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Heat-related morbidity and mortality in New England: Evidence for local policy

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ABSTRACT

Background: Heat-related morbidity and mortality is a recognized public health concern. However, public health officials need to base policy decisions on local evidence, which is often lacking for smaller communities.
Objectives: To evaluate the association between maximum daily heat index (HI) and morbidity and mortality in 15 New England communities (combined population: 2.7 million) in order to provide actionable evidence for local officials.
Methods: We applied overdispersed Poisson nonlinear distributed lag models to evaluate the association between HI and daily (May-September) emergency department (ED) admissions and deaths in each of 15 study sites in New Hampshire, Maine, and Rhode Island, controlling for time trends, day of week, and federal holidays. Site-specific estimates were meta-analyzed to provide regional estimates.
Results: Associations (sometimes non-linear) were observed between HI and each health outcome. For example, a day with a HI of 95°F vs. 75°F was associated with a cumulative 7.5% (95% confidence interval [CI]: 6.5%, 8.5%) and 5.1% (95% CI: 0.2%, 10.3%) higher rate of all-cause ED visits and deaths, respectively, with some evidence of regional heterogeneity. We estimate that in the study area, days with a HI≥95°F were associated with an annual average of 784 (95% CI: 658, 908) excess ED visits and 22 (95% CI: 3, 39) excess deaths.
Conclusions: Our results suggest the presence of adverse health impacts associated with HI below the current local guideline criteria of HI≥100°F used to issue heat advisories. We hypothesize that lowering this threshold may lead to substantially reduced heat-related morbidity and mortality in the study area.

1. Introduction

There is a well-established relationship between warm ambient temperatures (i.e., "heat") and higher risk of mortality in many parts of the world, with excess risk of death observed during periods of both moderate and extreme heat (Anderson and Bell, 2011; Basu, 2009; Bobb et al., 2014b; Curriero et al., 2002; Gasparrini et al., 2015b; Guo et al., 2014; Lee et al., 2014; Nordio et al., 2015). Recent evidence suggests that while the relative risk for death is greatest in association with extreme heat events (i.e., heat waves), the absolute number of deaths attributable to more moderate warm temperatures can be much larger than the number of deaths attributable to extreme heat (Gasparrini et al., 2015b). The association between heat and risk of non-fatal health outcomes as reflected by hospital or emergency department (ED) admissions has been less thoroughly studied, but the current evidence suggests that both extreme and moderate heat are associated with substantial morbidity as well (Basu et al., 2012; Bobb et al., 2014a; Green et al., 2010; Gronlund et al., 2014, 2016; Kingsley et al., 2016; Knowlton et al., 2009).

Given the abundant evidence linking extreme heat to morbidity and mortality, many communities in the US and Europe have implemented heat communication plans, warning systems and/or heat response plans aimed at reducing the public health burden of future events (Bittner et al., 2014; White-Newsome et al., 2014). In the US, most communities rely on the National Weather Service (NWS) to provide primary communication about unsafe levels of heat to officials and the public. Moreover, public health communication and response plans are often triggered only after the NWS issues a heat advisory or warning.

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The thresholds at which heat advisories and warnings are issued are the same across most of the US Northeast, Ohio, and West Virginia. Specifically, local NWS field offices in this broad region typically issue heat advisories when the heat index (HI) is forecast to be between 100°F and 104°F for 2 or more hours, and excessive heat warnings are issued when the HI is forecast to be ≥105°F. HI combines temperature and humidity to provide a measure of thermal comfort (Anderson et al., 2013) or "how hot it really feels when relative humidity is factored in with the actual air temperature" (NWS, 2017).

Prior work highlights that the shape and magnitude of the exposure-response curve relating temperature to health outcomes can vary considerably by geographic location, local climate, population and housing characteristics, and a number of area-level factors (Curriero et al., 2002; Gasparrini et al., 2015b; Guo et al., 2014; Klein Rosenthal et al., 2014; Nordio et al., 2015; Reid et al., 2009). Given this evidence of geographic variability, some jurisdictions have adopted heat advisory and warning criteria based on local conditions (e.g. Philadelphia (Ebi et al., 2004)) or have conducted local evaluations of the heat-health relationship (e.g. New York City (Metzger et al., 2010)). In the case of New York City, the NWS changed the criteria for issuing local heat advisories in response to local evidence such that the current criteria for New York City is that a heat advisory is issued when the HI is forecast to exceed 95°F for two or more days or to exceed 100°F for any length of time; the criteria for issuing excessive heat warnings was left unchanged.

Given the clear importance of such local information, public health and emergency preparedness officials need to develop risk communication strategies, warning systems, and/or heat response plans based on evidence of adverse health effects in the local population. While generating and acting on local evidence is often possible in larger metropolitan areas, smaller cities and towns typically do not individually have sufficient data or other resources needed to obtain the necessary evidence to directly support policy changes. Moreover, the populations of these smaller communities are typically underrepresented or excluded in large analyses spanning broader geographic areas (Anderson and Bell, 2011; Basu et al., 2012; Bobb et al., 2014a, 2014b; Curriero et al., 2002; Gronlund et al., 2014).

Accordingly, the aim of this study was to assess heat-related morbidity and mortality in 15 communities across three New England states (Maine, New Hampshire, and Rhode Island) in order to provide actionable evidence to local forecast, public health, and emergency preparedness officials in the study area. New England is a region in the Northeast US that consists of 6 states with a combined population of approximately 14.4 million residents; this analysis leverages data from population centers in three of those states (Fig. 1). The Northeast US is particularly interesting in this regard due to the number of smaller cities and towns with distinct population centers surrounded by undeveloped land. Specifically, the population density of New England is higher than that of the US as a whole (US Census Bureau, 2014), with most New England residents living along a near continuum of coastal urban centers and smaller towns. In addition, evidence suggests that populations in the Northeast may be simultaneously more susceptible to heat-related mortality (Anderson and Bell, 2011; Nordio et al., 2015) and poised to experience some of the biggest increases in summer-time temperatures and temperature-related mortality in the US due to projected climate change (Schwartz et al., 2015). Specifically, we sought to: 1) estimate the association between maximum daily HI and rates of emergency department (ED) visits and deaths in these communities, 2) quantify the public health burden associated with excess heat across the study area, and 3) assess how NWS heat advisories or excessive heat warnings might be modified to better protect the public's health.

2. Methods

Daily counts of ED visits and deaths for May through September of each year were extracted from hospital discharge and vital statistics databases in Rhode Island, New Hampshire, and Maine. Specifically, we obtained from the Rhode Island Department of Health individual-level data on all ED admissions between 2005 and 2012 to Rhode Island hospitals, excluding the Veterans Affairs Hospital and psychiatric hospitals, and data on all deaths in the state from 1999 to 2011. In New Hampshire, data on ED admissions for any cause from all hospitals excluding Veterans Affairs hospitals and data on all-cause deaths were available for 2000–2009 from the New Hampshire Department of Health and Human Services. In Maine, these data were available from 2001 to 2010 from the Maine Department of Health and Human Services. Data available on each ED visit included sex, age, race, admission date, and primary and secondary discharge diagnoses using International Classification of Disease (ICD)-9 codes. Mortality records included information on sex, age, race, date of death, and primary and secondary cause of death using ICD-10 codes. Records of ED admissions and deaths included information on the location of residence: census tract of residence in Rhode Island and town of residence in New Hampshire and Maine. Each partner institution determined that this analysis did not require approval by local institutional review boards.

We obtained hourly data on ambient temperature and relative humidity for 15 first-order weather stations (Supplemental Table 1) from the National Oceanic and Atmospheric Administration's (NOAA) Integrated Surface Database (NOAA, 2014). These stations were chosen for being in close proximity to population centers and having nearly complete hourly data on temperature and relative humidity over the entire time period. We calculated hourly HI as a function of temperature and relative humidity using the approach used by the NWS (NWS, 2016) and described in detail in the Supplemental Material. Maximum daily HI was calculated for each day at each weather station. This method of calculating HI has been shown to correlate well with apparent temperature (Anderson et al., 2013) and is consistent with the approach currently used by most local NWS offices for determining when to issue heat advisories or excessive heat warnings.

Each study sites consisted of multiple small towns. Sites in New Hampshire and Maine included the population living in towns with any portion within 16.1 km (10 miles) of the selected NWS weather station. In New Hampshire and Maine, some towns were within the radius of more than one weather station. In such cases, to avoid double counting of ED admissions and deaths, the population of that town was assigned to the study area where the majority of ED admissions from that town were admitted (New Hampshire) or to the weather station nearest to the town centroid (Maine). The entire state of Rhode Island was considered as a single site given the small geographic extent and limited topographical variation across the state. The location of study sites is shown in Fig. 1, with additional details provided in the Supplemental Material. We obtained population estimates for each study site from the 2010 US Census (US Census Bureau, 2014).

Our primary analyses focused on all-cause ED admissions or deaths, including external injury. We additionally defined "heat-related" ED admissions as those with a primary or secondary diagnosis of ICD-9 992 (effects of heat and light), E900 (accident caused by excessive heat), or 276.5 (volume depletion disorder, including dehydration and hypovolemia) or a primary diagnosis of ICD-9 580–589 (nephritis, nephrotic syndrome, and nephrosis). This represents a composite outcome, which groups multiple conditions that have been previously shown to be strongly associated with excess heat (Basu et al., 2012; Bobb et al., 2014a; Gronlund et al., 2014; Kingsley et al., 2016; Knowlton et al., 2009). We additionally identified ED admissions with a primary diagnosis of cardiovascular disease, respiratory disease, renal disease, or asthma (Supplemental Table 3).

We used a two-stage analytic approach to estimate the association between HI and ED admissions or deaths across the region. In the first stage, we used over-dispersed Poisson distributed lag non-linear