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Review Article

Impact of heatwave on mortality under different heatwave definitions: A systematic review and meta-analysis

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ABSTRACT

Heatwave effects on human health and wellbeing is a great public health concern, especially in the context of climate change. However, no universally consistent heatwave definition is available. A systematic review and meta-analysis was conducted to assess the heatwave definitions used in the literature published up to 1st April 2015 by searching five databases (PubMed, ProQuest, ScienceDirect, Scopus, and Web of Science). Random-effects models were used to pool the effects of heatwave on total and cardiorespiratory mortality by different heatwave definitions. Existing evidence suggests a significant impact of heatwave on mortality, but the magnitude of the effect estimates varies under different heatwave definitions. Heatwave-related mortality risks increased by 4% (using "mean temperatures ≥95th percentile for ≥2 days" as a heatwave definition), 3% (mean temperatures ≥98th percentile for ≥2 days), 7% (mean temperatures ≥99th percentile for ≥2 days) and 16% (mean temperatures ≥97th percentile for ≥5 days). Heatwave intensity plays a relatively more important role than duration in determining heatwave-related deaths. Heatwaves significantly increase mortality across the globe, but the effect estimates vary with the definition of heatwaves. City- or region-specific heat health early warning systems based on identified local heatwave definitions may be optimal for protecting and preventing people from the adverse impacts of future heatwaves.

Contents

Abbreviations: CI, confidence interval; OR, odds ratio; RR, relative risk.

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1. Introduction

Heat is a well-recognized public health hazard (Basu and Samet, 2002; Basu, 2009; Ye et al., 2012). When exposed to heat, the thermoregulation system of human responds to offset the adverse effect of heat. However, once the heat is beyond certain limits, the risk of disease and death increases substantially on the day of exposure or few days after. The health impacts of sustained extreme heat, i.e., heatwaves, have been extensively researched (Kovats et al., 2004; Anderson and Bell, 2009, 2011; D'Ippoliti et al., 2010; Tong et al., 2014b), with some population groups, such as elderly people (D'Ippoliti et al., 2010; Son et al., 2012) and people living in urban areas (Conti et al., 2005; Madrigano et al., 2015), being reported to be particularly vulnerable to heatwave effects. It is projected that the intensity, frequency, duration, and geographic extent of heatwaves will increase as climate change progresses (Meehl and Tebaldi, 2004). Heatwaves will be very likely to pose a greater threat to human health and wellbeing as the world population is ageing (Lutz et al., 2008) and the pace of urbanization is accelerating at the global scale (McMichael, 2013), although heterogeneity in heatwave impact on mortality across different regions may exist (Benmarhnia et al., 2014; Vardoulakis et al., 2014).

Even though a heatwave is generally considered as a meteorological event, it should not be assessed without reference to its human health impacts (Robinson, 2001). Given this fact, it is very hard to reach a widespread consensus on how to define a heatwave as population acclimatization and adaptation is diverse across different regions. Prior research quantifying the health effects of heatwaves used various definitions of a heatwave, most of which adopted a combination of intensity and duration of heat to define a heatwave (Hajat et al., 2006; Anderson and Bell, 2009; Ma et al., 2015). Some studies compared the health impacts of heatwaves (or conducted sensitivity analysis) using different heatwave definitions, and found that even a slight change in the heatwave definition had an apparent effect on the estimated health impacts (Anderson and Bell, 2009; Tong et al., 2010b; Kent et al., 2015). These findings suggest that it is not appropriate to directly compare the findings of different studies assessing the health impacts of heatwaves if they are using different heatwave definitions.

Although the development of an internationally consistent heatwave definition may be unachievable, it is possible to develop an appropriate heatwave definition at a local or regional level. Several efforts have been made so far in Brisbane, Australia, and several mega-cities of China (Tong et al., 2014a; Gao et al., 2015). It is important to have a comprehensive understanding of heatwave definitions used in previous studies for the development of the guidelines to define an appropriate and consistent definition and to facilitate a comparison across different studies. In this paper, we systematically reviewed existing epidemiological evidence concerning the impacts of heatwaves on mortality, evaluated different heatwave definitions used in the existing literature, and pooled the mortality risks associated with heatwaves under various heatwave definitions.

2. Materials and methods

2.1. Data sources

Databases including PubMed, ProQuest, ScienceDirect, Scopus, and Web of Science were used to retrieve papers published between 1st January 2000 and 1st April 2015 regarding heatwaves and mortality. We manually checked the references of the identified papers to make sure all relevant papers were included.

2.2. Inclusion criteria

We used the following U.S. National Library of Medicine's Medical Subject Headings (MeSH terms) and keywords in the primary search: "climate change", "temperature", "heat wave", "heatwave", "death" and "mortality". Eligibility included any empirical studies written in English which used original data and appropriate effect estimates (e.g., relative risk (RR), odds ratio (OR), percentage change in mortality or excess mortality following heatwaves); where there was a clear definition of heatwave and heatwave was a main exposure of interest; and where all-cause mortality was analysed as a major outcome. For those studies using the same dataset and statistical approaches, we chose only one of them in the review. For example, Anderson et al. (Anderson and Bell, 2009) and Barnett et al. (Barnett et al., 2012) used the same US dataset, and we excluded the study of Barnett et al. in the review.

2.3. Meta-analysis

Mortality risks associated with heatwave, including total, cardiovascular, and respiratory mortality, were extracted from the identified papers. For those subgroups with two or more studies using the same heatwave definition, we pooled the relative risks (RRs) using meta-analysis (Table 1). Several studies were excluded from the meta-analysis either because they examined the main (i.e., the independent effects of daily ambient temperature) and added (i.e., the effect of persistent periods of heat) effects of heatwaves (Gasparrini and Armstrong, 2011; Zeng et al., 2014), or because the effect estimates it supplied were not suitable to be pooled (Williams et al., 2012). We also did not pool the added effect of heatwaves on mortality as the studies used different heatwave definitions (Gasparrini and Armstrong, 2011; Zeng et al., 2014). Another two studies (Chen et al., 2015; Kent et al., 2015) were excluded from the analysis because the temperature intensity metric they used were different from others. For example, other studies used mean temperature ≥95th percentile, while these two studies used >95th percentile. The RRs of two studies using the same heatwave definitions were not quantitatively combined as they used the same data but focused on different age groups (Tong et al., 2010a; Wang et al., 2012). Random-effects models were mainly used for the meta-analysis, and fixed-effects models were only used when no heterogeneity was detected. Heterogeneity was assessed by Cochran Q ($P < 0.10$ was considered statistically significant) and Higgins I^2 statistics ($I^2 > 40\%$ and $I^2 > 75\%$ were considered to indicate moderate and high heterogeneity, respectively). STATA version 12.0 (StataCorp, College Station, TX) was used to conduct the meta-analysis.

3. Results

3.1. Descriptive characteristics of identified studies

1608 papers were identified in the initial search. According to the inclusion criteria, 60 studies were included in the final review (Fig. 1). Among the 60 studies, 32 were conducted in Europe (Huynen et al., 2001; Hajat et al., 2002,2006; Kovats et al., 2004,2006; Vandentorren et al., 2004; Conti et al., 2005,2007; Dear et al., 2005; Grize et al., 2005; Johnson et al., 2005; Michelozzi et al., 2005; Nogueira et al., 2005; Pirard et al., 2005; Simón et al., 2005; Borrell et al., 2006; Le Tertre et al., 2006; Hutter et al., 2007; Rey et al., 2007; Fouillet et al., 2008; Revich and Shaposhnikov, 2008; Hertel et al., 2009; Schifano et al., 2009; D'Ippoliti et al., 2010; Basagaña et al., 2011; Green et al., 2012; Laaidi et al., 2012; Xu et al., 2013; Analitis et al., 2014; Miron et al., 2015; Rocklöv et al., 2014; Astrom et al., 2015), nine in the US (Kaiser et al., 2007; Yip et al., 2008; Anderson and Bell, 2009,2011; Ostro et al., 2009; Gasparrini and Armstrong, 2011; Kent et al., 2015; Zhang et al., 2015), eight in Australia (Tong et al., 2010a,2010b; Nitschke et al., 2011; Schaffer et al., 2012; Wang et al., 2012; Williams et al., 2012; Tong et al., 2014a,2014b), seven in China (Huang et al., 2010; Lan et al., 2012; Yang et al., 2013; Sun et al., 2014; Zeng et al.,