8 (1.1)	17.2	5.6 (−11.6)	6.8	5.5 (−1.3)
Heat exhaustion	992.3–992.5	62.8	71.6 (8.8)	62.5	72.9 (10.4)	69.9	72.8 (2.9)
Heat fatigue	992.6	7.0	1.3 (−5.7)	1.6	1.4 (−0.2)	0.7	0.5 (−0.2)
Heat edema	992.7	1.0	0.8 (−0.2)	0.0	0.0 (0.0)	0.7	0.0 (−0.7)
Heat-unspecified	992.8–992.9	12.9	10.9 (−2.0)	7.8	9.8 (2.0)	10.9	14.2 (3.3)

Differences between observed and expected visits are provided in parentheses

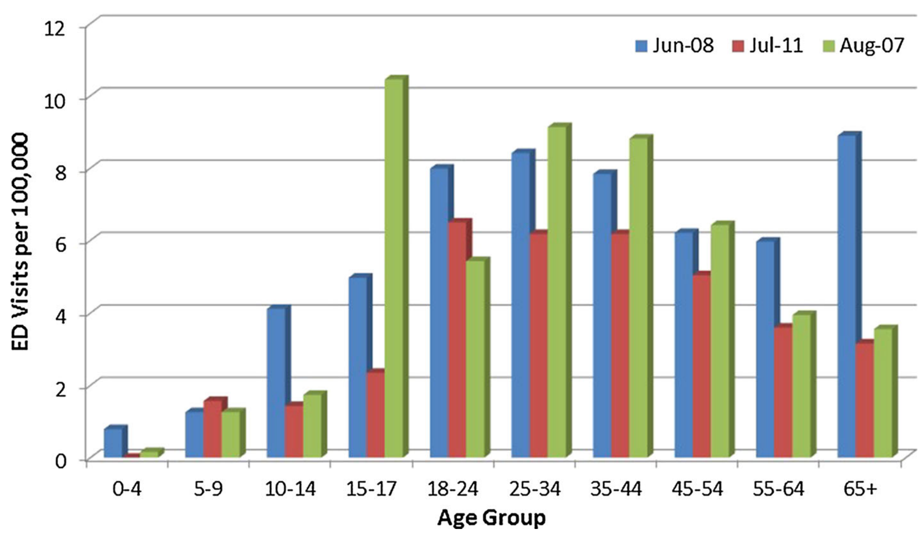

Fig. 3 Per capita rates of ED visits for HRI by age group for each of the three heat waves

during the June 2008 event were found among the elderly (>65 years of age), with a secondary peak among young to middle age adults (18–44 years of age). A similar, but smaller peak among the 18–44 year old age groups was also noted during the July 2011 heat event, while the highest rates of HRI visits during the August 2007 event were noted among adolescents (15–17 years of age), with a secondary peak among the 25–44 year old age groups. Rates were lowest among infants and children (0–9 years of age) during all heat events.

Cardiovascular and Cerebrovascular Diseases

Statistically significant increases in the number of ED visits with at least one coded diagnosis of cardiovascular or cerebrovascular disease were noted during all three heat events (Table 2). Increases of 12–23 % were seen in visits with hypotension, but were only statistically significant during the August 2007 event. Visits with ischemic heart disease were statistically elevated during the June 2008 and August 2007 heat events. In general, the most notable differences in the observed and expected visits for cardiovascular and cerebrovascular diseases were seen in the June 2008 event. In particular, the largest and most significant increase (30.2 %) was seen in visits for sequelae, or the late effects of a previous cerebrovascular accident (CVA, e.g. stroke). Though not statistically significant, visits with acute myocardial infarction were 13 % higher than expected during the June 2008 event, but only 5–7 % higher during the other two events. Similar increases were seen among visits with ischemic stroke. Additionally, while increases in visits with hemorrhagic stroke were noted during the June 2008 event, decreases were noted during the other two heat events. Decreases in visits with aneurysm were also seen during the June 2008 heat event.

Respiratory Diseases

Increases in ED visits associated with respiratory disease were noted during all three heat events, with the greatest increase during the June 2008 event (Table 3). Statistically significant increases in visits with pneumonia and influenza (15.5 %), as well as chronic obstructive pulmonary disease (12.2 %), were also noted during the June 2008 event. Increases in chronic bronchitis and emphysema, while not statistically significant, were notably elevated during the June 2008 event (13.7 %) compared to the other two heat events (1–3 %). In contrast, ED visits with asthma were especially elevated, though statistically insignificant, during the August 2007 heat event (8.3 %) compared to the other two events (<2 %).

All Causes and Other Diseases

Statistically significant increases in all ED visits were noted across all three heat events (Table 4). Statistically elevated numbers of visits due to dehydration, acute renal failure, and syncope were also found across all three events. The percent increase for dehydration and syncope was higher during the July 2011 and August 2007 heat events (20–30 %) compared to the June 2008 event (13–14 %), which exhibited a slightly greater increase for acute renal failure (33.6 % compared to 28–29 %). Other notable differences among the heat events included

Table 2 Excess ED visits for cardiovascular and cerebrovascular diseases during each heat event

Diagnosis	ICD-9-CM codes	5–11 June 2008		20–26 July 2011		7–11 August 2007	
		Excess visits (%) (95 % CI)	*p* value	Excess visits (%) (95 % CI)	*p* value	Excess visits (%) (95 % CI)	*p* value
All cardiovascular diseases	390–459	775 (5.2) (4.2 to 6.2)	0.034	1388 (8.2) (6.4 to 10.0)	0.001	470 (3.5) (2.1 to 4.9)	0.018
Ischemic heart disease	410–414	226 (7.5) (4.1 to 10.9)	0.038	36 (1.1) (−3.5 to 5.7)	0.796	141 (6.6) (4.5 to 8.7)	0.047
Acute myocardial infarction	410	30 (13.0) (−3.7 to 29.7)	0.273	24 (7.1) (−4.8 to 19.0)	0.488	11 (5.3) (−1.7 to 12.3)	0.590
Cardiac dysrhythmias*	427	21 (0.9) (−1.7 to 3.5)	0.767	185 (7.5) (3.1 to 11.9)	0.092	35 (2.1) (0.1 to 4.1)	0.443
Heart failure*	428	171 (9.7) (8.1 to 11.3)	0.061	173 (9.0) (2.8 to 15.2)	0.121	15 (1.2) (−0.7 to 3.1)	0.638
Hemorrhagic stroke*	430–432	14 (17.9) (−5.7 to 41.5)	0.388	−11 (−13.0) (−23.6 to −2.4)	0.371	−16 (−24.2) (−30.6 to −17.8)	0.316
Ischemic stroke*	433–436	43 (12.3) (0.9–23.7)	0.321	41 (7.3) (13.1 to 1.5)	0.170	53 (5.6) (2.1 to 9.1)	0.090
Late effects*	438	65 (30.2) (22.1–38.3)	<0.001	9 (3.2) (−2.3 to 8.7)	0.687	23 (16.2) (11.9 to 20.5)	0.115
Aneurysm*	441–44	−17 (−15.2) (−21.7 to −8.7)	0.189	1 (0.8) (−5.9 to 7.5)	0.949	3 (4.0) (−3.5 to 11.5)	0.819
Hypotension	458	69 (14.9) (7.3–22.5)	0.104	68 (12.7) (5.0 to 20.4)	0.174	64 (22.6) (15.4 to 29.8)	0.017

Percent increases/decreases and 95 % confidence intervals are provided in parentheses. An asterisk denotes those diagnoses where more than 60 % of visits were among those >65 years of age

Table 3 Same as Table 2, but for respiratory diseases

Diagnosis	ICD-9-CM codes	5–11 June 2008		20–26 July 2011		7–11 August 2007	
		Excess visits (%) (95 % CI)	p value	Excess visits (%) (95 % CI)	p value	Excess visits (%) (95 % CI)	p value
All respiratory diseases	460–519	733 (7.3) (5.7 to 8.9)	0.038	671 (6.4) (5.0 to 7.8)	0.092	330 (5.1) (2.9 to 7.3)	0.056
Pneumonia and influenza*	480–487	171 (15.5) (9.9 to 21.1)	0.012	47 (3.5) (0.8 to 6.2)	0.254	67 (5.4) (3.3 to 7.5)	0.159
Chronic bronchitis/emphysema	491–492	93 (12.2) (4.9 to 19.5)	0.170	16 (1.8) (−2.9 to 6.5)	0.768	9 (1.9) (−4.3 to 8.1)	0.733
Asthma	493	35 (1.5) (−1.3 to 4.3)	0.676	6 (0.2) (−2.6 to 3.0)	0.963	140 (8.3) (3.9 to 12.7)	0.155
Chronic obstructive pulmonary disease (COPD)	496	213 (13.7) (10.1 to 17.3)	0.003	43 (3.1) (0.2 to 6.0)	0.543	8 (0.7) (−1.5 to 2.9)	0.850

Table 4 Same as Table 2, but for all causes, injuries and other diseases

Diagnosis	ICD-9-CM codes	5–11 June 2008		20–26 July 2011		7–11 August 2007	
		Excess visits (%) (95 % CI)	p value	Excess visits (%) (95 % CI)	p value	Excess visits (%) (95 % CI)	p value
All causes and injuries	001.0–999.9	4982 (7.8) (7.0 to 8.6)	0.015	5774 (8.6) (7.5 to 9.7)	0.002	2284 (5.3) (4.3 to 6.3)	0.006
Diabetes	250	248 (4.4) (3.2 to 5.6)	0.095	583 (9.7) (8.2 to 11.2)	<0.001	191 (4.9) (2.0 to 7.8)	0.135
Dehydration	276	457 (12.9) (8.5 to 17.3)	0.014	862 (24.7) (20.0 to 29.4)	<0.001	500 (21.7) (18.6 to 24.8)	0.003
Mental disorders	290–319	689 (5.2) (3.5 to 6.9)	0.142	−753 (−4.4) (−6.1 to −2.7)	0.127	570 (6.4) (4.3 to 8.5)	0.148
Nervous system disorders	320–389	1103 (15.9) (14.2 to 17.6)	0.008	−554 (−5.7) (−7.5 to −3.9)	0.068	97 (2.1) (0.4 to 3.8)	0.362
Degenerative CNS disorders*	330–337	82 (11.8) (5.7 to 17.9)	0.085	−36 (−4.2) (−9.7 to 1.3)	0.491	26 (5.4) (2.7 to 8.1)	0.300
Nephritis/nephrotic syndrome	580–589	109 (5.5) (2.1 to 8.9)	0.268	150 (5.3) (−0.5 to 11.1)	0.386	104 (7.4) (4.6 to 10.2)	0.087
Acute renal failure	584	221 (33.6) (23.8 to 43.4)	<0.001	297 (28.3) (18.2 to 38.4)	0.006	130 (29.3) (22.8 to 35.8)	<0.001
Syncope and collapse	780.2	123 (13.6) (8.9 to 18.3)	0.044	266 (28.2) (19.4 to 37.0)	0.001	167 (29.6) (23.2 to 36.0)	0.012

statistically significant increases in ED visits with mental, nervous, and degenerative central nervous system disorders during the June 2008 heat event (5–16 %), while decreases in visits with these diagnoses were noted during the July 2011 event. Increases in these visits were also noted during the August 2007 heat event, but were not statistically significant. ED visits with diabetes were elevated during all three heat events, with the greatest and only statistically significant increase during the July 2011 event (9.7 %).

Discussion

The results of this study provide both new and supporting evidence regarding the health effects of extreme heat. We found that the most common form of HRI was heat exhaustion. During the three analyzed heat events, the percentage of these visits increased to over 70 %, compared to 60 % during the control periods. These values are consistent with recent studies of ED visits nationally [10, 30]. It is likely that individuals experiencing less severe forms of HRI, such as cramps and fatigue, may not visit an ED for treatment. However, the reason for the low percentage (<10 %) of HRI visits with heat stroke is not clear. One possibility may be that most individuals presenting with HRI in the ED do not meet the clinical definition for heat stroke (i.e. core body temperature >104 °F and evidence of organ damage or failure). Additionally, since heat stroke typically requires hospitalization [30], most cases may not receive a coded diagnosis in the ED, even if it was their initial access point for receiving treatment.

Differences in vulnerable age groups were noted between the three heat events. During the early season (June) event, the greatest risk for HRI in the ED was seen among the elderly. Previous research on the 1995 Chicago heat wave found that over 75 % of hospitalizations for heat stroke were among individuals >65 years of age [20]. Similarly, elderly patients were responsible for the increase in visits presenting with heat stroke during the June heat event (3.5 %), which was not seen during the other two events. In contrast, the lowest risk for HRI in the ED was seen among infants and children. Children have not been consistently identified as a vulnerable demographic, suggesting that very particular risk factors and circumstances must be present [31].

The greatest risk for HRI during the mid-season (July) heat event was seen among young and middle age adults. A recent assessment of ED visits in New York City from 2005 to 2010 also found this demographic to be at high risk for HRI [32]. In North Carolina, many of the ED visits seen during the July event were likely work-related, as most occupations with high exposure to extreme heat employ individuals in these age categories [33]. Indeed, about one-third of all HRI visits in the NC DETECT dataset from 2008 to 2010 were work-related according to available triage notes [17]. One occupational group that is particularly vulnerable in North Carolina is migrant and seasonal farm workers, who exhibit the highest mortality rates for HRI of all farm workers across the U.S. [34]. An earlier study on heat-related mortality in North Carolina found that almost half of all occupational heat-related deaths from 1977 to 2001 were among farm workers [35]. Several risk factors have been identified among this demographic, including the exertional nature of their work (many labor-intensive crops are typically harvested in July), excessive clothing, poor housing conditions, lack of preventative training, lack of access to health care, and underlying illness or disease [19, 34, 36–38]. Since we did not have access to any individual information on the circumstances surrounding each ED visit, we could not confirm what specific occupations were in fact associated with HRI. In general, more research is needed to better understand how workers of various occupations are uniquely impacted by extreme heat [33].

The most vulnerable age demographic during the late season (August) heat event was adolescents, followed by young and middle aged adults. Examination of available triage notes in the NC DETECT dataset revealed that >40 % of HRI visits were associated with exercise or recreation, of which two-thirds were linked to organized sports among 10–18 year olds [17]. Football players are particularly vulnerable to HRI due to uniform requirements and physiological characteristics that increase metabolic heat production and storage [39, 40]. These risk factors are especially evident during pre-season practices (usually in late July and early August) when players are not yet acclimatized to performing in high heat and humidity [41]. Adult recreational athletes (e.g. runners) are also vulnerable to HRI. Many are unaware of their physical and environmental limitations, and may underestimate how quickly mild heat stress can evolve into heat exhaustion and heat stroke [42, 43]. Performance enhancing drugs also increase the risk of HRI by altering cardiovascular output and decreasing sweat production [8].

In addition to HRI, we examined both the observed and expected number of ED visits for all causes as well as a number of different disease categories associated with each heat event. Since all available diagnostic codes (i.e. primary and secondary diagnoses) were examined for each visit, we were able to account for underlying health conditions. Therefore, our results may provide insight into the specific pathophysiologic mechanisms associated with exposure to extreme heat. The total number of ED visits for all causes was significantly elevated during all three heat events, a finding that is supported by studies of other heat events across the U.S. and abroad [20, 21, 24, 44].

While overall patient demand was found to increase during each heat event, some important differences were noted among specific illness and diseases. The greatest increases among several cardiovascular and cerebrovascular diseases were seen during the early season heat event, with elderly patients accounting for the majority of these visits. The body's natural response to hyperthermia primarily involves variations in cardiac output, which are controlled by the brain and help redirect metabolic heat to the skin where it can be dissipated via sweat production. Conditions that may disrupt or be triggered by this response include heart disease, dysrhythmia, and hypotension [25, 45], all of which were elevated during the June 2008 heat event and, in some cases, during the other two heat events. In particular, ED visits with hypotension were significantly elevated (>20 %) during the August 2007 event. Hyperthermia may also contribute to acute myocardial infarction (i.e. heart attack), which was elevated during the June 2008 event. These findings are generally consistent with previous studies [20–25, 32, 44].

Increases in certain CVAs were also noted, particularly during the June 2008 heat event, and support the results of earlier studies [20, 25]. Hyperthermia typically contributes to vascular inflammation and decreased blood oxygen levels, which can lead to hypercoagulation and an increased risk of clotting and stroke. Indeed, the number of visits with ischemic stroke was elevated during each heat event. Hemorrhagic stroke, on the other hand, was only elevated during the June 2008, while the number of these visits decreased during the other two heat events. Decreases were also noted in visits with aneurysm, which exhibits a similar pathology to hemorrhagic stroke (i.e. the rupture of a weakened blood vessel or blood-filled bulge). One possible explanation for the decrease in these visits is that individuals who present with hyperthermia are often hypotensive, which may reduce the risk of rupture. Future work will examine the interactive effects of hyperthermia with other health conditions through separation of primary and secondary diagnoses, which will better help us test this and other related hypotheses.

One of the greatest and most statistically significant increases in ED visits (>30 %) was seen among individuals presenting with symptoms and complications from a previous CVA during the June 2008 heat event. Increases in hospitalization for sequelae were also noted during the 1995 Chicago heat wave [20], though the exact pathophysiological mechanism is not clear. It is also worth noting that, while the early season heat event exhibited the greatest increases in many individual cardiovascular and cerebrovascular diseases, the mid-season (July) heat event exhibited the greatest overall increase of all cardiovascular and cerebrovascular diseases combined. To investigate this further, we examined several other diseases in this category (not presented in Table 2) and found a statistically significant increase (>10 %, $p < 0.001$) in visits with hypertension and rheumatic disease (ICD-9-CM 401-405) during the July event, with negligible and insignificant increases during the other two heat events. Previous research found that about 18 % of ED visits with HRI were associated with hypertension, most within the 25 to 54 age groups [17]. Some research suggests that short-term spikes in blood pressure can occur from exposure to heat, though the pathophysiological link between hypertension and heat stress may manifest through other cardiovascular and respiratory conditions [46]. Neurological impairments, which can affect thermoregulation, have also been noted in chronically hypertensive rats when exposed to extreme heat [47]. Future research will more closely examine the association between abnormalities in blood pressure and hyperthermia.

Increases in ED visits with respiratory disease were noted among all three heat events. General increases in all respiratory diseases have not been consistently identified in the literature, though some specific diseases may be more prevalent during heat events than others [20–25, 44]. We noted increases in visits with pneumonia and influenza, bronchitis and emphysema, and COPD, with the greatest increases during the June heat event. ED visits with asthma were not significantly elevated. Past studies have considered possible effect modification from air pollution, which often accompanies heat events [48]. Future work will incorporate air quality data to determine if effect modification is a factor during extreme heat events in North Carolina.

Several other diseases presented more frequently in the ED during periods of extreme heat. Statistically significant increases in acute renal failure were noted across all three heat events, while ED visits with diabetes were significantly elevated during the July 2011 event. About 7 % of HRI visits in the NC DETECT dataset were associated with diabetes [17]. Dehydration and reduced cardiac output are common risk factors for acute renal failure in heat-stressed individuals [20–24], while dehydration can exacerbate the effects of diabetes if glucose levels are not properly maintained [21–23, 25, 32].

ED visits with nervous system disorders, which include epilepsy, migraines, insomnia, and multiple sclerosis, were slightly elevated during the three heat events. The pathophysiology of these disorders and their relationship to hyperthermia is not well documented; however, because thermoregulation is a neurologic function, any abnormalities in brain condition could hinder the dissipation of metabolic heat. Individuals with degenerative CNS disorders, such as Parkinson's and Alzheimer's, as well as individuals with mental illness, may be unable to care for themselves during a heat event, and medications for these disorders can lead to a reduction in thirst sensation, increasing the risk for dehydration and renal failure [9, 24, 32, 44].

It is important to note several limitations to our study. While there is a significant military presence in North Carolina, data from the Womack Army Medical Center at Fort Bragg and the Naval Hospital at Camp Lejeune are not currently available in NC DETECT. We also did not have data on the final disposition of the ED patient (i.e. discharged, admitted to the hospital, or deceased). While EDs are a common access point for many people seeking treatment for HRI [17], there is likely a large but unknown population who are unable or unwilling to access an ED [13]. Therefore, using ED visits alone results in an underestimation of the overall health burden associated with extreme heat. Additionally, because ICD-9-CM codes are primarily used for billing and reimbursement, a patient's insurance status may influence the coding of specific diseases [17].

In an effort to provide information that may be relevant to the proposed heat response plan in North Carolina, we adopted a rather strict criteria for identifying periods of extreme heat that emphasized widespread, long-duration events with exceptionally high heat index values. In doing so, individuals that reside in the mountainous western (and cooler) region of the state were not included in this study. Future work will focus on shorter duration events that fall below the current thresholds of NWS heat products, as these events likely constitute a much greater proportion of the overall health burden of summertime heat and humidity [49]. Although it has been noted that lag effects associated with heat-related morbidity are generally much shorter than those associated with heat-related mortality, it is likely that the specific effects vary across different disease categories and these will be addressed in future studies. Additionally, spatial variations in ED visits associated with heat events will also be examined, as regional differences in vulnerability have been noted, most notably across North Carolina [18, 19] and California [21, 44].

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Compliance with Ethical Standards

Conflict of interest None.

Appendix

See Table 5.

Table 5 Dates of control periods

Heat event	Control periods
August 7–11, 2007	August 12–15, 2008; August 19–23, 2008; August 15–19, 2009; August 16–20, 2011
June 5–11, 2008	June 4–10, 2009; June 11–17, 2009; June 3–9, 2010; 19–25 June 2011
July 20–26, 2011	July 9–15, 2008; July 23–29, 2008 July 8–14, 2009; July 22–28, 2009

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