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Decompose the association between heatwave and mortality: Which type of heatwave is more detrimental?

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ABSTRACT

Background: Heatwaves is the most hazardous natural disaster in Australia and its health impacts need to be well unveiled, but how to properly define a heatwave is still debatable. This study aimed to identify which type of heatwave is more detrimental to health and to elucidate which temperature indicator is more suitable for heatwave definition and early warning.

Methods: We categorized temperature into extremely-hot and not-extremely-hot, and extremely-hot temperature refers to temperature at least ≥96th percentile of the monthly temperature distribution, and accordingly, heatwaves were categorized into four types: 1) Type I: extremely-hot days followed by extremely-hot nights (HW_{both}); 2) Type II: extremely-hot days followed by not-extremely-hot nights (HW_{day}); 3) Type III: not-extremely-hot days followed by extremely-hot nights (HW_{night}); and 4) Type IV: not-extremely-hot days followed by not-extremely-hot nights (HW_{warm}). A Poisson regression allowing for over-dispersion was used to examine the relationship between different types of heatwaves and mortality in Sydney, Melbourne and Brisbane using the data from 1988 to 2011.

Results: Mortality in Brisbane increased significantly during HW_{both} and HW_{warm}, and mortality in Melbourne increased significantly during HW_{both} and HW_{day}. For Sydney, HW_{both}, HW_{warm}, and HW_{day} were all associated with mortality increase, although no appreciable difference in the magnitudes of mortality increase among these three heatwave types was observed. HW_{night} was not associated with any significant mortality increase in these cities. Mean temperature is the best temperature indicator for heatwaves in Brisbane and maximum temperature is the best temperature indicator for heatwaves in Melbourne.

Conclusions: Extremely-hot days rather than extremely-hot nights played a critical role in heatwave-related mortality. City-specific heatwave early warning may be optimal for Australia.

1. Introduction

Climate change is unequivocal, and its impacts on human health have become a big concern of policy makers, scientists and the public (McMichael, 2013). Effectively tackling climate change could be the greatest opportunity to protect public health in the 21st century (Watts et al., 2015). A symbolic parameter of climate change is the increasing frequency, intensity and duration of heatwaves (Meehl and Tebaldi, 2004). Australia has experienced some record-breaking summers in the past decade (ABoM, 2014) and heatwaves were associated with significant increases in mortality in Australia (Tong et al., 2014b).

Although the health impacts of heatwaves have been extensively researched (Basu and Malig, 2011; Basu and Samet, 2002; Li et al., 2015; Xu et al., 2016; Ye et al., 2012), no universal heatwave definition is available so far. Heatwave definitions used in prior research differ in three aspects, i.e., temperature indicator, intensity and duration (Xu et al., 2016). Regarding temperature indicator, some studies used maximum temperature as the indicator because it is a good proxy of daytime temperature and people are more exposed to daytime temperature because they have more activities during daytime (Basagaña et al., 2011; Nitschke et al., 2011; Tong et al., 2010a; Wang et al., 2012; Xu et al., 2013). Some studies used mean temperature as the indicator because it better represents the temperature exposure during both daytime and night time (Anderson and Bell, 2011; Gasparrini and Armstrong, 2011; Hajat et al., 2002). Laaidi et al. (2012) found that, in urban areas of Paris, exposure to high night time minimum temperature was associated with a significant increase of deaths among elderly people during a heatwave, and they observed that night time temperature was more important than daytime temperature for elderly people. High nocturnal minimum temperature during heatwave periods in urban areas due to urban heat island effect makes people residing in urban areas hard to release from the daytime heat (Smith et al., 2011),

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and thus may cause/trigger diseases, particularly in vulnerable groups such as elderly people (Heaviside et al., 2016).

For wisely allocating limited health resources to protect the public from the adverse health impacts of heatwaves and to develop effective heatwave early warning systems, it is of great importance to understand whether daytime heat or night time heat is more detrimental to health. We defined "extremely-hot" as temperature at least ≥96th percentile of the monthly temperature distribution and decomposed heatwaves by daytime heat and night time heat, and accordingly, heatwaves can be categorized into four types: 1) Type I: extremely-hot days followed by extremely-hot nights (HW_{both}); 2) Type II: extremely-hot days followed by not-extremely-hot nights (HW_{day}); 3) Type III: not-extremely-hot days followed by extremely-hot nights (HW_{night}); and 4) Type IV: not-extremely-hot days followed by not-extremely-hot nights (HW_{warm}).

The present study used temperature, relative humidity, and mortality data in the three biggest cities of Australia, i.e., Sydney, Melbourne and Brisbane, and the objectives of this study were: 1) to understand which types of heatwave cause/trigger more deaths? 2) to examine whether extremely-hot days followed by not-extremely-hot nights cause/trigger deaths? and 3) to explore whether extremely-hot nights following not-extremely-hot days is detrimental to health.

2. Materials and methods

2.1. Data collection

Sydney, Melbourne and Brisbane include almost half of Australian's population (ABS, 2012). Data on daily non-accidental deaths for these three cities from 1st January 1988 to 31st December 2011 were collected from the Australian Bureau of Statistics. Data on daily relative humidity, maximum and minimum temperatures for the same time period were obtained from Australian Bureau of Meteorology. Daily mean temperature was calculated by averaging daily maximum and minimum temperatures. 1st November to 31st March (next year) were chosen as the study period as heatwaves primarily occur in summer (Tong et al., 2015). The Queensland University of Technology Human Research Ethics Committee approved the ethics application. All patient records were de-identified prior to analysis.

2.2. Data analysis

2.2.1. Heatwave definitions and categories

Our previous work found that a slight change in heatwave definition may have a significant impact on health effect estimates (Tong et al., 2010b). Thus, we adopted a range of heatwave definitions to make the results robust. There are two steps in producing the "heatwave type" variables. Step one: three temperature measures (maximum, mean and minimum temperatures) were used as the temperature indicator. Three percentiles (96th, 97th, and 98th) were used as the intensity, and three durations (2, 3 and 4 days) were used as the duration. Therefore, for each temperature indicator, nine heatwave definitions were created (e.g., maximum temperature ≥96th percentile of the monthly distribution of maximum temperature for ≥2 days). A binary heatwave variable was used for each day, with "1" representing heatwave day and "0" representing non-heatwave day. The three percentiles were chosen according to the study of Anderson et al. and our previous work (Anderson and Bell, 2009; Tong et al., 2014a), and we chose multiple temperature percentiles and durations for heatwave to make sure that the result produced from this study is robust as our prior work showed that the change in heatwave definition may affect the effect estimation (Tong et al., 2010b). Step two: we created the "heatwave type" variables based on the heatwave variables created in Step one. For example, for the "≥96th percentile and ≥2 days" heatwaves, there are three separate heatwave variables including "maximum temperature ≥96th percentile of the monthly distribution of maximum temperature for ≥2 days (HW_{max})", "mean temperature ≥96th percentile of the monthly distribution of mean temperature for ≥2 days (HW_{mean})", and "minimum temperature ≥96th percentile of the monthly distribution of minimum temperature for ≥2 days (HW_{min})". There are some overlapping days of these HW_{max}, HW_{mean} and HW_{min}. When $HW_{max}=1$, $HW_{mean}=1$, and $HW_{min}=1$ (i.e., the overlapping days), we created a "heatwave type" variable called "HW_{both}" which refers to heatwave days when both daytime and night time are extremely-hot; when $HW_{max}=1$, $HW_{mean}=0$, and $HW_{min}=0$, we created a "heatwave type" variable called "HW_{day}" which refers to heatwave days when daytime is extremely-hot and night time is not extremely-hot and mean temperature is not extremely high; when $HW_{min}=1$, $HW_{mean}=0$, and $HW_{max}=0$, we created a "heatwave type" variable called "HW_{night}" which refers to heatwave days when night time is extremely-hot and daytime is not extremely-hot and mean temperature is not extremely high; when $HW_{mean}=1$, $HW_{max}=0$, and $HW_{min}=0$, we created a "heatwave type" variable called "HW_{warm}" which refers to heatwave days when both daytime and night time are not extremely-hot but mean temperature is extremely high.

2.2.2. Analytical approach

A Poisson generalized linear model allowing for over-dispersion was used to assess the effects of heatwave on mortality. A distributed lag non-linear model was adopted to examine the lag effect (Gasparrini, 2011). The greatest effect amongst lag 0–7 days was chosen to present in the Results section because sensitivity analyses had been done to test different lags and we found the lagged effects of the four types of heatwaves disappeared after one week. For heatwave variable, a natural cubic spline with three degrees of freedom (*df*) was used for the lag dimension. A number of possible confounders, including relative humidity, day of week, long-term trend and seasonality, were controlled for in the model. Natural cubic spline with three *df*s was used for relative humidity, and for long-term trend and with-in season variation (Tong et al., 2015). These *df*s were chosen based on the minimum value of Akaike information criterion (AIC).

3. Results

Table 1 depicts the summary statistics of temperature, relative humidity and deaths in the three cities. The mean values of three temperature measures in Brisbane were the highest amongst three cities, but the maximum values of three temperature measures were the highest in Melbourne, suggesting that Brisbane was warmer than other two cities in average, but Melbourne had more extremely-hot days. The average values of daily deaths in Sydney, Melbourne and Brisbane were 62.4, 54.4, and 24.4, respectively.

Table 2 reveals the relationships between different types of heatwaves and deaths in the three cities. Unsurprisingly, people in the three cities were all vulnerable to extremely-hot days followed by extremely-hot nights (type I heatwave). Brisbane had more type I heatwaves, and Brisbane people (relative risk (RR): 1.255; 95% confidence interval (CI): 1.148, 1.371) were more vulnerable than those in Melbourne (RR: 1.147; 95% CI: 1.076, 1.223) and Sydney (RR: 1.070; 95% CI: 1.004, 1.142) to type I heatwave. As indicated in Table 2, residents in Brisbane were sensitive to type I and type IV heatwaves, but were not sensitive to type II and type III heatwaves, indicating that people in Brisbane were vulnerable to persistent heat in a day, no matter whether it was extreme heat or not. For people in Melbourne, mortality risk increased when daytime was extremely-hot (RR ranging from 1.006 to 1.546), regardless of whether night time was extremely-hot or not. People in Sydney were sensitive to heatwave types I, II, and IV (RR ranging from 1.047 to 1.292). Intriguingly, solely extremely high night time temperature (i.e., type III heatwave) was not associated with any mortality increase for all three cities. Fig. 1 presents the lag structure of the association between heatwave and deaths using the 1st heatwave definition (96th percentile for ≥2 days) (HW_{both}).