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Heatwave and elderly mortality: An evaluation of death burden and health costs considering short-term mortality displacement

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ABSTRACT

Background: A heatwave can be a devastating natural disaster to human health, and elderly people are particularly vulnerable. With the continuing rise in earth's surface temperature alongside the world's aging population, research on the mortality burden of heatwave for the older population remains relatively sparse. The potential magnitude of benefits of averting such deaths may be considerable.
Objectives: This paper examined the short-term mortality displacement (or "harvesting") of heatwave, characterized the heatwave-mortality relationship, and estimated death burden and health costs attributable to heatwave among the elderly in Australia.
Methods: We collected daily data on the temperature and deaths of people aged ≥75 years in the five largest cities of Australia (Sydney, Melbourne, Brisbane, Perth and Adelaide), totaling 368,767 deaths in different periods between 1988 and 2011. A total of 15-tiered heatwave definitions, based on intensity (95th to 99th percentiles of temperature distribution) and duration (two or more consecutive days), were used to quantify heatwave effects, using time-series regression and random-effects meta-analysis. We calculated attributable deaths for each city and by different types of heatwave. Potential economic benefits in monetary terms were also estimated, considering that heat-related deaths are avoidable.
Results: Among the Australian elderly population, we found significant associations between heatwave and deaths, with raised mortality immediately in the first few days followed by lower-than-expected mortality. In general, heatwave was associated with an average death increase of 28% (95% confidence interval: 15% to 42%), and greater increases were mostly observed for more intense heatwaves across multiple megacities. During the study period, there were dozens to hundreds of deaths attributable to heatwave for each city, equating to an economic loss of several million Australian dollars every year. Although the estimated attributable deaths varied by heatwave intensity and duration, the pattern was not consistent across cities.
Conclusions: Heatwave caused harvesting effects on mortality in the elderly population of Australia, and contributed to a substantial amount of death burden and indirect financial costs. To lessen the health impacts of heatwave in the affected regions, effective heatwave early warning systems and interventions targeted at the elderly population could be beneficial, both now and in the future.

1. Introduction

Heatwaves have adverse impacts on human health and well-being historically, making it one of the most hazardous natural disasters in many regions of the world (Coates et al., 2014; Mora et al., 2017; Forzieri et al., 2017). The well-known 2003 European heatwave is a vivid example that the resulting death toll reached over 70, 000 (Robine et al., 2008). A series of lethal heatwaves has been recorded worldwide, and ongoing climate change will cause more intense, more frequent and longer-lasting heatwaves in the 21st century (Mora et al., 2017; Xu et al., 2016; Meehl and Tebaldi, 2004). Preventing the adverse health consequences of hot weather is now an important subject for public health locally, regionally and globally (Hajat et al., 2010; Guo et al., 2017). Meanwhile, aged people are particularly vulnerable to heat owing to the diminished thermoregulatory ability with age (e.g., reduced sweat gland output, reduced skin blood flow and smaller

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increase in cardiac output), as well as the increased likelihood of living alone, physical inactivity, having chronic disease and taking medications (Kenney and Munce, 2003; Hajat et al., 2010). Given the global warming scenarios, plus the world's population aging that may amplify heat-related mortality (Li et al., 2016), investigating the health impacts of heatwave on older people is imperative (Guo et al., 2012; Bobb et al., 2014).

In the assessment of heatwave effects, a key issue to be considered is the short-term mortality displacement (or "harvesting"), a phenomenon often noted in many locations suggesting that heat will cause not only the sudden increases in deaths during the first few days but also the subsequent significant decreases in deaths (i.e., lower-than-expected mortality) (Qiao et al., 2015; McGregor et al., 2015; Baccini et al., 2013; Hajat et al., 2005; Guo et al., 2014). It is likely that a proportion of deaths are those that have only been brought forward by a few days as a result of the extreme weather, or occur in already frail individuals and with a very short life expectancy (Baccini et al., 2013; Qiao et al., 2015; McGregor et al., 2015). Mortality displacement thus could have great influence on the actual heat-induced burden of death (McGregor et al., 2015), as shown in a European study reporting the reduction of heat impacts by 75% allowing for mortality displacement (Baccini et al., 2013).

However, existing studies of heatwave and mortality focus largely on acute exposure effects and qualitative analysis (e.g., relative risk and percent change) (Tong et al., 2014, 2015; Ma et al., 2015; Anderson and Bell, 2011). A key question for policy makers and stakeholders arises as to how many or to what extent deaths can be attributable to heatwave exposure, and whether it is urgent or cost-effective to develop and implement targeting policies and intervention measures. The answer relies on a reliable estimate of the burden of heatwave on mortality, including taking into account potential harvesting effect and employing more informative health risk assessment indicators, attributable risk and years of life lost for example (Steenland and Armstrong, 2006; Gasparrini et al., 2015; Huang et al., 2012; Xu et al., 2014). While several recent studies have estimated the premature mortality attributable to ambient temperature (Gasparrini et al., 2015; Yang et al., 2016; Heaviside et al., 2016), few have investigated the mortality displacement and provided estimates of attributable burden for heatwave. Also, health costs due to historical heatwave events remain inexplicit so far.

To address these knowledge gaps, we conducted a time-series analysis involving a large ensemble of the Australian elderly from 1988 through 2011. The objectives of this study were to (i) examine the harvesting effects of heatwave in the elderly across Australian cities; (ii) characterize the mortality risk by heatwave intensity and duration; and (iii) estimate the deaths and health costs attributable to heatwave. All analyses were based on 15-tiered definitions of heatwave with increases in its intensity (a measure for mean temperature on heatwave period) and duration (a measure for heatwave's length in days), and advances in modelling heatwave-mortality relationship to adequately account for mortality displacement.

2. Methods

2.1. Data collection

2.1.1. Mortality data

This study was conducted in the five largest cities in Australia (Sydney, Melbourne, Brisbane, Perth and Adelaide), which are home to most of Australian population (Supplementary Fig. 1). These cities are the state capitals of five different states with distinct climate and demographic contexts (Supplementary Fig. 2). Daily death counts were acquired from Australian Bureau of Statistics in different periods between 1988 and 2011. The broad health impacts of heat are known to involve almost the whole disease spectrum (Gasparrini et al., 2012; Kim et al., 2015), so we used all-cause mortality data in order to estimate the overall death burden caused by heatwave. We restricted the study population to the elderly (≥75 years), considering that this group of people is generally at highest likelihood of dying from heat and likely contributes the largest part of heat-associated deaths across the whole age range (Baccini et al., 2013; Yang et al., 2015; Tong et al., 2014, 2015; Ma et al., 2015; Ng et al., 2016; Coates et al., 2014; Chen et al., 2015). In addition, mortality displacement phenomenon is more likely to happen in the older elderly and recent researchers believe it is necessary to push back the definition of old age to 75 years of age in view of progressively aging society and raised average life expectancy (Ouchi et al., 2017).

2.1.2. Exposure data

Daily weather data, including maximum temperature and minimum temperature, were downloaded from Australian Bureau of Meteorology's online database. The location of weather station for each city is shown in the Supplementary Fig. 3. We used the daily mean temperature, averaged values of daily maximum temperature and daily minimum temperature, as the exposure index. This choice is in line with recent burden-of-disease research of temperature and mortality (Gasparrini et al., 2015; Huang et al., 2012), and our previous analyses suggesting mean temperature was a slightly better predictor of mortality compared with maximum or minimum temperature in Australia (Yu et al., 2010; Vaneckova et al., 2011). Additional information such as relative humidity and air pollution measures were collected in a subset of cities and used in sensitivity analyses.

We considered 15-tiered definitions of heatwave to capture and characterize the effects of heatwave. In keeping with previous studies (Tong et al., 2015; Cheng et al., 2016; Anderson and Bell, 2011), a heatwave within a region was defined as daily mean temperature above certain percentile of the temperature distribution that lasts for several days in the warm season (November to March of next year). We set the intensity of heatwave at 95th to 99th percentile of temperature distribution, since our previous analyses showed that heatwave effects on the mortality in Australia started to increase around the 95th percentile and rose alarmingly at the 99th percentile (Tong et al., 2015), and set the duration of heatwave at two to four days in case "zero" heatwave event may happen in most cities. Details on definitions of heatwave and its characteristics are provided in the Web Appendix (Supplementary Table 1).

2.2. Statistical analyses

2.2.1. First-stage: modelling heatwave-mortality association

We performed a standard time-series quasi-Poisson regression analysis in each city (Gasparrini et al., 2015; Guo et al., 2017), to explore the association between heatwave and mortality. Heatwave as the binary independent variable (1 for heatwave days and 0 for non-heatwave days), and daily count of deaths as the dependent variable were included in the distributed lag non-linear model (Gasparrini, 2014). To control for long term trend and seasonality, we included in the model a natural cubic spline with three degrees of freedom per year for time (Anderson and Bell, 2011; Chen et al., 2015). The day of week was controlled for as a categorical variable. Each year's elderly population in log scale were also included in the model as an offset to control for potential confounding effect of demographic shifts over time (Qiao et al., 2015; Tong et al., 2015).

To detect if mortality displacement does exist across cities, we initially used lags up to 21 days (Qiao et al., 2015). When defining heatwave as ≥2 days with temperature ≥ 96th percentile, except for Brisbane, the remaining four cities saw evident mortality displacement that manifested as negative estimates (relative risk) following the positive estimates in the first few days (Supplementary Fig. 4). Noticeably, subjective selection of the lag may result in inaccurate estimation of heatwave impacts; for example, using a few lag days sometimes cannot capture the mortality harvesting effects, and too many days are likely to generate underestimation of heat-related deaths if mortality harvesting