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Ambient temperature and emergency department visits for heat-related illness in North Carolina, 2007–2008

Steven J. Lippmann [a,*], Christopher M. Fuhrmann [b,c], Anna E. Waller [d], David B. Richardson [a]

[a] Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina, 2101 McGavran-Greenberg Hall, CB #7435, Chapel Hill, NC 27599-7435, USA
[b] Department of Geography, University of North Carolina, Saunders Hall, Campus Box 3220, Chapel Hill, NC 27599, USA
[c] Southeast Regional Climate Center, University of North Carolina, Coates Building, 223 East Franklin Street, Chapel Hill, NC 27514, USA
[d] Carolina Center for Health Informatics, Department of Emergency Medicine, University of North Carolina, 100 Market St, Chapel Hill, NC 27516, USA

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ABSTRACT

Purpose: To estimate the association between environmental temperatures and the occurrence of emergency department visits for heat-related illness in North Carolina, a large Southern state with 85 rural and 15 urban counties; approximately half the state's population resides in urban counties.
Methods: County-level daily emergency department visit counts and daily mean temperatures for the period 1/1/2007–12/31/2008 were merged to form a time-series data structure. Incidence rates were calculated by sex, age group, region, day of week, and month. Incidence rate ratios were estimated using categorical and linear spline Poisson regression models and heterogeneity of the temperature-emergency department visit association was assessed using product interaction terms in the Poisson models.
Results: In 2007–2008, there were 2539 emergency department visits with heat-related illness as the primary diagnosis. Incidence rates were highest among young adult males (19–44 year age group), in rural counties, and in the Sandhills region. Incidence rates increased exponentially with temperatures over 15.6 °C (60 °F). The overall incidence rate ratio for each 1 °C increase over 15.6 °C in daily mean temperature was 1.43 (95%CI: 1.41, 1.45); temperature effects were greater for males than females, for 45–64 year olds, and for residents of rural counties than residents of urban counties.
Conclusions: As heat response plans are developed, they should incorporate findings on climate effects for both mortality and morbidity. While forecast-triggered heat health warning systems are essential to mitigate the effects of extreme heat events, public health preparedness plans should not ignore the effects of more persistently observed high environmental temperatures like those that occur throughout the warm season in North Carolina.

1. Introduction

Public health practitioners have become increasingly aware of the health effects of heat waves and other periods of high ambient temperature. This is due in large part to the occurrence of major heat waves over the past decade, including in western Europe in 2003 (Kosatsky, 2005), western North America and Europe in 2006 (Gershunov et al., 2009; Fouillet et al., 2008), the Southeast United States in 2007 (Fuhrmann et al., 2011), southern Australia in 2008 and 2009 (Karoly, 2009; Mayner et al., 2010) and eastern Europe in 2010 (Barriopedro et al., 2011). Many public health agencies have begun to incorporate extreme heat preparedness plans into their overall natural disaster readiness strategies (Bernard and McGeehin, 2004). Most of these extreme heat response plans have been devised based on findings from studies examining the effect of temperature on *mortality*. Fewer studies have examined the effect of temperature on morbidity due to the more limited availability of large-scale hospital admission and emergency department visit surveillance systems.

This study analyzes the association between temperature and heat-related morbidity in North Carolina. North Carolina is the 10th most populous US state and had the 6th highest population growth rate between 2000 and 2010 (18.5%) (Mackun et al., 2011). Due to its humid subtropical climate, topographic variability, large and rapidly growing population, and statewide morbidity surveillance network, North Carolina provides an excellent setting to study patterns of temperature and health outcomes. Prior work examined heat-related deaths in North Carolina between 1977 and 2001 using medical examiner data, but heat-related fatalities are rare and that study encompassed only 161 events (Mirabelli and Richardson, 2005). With the development of the North Carolina

Abbreviations: ICD-9-CM, 9th Revision of the International Classification of Diseases—Clinical Modification.

* Corresponding author. Fax: +1 919 843 1226.
E-mail addresses: slippmann@unc.edu (S.J. Lippmann), fuhrman1@email.unc.edu (C.M. Fuhrmann), awaller@med.unc.edu (A.E. Waller), david.richardson@unc.edu (D.B. Richardson).

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Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT; hereafter referred to as “the NC emergency department surveillance data system”) (Hakenewerth et al., 2009), state-wide data on emergency department visits in North Carolina are now available.

In this paper we use NC emergency department surveillance data from 2007 and 2008 to describe the incidence of heat-related emergency department visits in North Carolina and investigate the association between temperature and the incidence rate of emergency department visits for heat-related illness, including heat exhaustion, heat stroke, and heat syncope. We also examine variation in the association between temperature and heat-related emergency department visits by age, sex, urbanization, and region. By drawing upon a state-wide surveillance system for emergency department visits, we derive information that allows us to examine geographic variation in this association, including differences between urban and rural populations. Such analyses are not possible in studies that focus on heat-related illness in a single city, or in studies that pool data from several large urban populations. By focusing on emergency department visit data, we are able to study heat-related events that may be less serious than those leading to hospital admission or death. Consequently, our analysis of emergency department visits provides further insight regarding the public health impacts of heat waves and other periods of high ambient temperature.

2. Materials and methods

2.1. Data sources

In 2005 North Carolina mandated the creation of a statewide emergency department surveillance system. All hospitals in North Carolina with 24-h acute care emergency departments must report electronic visit data to the NC emergency department surveillance data system in near-real time via the North Carolina Hospital Emergency Surveillance System. This system provides information on the age, sex, and county of residence of the patient, the date of the emergency department visit, and up to 11 diagnoses at discharge coded to the 9th Revision of the International Classification of Diseases—Clinical Modification (ICD-9-CM) (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, and the Centers for Medicare and Medicaid Services, 2009). Discharge diagnoses are the *final* diagnoses given by an emergency department practitioner (typically a physician) and coded for billing and reimbursement. The visit date-time recorded in the data system is the earliest date/time documented in the patient's record for the emergency department visit. Data conform to the Data Elements for Emergency Department Systems guidelines (National Center for Injury Prevention and Control, 1997). This system does not provide information on the patient's race or ethnicity. By the end of 2007 the system had reached near full compliance, with essentially all hospitals reporting emergency department visit data in electronic form to the NC emergency department surveillance data system; it is estimated that the system captured data for 92% of all emergency department visits state-wide in 2007 and 99.5% of such visits in 2008 (Hakenewerth et al., 2009; Carolina Center for Health Informatics, University of North Carolina at Chapel Hill, 2010). Analyses of these data that use information on the discharge diagnoses coded to ICD-9-CM cannot be conducted in real-time, since NC hospitals may experience a lag of several months between the emergency department visit and submitting the final ICD-9-CM discharge diagnoses to the NC emergency department surveillance data system. The current project, which commenced in 2010, therefore analyzed emergency department visits with a primary diagnosis of heat effects (ICD-9-CM code 992.xx) reported from January 1, 2007 to December 31, 2008.

County-specific average daily temperature estimates were obtained from records of the State Climatologist. Fahrenheit scale was used for data management and analysis; Celsius conversions are presented here in consideration of non-U.S. readers. Average daily temperatures for 73 of the 100 counties in North Carolina were derived using hourly observations from first-order weather stations maintained by the National Weather Service and Federal Aviation Administration, as well as from stations in the North Carolina Environment and Climate Observing Network. Estimates of average daily temperature for an additional 20 counties were calculated using daily minimum and maximum temperature recorded at stations in the Cooperative Observer network. Seven counties (Camden, Catawba, Gates, Jones, Mitchell, Perquimans, and Tyrrell) had incomplete temperature records and were excluded from this study. Therefore, the current analysis is restricted to people who resided within the 93 counties in North Carolina for which we could derive estimates of average daily temperature from operational weather stations (Fig. 1).

Other temperature metrics such as apparent temperature were considered. However, recent investigations into the sensitivity of temperature-health associations to the selection of temperature metric have concluded that these alternate metrics are highly correlated and, as a result, metric choice has limited impact on temperature-health associations (Barnett et al., 2010; Vaneckova et al., 2011; Yu et al., 2011). Those researchers suggest that metric selection be based on data quality, completeness, and coverage; average daily ambient temperature was chosen because it was available for the largest number of counties.

Certified age- and sex-specific estimates of the population on July 1, 2007 and July 1, 2008 in each of the 93 counties included in this analysis were obtained from the State Demographer at the North Carolina Office of State Budget and Management based on data from the United States Bureau of the Census (North Carolina Office of State Budget and Management, 2011). These Census-based population estimates are used as population denominators in the estimation of crude and stratified incidence rates and incidence rate ratios, and to describe the population-level exposure to temperature levels. We classified counties in North Carolina as urban or rural based on population data provided by the NC Rural Economic Development Center, Inc. (2011). Counties with a population density of less than 250 people per square mile were classified as rural and thus eligible for the center's programs, based on data from the 2000 Census, while other counties were classified as urban. Using this criterion, 15 NC counties were classified as urban (Fig. 1). These counties represented all major metropolitan areas and approximately 51% of the state population. The remaining counties were classified as rural.

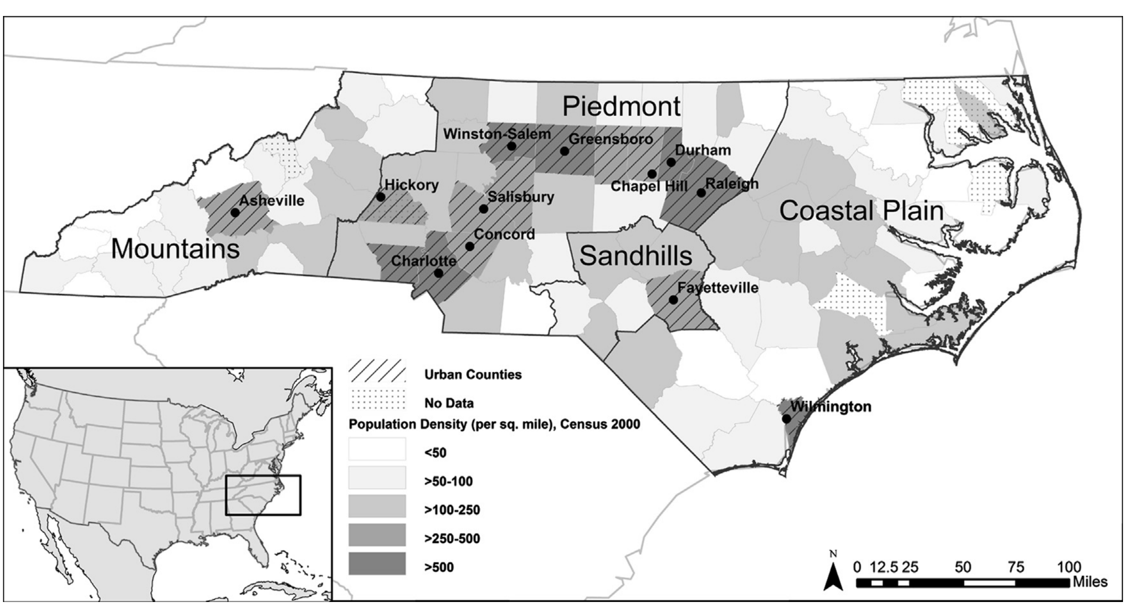

Fig. 1. Map of study area featuring major cities, county and region boundaries, population density (per square mile), and urban/rural classification.

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2.2. Statistical methods

Letting i,j,k,l index age category, sex, county, and calendar time, a spatiotemporally-merged data structure was generated with d_{ijkl} events, p_{ijkl} person-years, and t_{kl} Celsius degrees county-specific average daily mean temperature in county k on day l. Poisson regression was used to estimate the association between average daily mean temperature and emergency department visits with a primary diagnosis of heat-related illness. Log-rate models were constructed using the Poisson procedure of the Stata 11.1 statistical software package (College Station, TX) using the model:

$$\ln(d_{ijkl}) = a_0 + f(\beta; t_{kl}) + \ln(p_{ijkl}/100,000),$$

where $f(\beta;t_{kl})$ is a function of daily mean temperature and estimated coefficients, β, and $\ln(p_{ijkl}/100,000)$ represents the population denominator offset term. Census estimates of the person-time denominators may have error; however, previous research has shown that Poisson rate ratio estimates are highly robust to errors in denominators (Bena et al., 2004; Richardson et al., 2004).

To assess the shape of the exposure–response relationship, we initially fitted a piecewise constant function (i.e. indicator terms for categories of temperature) to describe the association between daily mean temperature and emergency department visits by including indicator terms for eight categories of daily mean temperature (°C): < 10, 10– < 15.6, 15.6– < 21.1, 21.1– < 23.9, 23.9– < 26.7, 26.7– < 29.4, 29.4– < 32.2, ≥32.2 (°F: < 50, 50– < 60, 60– < 70, 70– < 75, 75– < 80, 80– < 85, 85– < 90, ≥90). We subsequently fitted smooth functions of temperature, assessing a restricted cubic spline function, with 3 knots at the 10th, 50th, and 90th percentiles, which allows for a curvilinear exposure–response curve but constrains it to be linear below the 10th and above the 90th percentiles, respectively. Restricted cubic splines with up to 7 knots were also tested, but the additional degrees of freedom did not improve model fit. After visual inspection of the predicted incidence rates produced by these two flexible model forms, plotted on the log (rate) scale, we identified an inflection point in the slope and used this inflection point as the knot location for a linear spline model. Model fit was compared using Akaike Information Criterion. The final linear spline approach, which assumes linear relationships above and below the threshold temperature of 15.6 °C (60 °F), was selected because it provided a reasonable fit and readily interpretable coefficients, and was parsimonious (Armstrong, 2006).

Heterogeneity in the association between temperature and emergency department visits was estimated using interaction terms for the product of the linear spline term for temperature and each potential effect measure modifier, including sex, age group, region, and urbanicity. Interaction terms between the main temperature term and each potential modifier were not included, such that stratified estimates would be constrained to be the same for temperatures below 15.6 °C (60 °F). Stratified predicted incidence rates were calculated and plotted against temperature above 15.6 °C (60 °F). For descriptive purposes we also plotted the daily population-weighted average temperature for the entire state of North Carolina against the total number of heat-related emergency department visits each day. This state-level population-weighted average daily temperature was derived by summing up the products of each county's daily temperature value multiplied by the county's population and then dividing the summation by the total state population. This weighted average should, in theory, provide a more accurate representation of the temperatures actually experienced by the state's population than a simple average of county-specific temperatures would.

Table 1
Characteristics and crude incidence rates for emergency department visits for heat-related illness recorded in the North Carolina Disease Event Tracking and Epidemiologic Collection Tool surveillance system in North Carolina, 2007–2008.

	Heat-related emergency department visits	Person-time (person-years*10^{-5})	Crude incidence rate (per 100,000 person-years)
Sex			
Female	690	90.5	7.63
Male	1849	88.2	20.96
Age (years)			
0–9	55	24	2.29
10–18	368	21.8	16.9
19–44	1263	65.8	19.21
45–64	596	45.5	13.09
65 or older	257	21.7	11.86
Geographic region			
Coastal plains	723	41.6	17.38
Mountains	158	21	7.52
Piedmont	1341	102.2	13.12
Sandhills	317	13.9	22.88
Urbanicity			
Urban	1146	89.1	12.8
Rural	1393	89.6	15.6
Month			
January	< 10*	15.2	0.46
February	< 10*	13.9	0.29
March	17	15.2	1.12
April	44	14.7	3
May	123	15.2	8.12
June	754	14.7	51.4
July	457	15.2	30.15
August	892	15.2	58.85
September	177	14.7	12.07
October	44	15.2	2.9
November	11	14.7	0.75
December	< 10*	15.2	0.59
Day of week			
Sunday	232	25.4	9.13
Monday	336	25.7	13.09
Tuesday	406	25.7	15.82
Wednesday	418	25.7	16.28
Thursday	414	25.4	16.28
Friday	362	25.4	14.24
Saturday	371	25.4	14.59

* Small cell sizes (> 0– < 10) are suppressed. The combined count for December, January, and February was 20.

3. Results

Between January 1, 2007 and December 31, 2008 there were 2539 emergency department visits with a heat-related illness as the primary diagnosis across the 93 counties. 72.8% of the heat-related emergency department visits were made by males, and the incidence rate for males was nearly three times that for females (Table 1). The 19–44 year old age group contributed the most heat-related emergency department visits (49.7%) and also had the highest incidence rate among all the age groups (19.2 per 100,000 person-years). The incidence rate for children aged 0 to 9 years (2.29 per 100,000 person-years) was considerably lower than that for older children and adults. Incidence rates ranged from 7.52 visits per 100,000 person-years in the Mountain region to 22.88 visits per 100,000 person-years in the Sandhills region. As expected, emergency department visit rates increased dramatically in the summer and approached zero in the winter, though events occurred in every calendar month. Emergency department visit rates were highest during the middle of the work-week (Wednesday and Thursday) and lowest on Sunday and Monday.

Fig. 2 shows the state-level population-weighted average daily temperature and daily count of emergency department visits for heat-related illness. Incidence spikes appear in early August 2007 and again in early June 2008, contemporaneous with periods of anomalously high temperatures across much of North Carolina. The period from August 7 to August 10, 2007 was one of the warmest on record in North Carolina, as at least 30 locations recorded all-time daily record maximum and high minimum temperatures, reaching above 40.6 °C (105 °F) in some locations with overnight minimums as high as 26.7 °C (80 °F) or higher (Fuhrmann et al., 2011). The following June, many locations in central and eastern North Carolina reported maximum temperatures above 37.8 °C (100 °F) between June 7 and June 10, which is more than 8.3 °C (15 °F) above average for that time of year. Although these two exceptionally hot periods only accounted for 1% of all days in the study period, they accounted for 19% (n=472) of all statewide heat-related emergency department visits in the study.

Poisson regression models were used to estimate the association between county-level daily temperature and emergency

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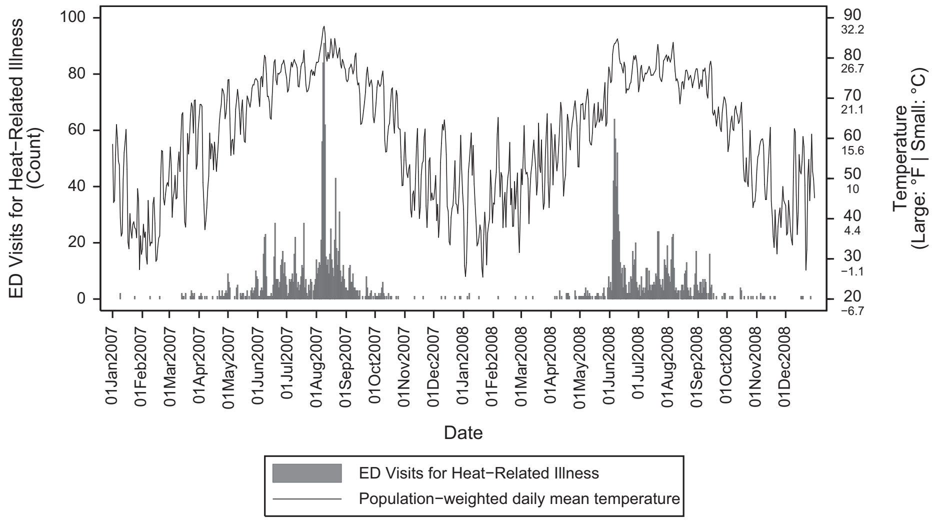

Fig. 2. Daily number of emergency department visits for heat-related illness and state-level population-weighted average of county-level daily mean temperatures, North Carolina, 2007–2008. The state-level population-weighted average daily temperature was derived by summing up the products of each county's daily mean temperature value multiplied by the county's population and then dividing the summation by the total state population.

Table 2
County-level heat-related emergency department visits by county-level daily mean temperature, North Carolina 2007–2008.

Temperature (C° (F°))	Heat-related emergency department visits	Person-time (person-years*10^{-5})	Crude incidence rate (per 100,000 person-years) (95% CI)	Incidence rate ratio (95% CI)
< 10 (< 50)	19	46.9	0.41 (0.24, 0.63)	0.11 (0.07, 0.18)
10– < 15.6 (50– < 60)	26	29.9	0.87 (0.57, 1.28)	0.24 (0.15, 0.37)
15.6– < 21.1 (60– < 70)	130	36.3	3.58 (2.99, 4.25)	1. (Reference)
21.1– < 23.9 (70– < 75)	216	20.3	10.65 (9.28, 12.17)	2.98 (2.38, 3.73)
23.9– < 26.7 (75– < 80)	740	25.5	29.01 (26.96, 31.18)	8.11 (6.72, 9.85)
26.7– < 29.4 (80– < 85)	790	11.2	70.48 (65.65, 75.57)	19.70 (16.34, 23.90)
29.4– < 32.2 (85– < 90)	515	2.3	224.50 (205.53, 244.76)	62.75 (51.67, 76.66)
32.2+ (90+)	44	0.1	355.75 (258.49, 477.58)	99.43 (68.98, 140.95)

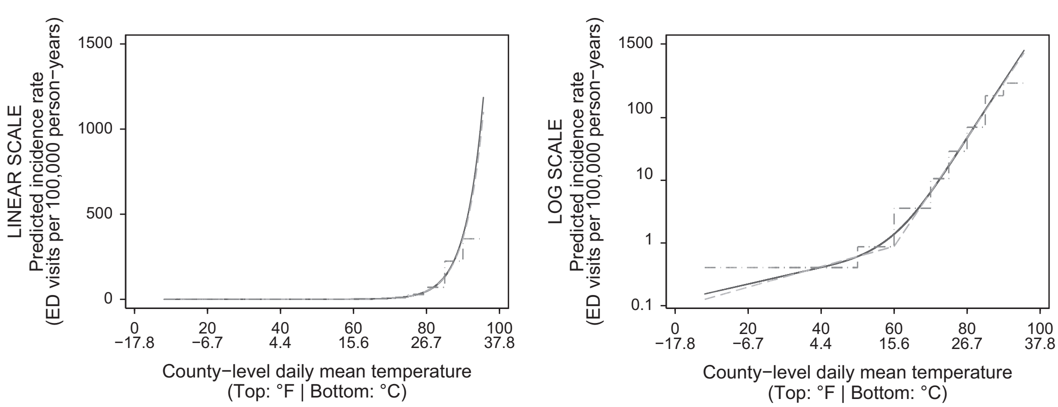

Fig. 3. Predicted incidence rates from Poisson regression models of the association between county-level daily mean temperature and emergency department visits for heat-related illness in North Carolina, 2007–2008. *Y*-axis is plotted with a linear scale in the left panel and a natural log scale in the right panel. Dash–dot lines: temperature parameterized using categorical indicator terms for temperature groups (°C: < 10, 10– < 15.6, 15.6– < 21.1, 21.1– < 23.9, 23.9– < 26.7, 26.7– < 29.4, 29.4– < 32.2, ≥32.2; °F: < 50, 50– < 60, 60– < 70, 70– < 75, 75– < 80, 80– < 85, 85– < 90, ≥90). Dashed lines: linear spline model with a knot at 15.6 °C (60 °F). Solid lines: restricted cubic spline with 3 knots (10th, 50th, 90th percentile).

department admission rates. In categorical analyses, the rate of heat-related emergency department visits rose rapidly with increasing daily mean temperature above 15.6 °C (60 °F) (Table 2), to a maximum of 355.75 per 100,000 person-years at the highest category of observed daily mean temperatures (32.2 °C (90 °F) and above). Using the category containing temperatures from 15.6 °C to < 21.1 °C (60– < 70 °F) as the reference, the incidence rate ratios for the higher temperature groupings rose exponentially, to as much as 99.43 (95%CI: 68.98, 140.95) in the 32.2 °C (90 °F) and above category. Although the incidence rates were greatest in the highest two temperature groups (29.4 °C (85 °F) and higher), little of the observed person-time (less than 2%) was accumulated under those conditions. The majority of visits ($n=1530$, or 62%) occurred on days with mean daily temperatures closer to their climatological average (23.9–<29.4 °C (75–<85 °F)), which represented approximately 21% of person-time observed.

The relationship between temperature and emergency department visit rates was non-linear. Fig. 3 illustrates the predicted incidence rates from Poisson regression model forms that relax the assumption of linearity in the log rate using three different parameterizations for temperature: (1) categorical indicator terms for temperature increments; (2) restricted cubic spline with 3 knots (10th, 50th, and 90th percentiles); and (3) linear spline with a knot at 15.6 °C (60 °F). In the temperature range above 15.6 °C (60 °F), the exposure-response was linear on the log (rate) scale, as shown in the log-scaled panel of Fig. 3. Based on the Akaike information criterion, the simpler linear spline model fit the data nearly as well as the more complex restricted cubic spline form; hence, the linear spline model was carried forward as the platform for the remainder of the analyses. Incidence rates were relatively low and varied minimally with temperature below 15.6 °C (60 °F) but rose steeply with increasing temperature above 15.6 °C (60 °F), as depicted in the linear-scaled panel of Fig. 3. Based on the coefficients from the linear spline model, the estimated incidence rate ratio was 1.43 (95% CI: 1.41, 1.45) for each 1 °C increase in temperature above 15.6 °C (60 °F).

We also examined heterogeneity in the associations by age, sex, geographic region, and rural–urban classification. Stratified incidence rate ratios estimating the effects of a 1 °C increase in temperature above 15.6 °C (60 °F) for each group are presented in Table 3. Fig. 4 depicts the stratified predicted incidence rates, which reflect differences between groups in both baseline rates and temperature-morbidity associations. The slope of the predicted incidence rate for males was considerably steeper than that for females. The 45–64 year old age group had the highest incidence rate ratio (1.46 (95%CI: 1.43, 1.50)), followed closely by the 19–44 year old group (1.45 (95%CI: 1.43, 1.48)). The 10–18 year old group had the lowest incidence rate ratio, but since that group's overall incidence rate was the second highest, the curve for its predicted incidence rate travels along a path similar to other age groups. The youngest age group had the median incidence rate ratio, but on an absolute scale, its predicted incidence rate curve is the lowest, reflecting the low overall incidence rate in this group.

Table 3
Stratified incidence rate ratios and 95% confidence intervals for the association between county-level daily mean temperature and emergency department visit rate for heat-related illness recorded in the North Carolina Disease Event Tracking and Epidemiologic Collection Tool surveillance system in North Carolina, 2007–2008.

	Incidence rate ratio for +1 °C increment above 15.6 °C (60 °F) (95% CI)
Sex	
Female	1.40 (1.37, 1.43)
Male	1.44 (1.42, 1.46)
Age (years)	
0–9	1.43 (1.33, 1.55)
10–18	1.34 (1.30, 1.38)
19–44	1.45 (1.43, 1.48)
45–64	1.46 (1.43, 1.50)
65 or older	1.42 (1.37, 1.47)
Geographic region	
Coastal plains	1.49 (1.46, 1.53)
Mountains	1.45 (1.39, 1.52)
Piedmont	1.41 (1.39, 1.43)
Sandhills	1.43 (1.39, 1.48)
Urbanicity	
Urban	1.43 (1.40, 1.45)
Rural	1.44 (1.42, 1.46)

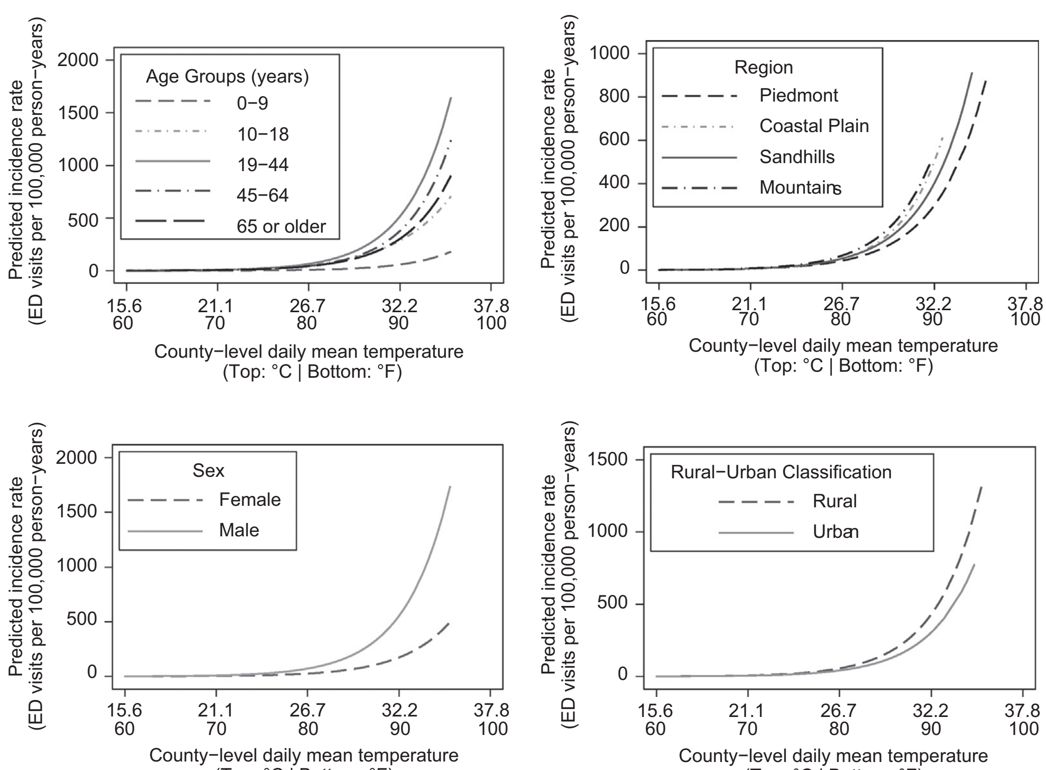

Fig. 4. Heterogeneity in the association between county-level daily mean temperature and incidence rates of emergency department visits for heat-related illness by age, sex, region, and rural–urban classification, North Carolina, 2007–2008.

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While all regions exhibited sharply increasing rates with higher temperatures, the incidence rate ratios were highest for the Coastal Plains and Mountain regions, even though these regions did not experience the highest mean temperatures across the state. Incidence rates rose more rapidly with higher temperatures than those in urban counties.

4. Discussion

The impact of temperature extremes on human health has been studied extensively, though most epidemiological studies to date have focused on the relationship between temperature and *mortality*. These studies reveal a curvilinear relationship that peaks at the high and low ends of the temperature spectrum (Basu and Samet, 2002; Kovats and Hajat, 2008; Basu, 2009; Gosling et al., 2009). While much attention has been given to individual heat wave events (e.g. Chicago 1995: (Semenza et al., 1996; Kaiser et al., 2007); Europe 2003: (Vandentorren et al., 2004; Garssen et al., 2005; Fouillet et al., 2006)), some recent studies have utilized time-series and case-crossover analysis methods to estimate the effects of temperature over broader time intervals and temperature ranges (Zanobetti and Schwartz, 2008; Anderson and Bell, 2009). Studies relating temperature to morbidity are less common and have thus far tended to focus on hospital admissions rather than emergency department visits, and thus may capture only the most severe non-fatal outcomes. Important contrasts have been noted when comparing temperature–mortality and temperature–morbidity associations, which makes examining emergency department visits a vital contribution to our understanding of the total public health impact of heat waves and high ambient temperatures (Kovats et al., 2004; Linares and Diaz, 2008). For example, while many temperature–mortality studies have focused on the elderly as a vulnerable population, the results from this study highlight young adults and the working age population as having the highest emergency department visit rates and steepest temperature-emergency department visit dose–response patterns. Although activities preceding the emergency department visit are not systematically recorded in the NC emergency department surveillance data system, descriptive analysis of case reports that included such information suggest that increased outdoor exposure, as a result of occupational and recreational activities, likely explains these high rates (Rhea et al., 2011). Moreover, while previous studies have emphasized high mortality rates in urban areas due to factors such as the urban heat island and lower socioeconomic conditions, the results of this work on morbidity and previous work on heat-related mortality in North Carolina (Mirabelli and Richardson, 2005), suggest that vulnerability to heat stress may be greatest in rural areas. Future work should address the reasons behind this discrepancy; possible differences include the age and thermal efficiency of housing stock; air conditioning prevalence; local meteorological, topographical, and geological conditions; land use; occupational and recreational behaviors; and other socioeconomic factors. These factors may also explain some of the regional differences in both the rates and the heat-morbidity associations found in our study. For example, we speculate that air conditioning prevalence may be lower in the Coastal Plains and Mountain regions because those areas typically experience fewer extreme temperature days; thus when extreme heat conditions occur, residents in those areas may be more vulnerable.

While some studies have examined the impact of temperature on the occurrence of hospital admissions (Green et al., 2009) and emergency medical service dispatches (Weisskopf et al., 2002; Golden et al., 2008; Bassil et al., 2009) for heat-related illness, few have specifically estimated the effect of temperature on emergency department visits for heat-related illness (Ye et al., 2011). Three notable studies that have examined this association with emergency department visit data only focused on individual heat-wave events rather than using time-series approaches. The total population rate ratios comparing rates during the identified heat-wave periods against those during a reference period (i.e. non-heat wave period) ranged from 2.34 to 12.01 (Rydman et al., 1999; Knowlton et al., 2008; Nitschke et al., 2011). Differences in temperature between the heat wave and non-heat wave periods were not always reported, making it difficult to make direct comparisons with our results. Another approach, the case-crossover design, was recently used in a study examining hospital admissions and found a percent excess risk per 10 °F of 404.0 (95% CI: 309.2, 520.8) for heat stroke (Green et al., 2009).

In the sub-tropical climate of North Carolina, it is not unusual for “high” temperatures to extend well into the Fall and Spring seasons, and even during the Winter season it is possible to have unseasonably warm periods (e.g. days with highs of >21.1 °C (>70 °F) in January and February). Many studies, especially those conducted in cooler climates, restrict their analyses to a “warm” season. Since there were events in every month of the year, we felt it was important to include the full calendar year in our analysis. We found that the rates of emergency department visits for heat-related illness were low in the range of mean temperatures below 15.6 °C (60 °F) but increased exponentially with increases in daily mean temperature over 15.6 °C (60 °F). We assumed *a priori* that the threshold above which the incidence rate slope would inflect would be at a higher temperature, but our inspection of rates in the flexible categorical and restricted cubic spline models supported a knot placement at 15.6 °C (60 °F). This low inflection point may be due to our choice of daily mean temperature as our exposure variable rather than daily maximum temperature. While the absolute change in the incidence rate is most noticeable as temperatures peak (left panel of Fig. 3), the relative change, illustrated in the right panel of Fig. 3, was roughly constant for each interval above the threshold, even when the number of knots in the cubic spline was increased (not shown).

The Raleigh, North Carolina office of the National Weather Service issues excessive *heat advisories* when the heat index is forecast to be 40.6 °C to 42.8 °C (105 °F to 109 °F) for two hours or more, and *excessive heat warnings* when the forecast predicts a heat index of 43.3 °C (110 °F) or greater for any duration of time (National Weather Service Raleigh NC, 2012). A large proportion of the heat-related illness emergency department visits occurred during two periods in August 2007 and June 2008 when excessive heat warnings were issued, providing evidence to support intervention strategies targeting short time periods of acutely high temperatures. Still, an even larger number of heat-related emergency department visits occurred on non-heatwave days dispersed throughout the warm season and at more climatologically normal temperatures. Time-targeted interventions focused exclusively on heat waves and the most extreme temperatures may fail to prevent the large number of heat-related illness emergency department visits that occur during these less deviant temperatures.

The time-series approach used here overcomes one limitation of both heat-wave event studies and case-crossover studies; in practice, both designs can typically examine the effects of heat only over a relatively narrow range of temperatures because the comparison periods are adjacent to the event periods. Heat-wave-centered studies may also yield results that are sensitive to the criteria used to define a heat wave (Tong et al., 2010). Still, several limitations apply to our study. We examine data from only two years, which may not be representative of typical North Carolina climate or emergency department utilization. The surveillance data used is derived from electronic administrative database used at the hospitals for their own billing/reimbursement and

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continuity of care, and therefore have the limitations associated with secondary, administrative data. The counts and rates presented are likely underestimates of the true occurrence of heat-related illness in North Carolina emergency department's as a result of underdiagnosis, either because heat-related illness is listed in the 2nd through 11th diagnosis slots instead of the primary diagnosis, or if emergency department physicians fail to appropriately document or diagnose heat-related illness symptoms (Oberlin et al., 2010). Furthermore, while many other conditions may be exacerbated by temperature, we focus here only on heat-related primary diagnoses in the ICD-9-CM 992 group. For example, while our data includes the diagnosis code for heat syncope (992.1), it would not include diagnoses of other forms of syncope such as ICD-9-CM codes 780.2 (“Syncope and collapse”) or 458.0 (“Orthostatic hypotension”) that may be included on other studies (Galli et al., 2011). Since severe forms of heat-related illness such as heat stroke can be fatal, our data may not capture the most severe cases, who may perish before seeking or obtaining medical care. We use the patient's county of residence to assign temperature exposure to each emergency department visit; exposure misclassification could arise due to: (a) differences between the temperature at the location of the precipitating event and those recorded in the patient's county of residence; or (b) sub-county temperature variation (i.e. micro-climates), including possible “urban heat island” effects. Since temperatures are not evenly distributed geographically within political boundaries like counties, a spatially-smoothed surface distribution of temperature could provide higher-resolution exposure measures; however, in this study, it would be impossible to match patients to finer-resolution exposure measurements because patient location data was restricted to the county level. Air conditioning also plays an important role in the temperature exposures of the population, at least for those who spend time indoors and have the financial means to utilize it (O'Neill, 2003); unfortunately, county-level data on air conditioning ownership and usage are not available. While there is no evidence suggesting a reporting bias, it is possible for the strength of the temperature–heat-related illness associations to be biased upwards if patients are more likely to get a diagnosis of heat-related illness, and for that diagnosis to be in the primary diagnosis slot, during periods of forecasted extreme heat, simply because physicians may be more attuned to the presentation of heat-related illness symptoms at those times.

In order to focus on spatial and demographic heterogeneity in the heat-morbidity associations, we did not investigate the potential delayed effects of temperature or the effects of temperature variability. Previous studies have shown that temperature–mortality effects can be delayed by up to several days; we only examined temperatures on the same day as the emergency department visit (i.e. lag 0). While lagged health effects of cold temperatures can extend up to 25 days; heat effects are generally found to have shorter lags, with the strongest effects typically seen on the same day or within with first few days (Anderson and Bell, 2009; Gasparrini and Armstrong, 2010; Goldberg et al., 2011). Recently developed distributed lag non-linear models provide an estimation method capable of accounting for both the delayed and non-linear nature of the temperature–health associations (Gasparrini et al., 2010). Other methods for non-linear models of lagged exposure effects, such as those developed for the study of exposure-time–response associations (e.g. latency models for occupational exposures and cancer) may also be adaptable to the study of delayed effects of temperature (Richardson and Ashmore, 2005; Richardson, 2008, 2009; Richardson et al., 2011, 2012). Intra- and inter-day temperature variability is another avenue for potential future exploration, since major swings in temperature may challenge human thermoregulatory adaptation (Galli et al., 2011).

5. Conclusion

As public health preparedness plans are created to respond to future extreme weather conditions, attention should be paid to the impacts on both mortality and morbidity. This study demonstrates the major incidence peaks associated with heat waves but also the fact that in North Carolina's humid sub-tropical climate, heat-related illness frequently occurs during non-heat wave periods. While forecast-triggered heat health warning systems with appropriate public health education messages are imperative for mitigating the effects of heat waves (Hajat et al., 2010), structural and policy changes in areas such as urban planning, occupational health, and recreation/athletics are also needed to prevent heat-related illness.

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Human subjects

This research project was approved as exempted research by the University of North Carolina at Chapel Hill Institutional Review Board.

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