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Influence of heat wave definitions to the added effect of heat waves on daily mortality in Nanjing, China

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HIGHLIGHTS

- Significant added effects of heat waves on cause-specific mortality were found.
- Heat wave definitions had considerable impacts on these added effects.
- Modifying effect of age, gender and education was found under different definitions.

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ABSTRACT

Background: Few studies have explored the added effect of heat waves, especially in China. Moreover, no prior studies have assessed whether the choice of heat wave definitions affected this added effect. This study compared the associations between heat waves defined by different heat wave definitions (HWs) and cause-specific mortality in warm season in Nanjing, China.
Methods: A distributed lag model was applied to evaluate the differences in daily mortality during heat-wave days (defined using 15 HWs) compared with non-heat-wave days in Nanjing, during 2007 to 2013. For different HWs, model fits were examined by the Akaike Information Criterion for quasi-Poisson and effects were compared by stratified analysis and bootstrapping. In addition, we explored the effect modifications by individual characteristics under different HWs.
Results: Different HWs resulted in considerable differences in associations between heat waves and mortality. Heat waves defined as ≥4 consecutive days with daily average temperature >98th percentile had the best model fit and were associated with an increase of 24.6% (95% CI: 15.6%, 34.3%) total mortality, 46.9% (95% CI: 33.0%, 62.3%) cardiovascular mortality, 32.0% (95% CI: 8.5%, 60.5%) respiratory mortality, 51.3% (95% CI: 23.4%, 85.6%) stroke mortality, 63.4% (95% CI: 41.5%, 88.8%) ischemic heart disease mortality, and 47.6% (95% CI: 14.5%, 90.3%) chronic obstructive pulmonary disease mortality at lag day 2. Under different HWs, added effects of heat waves on mortality were higher for females versus males, the elderly versus young residents, and people with low education versus those with high education. Results were less sensitive to the inclusion of air pollutants.
Conclusions: Heat wave definition plays a critical role in the relationship between heat waves and mortality. Selecting an appropriate definition of heat waves is therefore important to design local heat warning systems and to reduce the burden of disease during heat waves.

1. Introduction

Epidemiological studies have found consistent effect of heat waves on mortality across various countries (Anderson and Bell, 2011; Bi et al., 2011; Conti et al., 2005; D'Ippoliti et al., 2010; Huang et al., 2010; Son et al., 2012). Under a changing climate, higher mortality risks from heat waves are expected since the intensity, frequency, and duration of heat waves may increase in the future (Meehl and Tebaldi, 2004; Wu et al., 2014). The health effect of heat stress during heat waves can be divided into two parts: (1) the "main effect", which is related to the independent effect of the high temperature, and (2) the "added effect" due to heat waves (Gasparrini and Armstrong, 2011; Hajat et al., 2006). However, few previous studies of heat waves and mortality have assessed whether the "added effect" existed (Zeng et al., 2014), ignoring the independent effect of high temperature in time-series or case-crossover methods (Kent et al., 2014; Tian et al., 2013; Tong et al., 2012).

There is no single, universal definition of heat waves. In general, heat wave definitions (HWs) differ in (1) the metric of temperature

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(e.g., daily average or daily maximum), (2) the threshold of temperature (e.g., a relative threshold or an absolute threshold), and (3) the duration of a heat wave (Smith et al., 2013). Previous heat-related epidemiological studies generally applied several heat wave definitions as sensitivity analyses. However, recent studies in Australia and the United States showed that the diversity of heat wave definitions resulted in substantial differences in mortality risk estimates (Hajat et al., 2010; Kent et al., 2014; Tong et al., 2010; Zhang et al., 2012), leading to confusions in determining the most appropriate definition for heat wave warning systems. Moreover, heat wave definitions can also have a large impact on heat wave mortality projections. A recent study conducted in the eastern United States found that heat wave definitions accounted for 22.2% of the uncertainty for mortality risks during future heat waves (Wu et al., 2014).

Studies have shown that the added effects of heat waves on mortality varied greatly by location (Anderson and Bell, 2011; Son et al., 2012; Tong et al., 2014), which might be due to differences in geography, climate, housing, and populations among different regions. Thus, research in different regions is crucial for designing local heat wave warning systems to reduce heat-related adverse health effects and to prepare residents for future heat waves. Although people in developing countries are more vulnerable to heat-related mortality risks (McMichael et al., 2008), most studies have investigated the impacts of heat waves on mortality in developed countries. Relatively few studies have examined the added effect of heat waves on mortality in China (Bai et al., 2014; Zeng et al., 2014). Moreover, no previous studies have investigated the influence of various heat wave definitions on the added effect of heat waves in China.

Additionally, the impact of heat waves on mortality can be modified by individual characteristics, such as age, gender, education, and death location (Breitner et al., 2014; Son et al., 2012; Zeng et al., 2014). A recent study in Beijing found that the duration of heat waves presented different coronary heart disease mortality risks in different age groups (Tian et al., 2013). Thus, different heat wave definitions based on duration may have an influence on the modifying effect of individual characteristics on heat wave mortality estimates.

In this study, we aimed to examine the influence of different heat wave definitions to the added effects of heat waves on daily mortality, and explore whether effect modifications by individual characteristics changed under different heat wave definitions in Nanjing, China.

2. Materials and methods

Nanjing, the capital of Jiangsu Province in China, is located in the Yangtze River Delta and held a population of 8.0 million by the end of 2010. Our study population includes all permanent residents living in the city. Nanjing has a subtropical humid climate with an annual average temperature of 16.2 °C in 2010. Known as one of the 'three furnace cities' in China, Nanjing always experiences hot summers. The highest ever maximum temperature in Nanjing was 43 °C on July 13, 1934.

2.1. Data collection

Daily mortality data from January 1, 2007 to December 31, 2013 were collected from the Jiangsu Provincial Center for Disease Prevention and Control. Daily mortality counts were classified into the following categories using the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10): total (non-accidental) deaths (codes A00–R99), cardiovascular deaths (codes I00–I99), respiratory deaths (codes J00–J99), and deaths attributed to stroke disease (codes I60–I69), ischemic heart diseases (IHDs, codes I20–I25), and chronic obstructive pulmonary disease (COPD, codes J40–J47). We also investigated the effect of heat wave on total mortality modified by gender (male and female), age (0–64, 65–74, and ≥75 years old), education level (low: illiterate or primary school; high: high school or college), and death location (in hospital: ward or emergency room; out hospital: home or way to the hospital).

The daily average and maximum temperatures in Nanjing were provided by the China Meteorological Data Sharing Service System. Weather data were collected from a national principal weather station (Nanjing station). There were no missing data for the meteorological data. To adjust potential confounding effects of air pollutants, we obtained daily air pollution data for 2007–2013 from the nine monitoring stations of the Nanjing Environmental Monitoring Center. In accordance with China's air-quality monitoring standards, these monitoring stations were situated to avoid direct interference from vehicle exhaust and other sources. Monitors were set up approximately 3.5 m above ground level to measure daily air pollution levels. Daily mean concentrations of particulate matter with an aerodynamic diameter of 10 μm or less (PM_{10}), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) from nine stations were then averaged to derive the concentrations for Nanjing by simple mean. For all monitoring stations, only 2.0% data for SO_2, 1.3% data for NO_2, and 1.5% data for PM_{10} were missing for the whole period of analysis. There were no missing data for more than 2 consecutive days in all stations. The missing data in each station were then interpolated from data on the two adjacent days.

As in previous studies (Son et al., 2012; Tian et al., 2013; Zeng et al., 2014), the study period was restricted to the warm season (May–September) when heat waves generally occurred in Nanjing.

2.2. Heat wave definitions

Based on the differences of definitions in metric, threshold, and duration, fifteen HWs were identified from previous heat wave literature (Anderson and Bell, 2011; Peng et al., 2011; Son et al., 2012; Tian et al., 2013) and the definition used by the Chinese Meteorological Administration (Huang et al., 2010). These heat wave definitions are commonly used in heat wave studies and have been found to be significantly associated with daily mortality in different countries. Descriptions of these 15 HWs were shown in Table 1. Twelve HWs (HW01–HW12) were developed combining relative mean temperature thresholds (90th, 95th, 98th, and 99th) with duration of more than 2, 3, and 4 days. Daily maximum temperature with relative thresholds (HW13, 95th; HW14, 81st and 97.5th) or an absolute threshold (HW15, 35 °C) was also used to define heat waves.

2.3. Statistical analysis

In this study, we aimed to examine the added effect of heat waves on daily mortality. As daily mortality counts generally follow an overdispersed Poisson distribution, we used a distributed lag model (DLM) with a quasi-Poisson regression to evaluate the health effect of heat waves while adjusting for the effect of temperature at different lag days (Gasparrini, 2011). We controlled for long-term and seasonal time trends, relative humidity, daily average temperature, and day of the week. The DLM used the following formula:

$$\begin{aligned}\mathrm{Ln}E(Y_t) = \alpha + \beta HW_t + \varepsilon Cb.temp_l + ns(time) + ns(humidity) \\ + \delta DOW\end{aligned} \tag{1}$$

where $E(Y_t)$ is the expected daily mortality count at day t with $\mathrm{Var}(Y_t) = \varphi E(Y_t)$; φ is the overdispersion parameter; HW_t is a binary variable, which equals to 1 for heat-wave days and 0 for non-heat-wave days; $Cb.temp_l$ is a matrix obtained by applying to temperatures; l refers to the maximum lag days; β, ε, and δ are the coefficients for *HW* and *DOW*; the natural cubic spline function *ns*() captures the non-linear relationships between the covariates (time and relative humidity) and mortality; and *DOW* is the dummy variable for day of the week. The DLM was fitted using a quadratic spline with 2 degrees of freedom per warm season (2 equally spaced knots) for temperature and a natural spline with 3 degrees of freedom for the lag (knots at