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What is cold-related mortality? A multi-disciplinary perspective to inform climate change impact assessments

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ABSTRACT

Background: There is a growing discussion regarding the mortality burdens of hot and cold weather and how the balance between these may alter as a result of climate change. Net effects of climate change are often presented, and in some settings these may suggest that reductions in cold-related mortality will outweigh increases in heat-related mortality. However, key to these discussions is that the magnitude of temperature-related mortality is wholly sensitive to the placement of the temperature threshold above or below which effects are modelled. For cold exposure especially, where threshold effects are often ill-defined, choices in threshold placement have varied widely between published studies, even within the same location. Despite this, there is little discussion around appropriate threshold selection and whether reported associations reflect true causal relationships – i.e. whether all deaths occurring below a given temperature threshold can be regarded as cold-related and are therefore likely to decrease as climate warms.

Objectives: Our objectives are to initiate a discussion around the importance of threshold placement and examine evidence for causality across the full range of temperatures used to quantify cold-related mortality. We examine whether understanding causal mechanisms can inform threshold selection, the interpretation of current and future cold-related health burdens and their use in policy formation.

Methods: Using Greater London data as an example, we first illustrate the sensitivity of cold related mortality to threshold selection. Using the Bradford Hill criteria as a framework, we then integrate knowledge and evidence from multiple disciplines and areas- including animal and human physiology, epidemiology, biomarker studies and population level studies. This allows for discussion of several possible direct and indirect causal mechanisms operating across the range of 'cold' temperatures and lag periods used in health impact studies, and whether this in turn can inform appropriate threshold placement.

Results: Evidence from a range of disciplines appears to support a causal relationship for cold across a range of temperatures and lag periods, although there is more consistent evidence for a causal effect at more extreme temperatures. It is plausible that 'direct' mechanisms for cold mortality are likely to occur at lower temperatures and 'indirect' mechanisms (e.g. via increased spread of infection) may occur at milder temperatures.

Conclusions: Separating the effects of 'extreme' and 'moderate' cold (e.g. temperatures between approximately 8–9 °C and 18 °C in the UK) could help the interpretation of studies quoting attributable mortality burdens. However there remains the general dilemma of whether it is better to use a lower cold threshold below which we are more certain of a causal relationship, but at the risk of under-estimating deaths attributable to cold.

1. Introduction

Recently there has been much attention focused on the current and future effects of temperature on health. This has included debate around projected reductions in cold-related mortality burdens due to future climate warming and how these compare to increases in heat related health burdens (Woodward, 2014). Many epidemiological studies have demonstrated an increased risk of death as temperatures drop below a threshold across a number of locations (Bunker et al., 2016; Yu et al., 2012; Gasparrini et al., 2015). Within these studies, however,

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there are two distinct but linked issues which are rarely discussed, but which are integral to results obtained and their interpretation: temperature threshold choice (i.e. how 'cold' is defined) and whether the cold effects summarised in studies are indeed causal across the range of temperatures used to quantify health impacts. These are important issues. Understanding causal mechanisms can help identify downstream policy options and opportunities to prevent 'avoidable' deaths, and the magnitude of mortality burdens attributable to cold is dependent upon the threshold used in calculations. Implicit in any calculation of current or future attributable burden of mortality is that the exposure-response co-efficient used describes a causal relationship. This has particular importance for discussions regarding the extent to which reductions in future cold-related mortality will offset expected increases in mortality associated with hot weather – where impacts tend to be more direct and heat-thresholds better defined.

In this paper we explore these two related issues (and issues which inform these, such as the lagged (delayed) effect of cold on mortality), and, by integrating evidence from other disciplines, we aim to initiate a discussion around how best to interpret results from epidemiological and health impact assessment studies using a variety of cold thresholds. Of note, the metrics used both for cold exposure (e.g. mean temperature, apparent temperature, minimum temperature etc.) and for health outcomes (all-cause mortality vs cause-specific mortality or different causes of morbidity) are complex and vary across studies. For example, there is debate about whether the duration of low temperatures may be important (Barnett et al., 2012) and whether variability is important, both short term (e.g. diurnal variation in temperatures) or long term (e.g. deviation from a long-term average for that location) (Zhang et al., 2018). A wide range of health outcome measures are also used in epidemiological studies (e.g. falls and injuries, healthcare consultations such as hospital or primary care visits, acute respiratory illness in certain population groups etc.) which may have relevance to particular policy decisions but also different thresholds, time to effect and mechanisms of action.

Here, however, we focus on mean temperature as the exposure and all-cause mortality as the outcome metric, primarily because these are frequently used in both epidemiological studies of association between temperature and health outcomes (mortality is generally a more sensitive outcome in epidemiological studies) and in assessments of the potential health effects of temperature changes under climate change scenarios.

We have three main objectives:

1. To highlight some key issues around cold threshold selection – for example, the differences in temperature threshold choices between key London-based studies and the influence of threshold on the cold related mortality burden, using our own London dataset to illustrate this relationship. In doing this, we are not aiming to illustrate cold-mortality relationships for every context (we recognise that the exact relationship between temperature and mortality differs between regions and contexts (Gasparrini et al., 2015)), but aim to provide an illustration as a reference point for the evidence synthesis and discussion that follows.
2. To investigate and integrate evidence for causality across the different temperature ranges and time-periods used in studies using the Bradford Hill considerations (Hill, 1965) as a framework to do this. We appraise the range of evidence which suggests there are different health effects from extreme cold and more moderate cold conditions, with manifold mechanisms and operating over different (non-exclusive) time scales.
3. To discuss whether integrating this evidence from different disciplines can inform appropriate temperature threshold placement and interpretation of results, and to examine the policy and research implications of the preceding discussion. We consider the extent to which cold-related effects are likely to reflect causal mechanisms, and therefore how appropriate their use is in climate change risk assessments.

To address each of these objectives we use a range of different methods, described briefly below and divide our results and discussion into 3 main sections, which in turn address each of these objectives.

2. Methods

2.1. Objective 1

In order to highlight differences in common strategies used for threshold placement, we first summarise studies that analysed the relationship between daily temperature and all-cause mortality using data from Greater London. Given the aim here is not to provide a comprehensive review of the literature on the effects of cold in the UK (which has been done elsewhere (Hajat, 2017)), papers were identified through one database – Ovid Medline and were searched for combining terms for cold/low temperature and mortality. Studies which estimated the relationship between low temperature and all-cause mortality using Greater London data were selected from these, and the temperature threshold below which cold effects were estimated plotted in Fig. 1. Information about the lag period used was also noted (and summarised in Fig. 1).

In order to demonstrate the relationship between temperature and all-cause mortality in Greater London, we used mortality data provided by the Office for National Statistics (ONS). All deaths occurring in England between 1st January 1996 and December 2013 were used. We aggregated data to the Greater London conurbation level, as defined by the ONS Built-up Area codes from the 2011 census (Office for National Statistics (ONS), 2013). We used daily mean temperature (average of the daily maximum and minimum temperatures) between January 1996 and December 2013 as our main exposure variable, obtained from the UK Met Office UKCP09 gridded observation datasets (The Met Office, n.d). This dataset has the advantage of using observations from all available UK temperature stations, interpolated using inverse-distance weighting (using a regression model which includes information on longitude, latitude and importantly for Greater London, urban land use) to provide daily temperatures for 5 km^2 gridded areas.

We used a time series regression framework to analyse the risk of all-cause mortality for each 1 °C temperature decrease below a cold threshold. We controlled for the effect of season and secular trends using a cubic spline function with 7 degrees of freedom per year

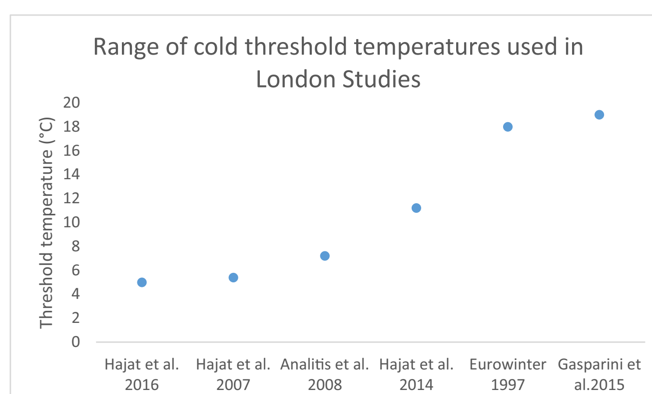

Fig. 1. Range of ambient (outdoor) cold threshold temperatures used in studies of cold related mortality in Greater London (where studies reported the threshold as a percentile of the temperature distribution, this has been converted to degrees Celsius using temperature distributions reported in the study). All studies used daily mean temeprature as the main exposure variable, with the exception of the Analitis et al. study (which used daily minimum apparent temperature). Lag periods for the included studies are as follows: Hajat et al., 2016 – 28 days, Hajat et al., 2007 – 14 days, Analitis et al., 2008 – 15 days, Hajat et al., 2014 – 28 days, Eurowinter, 1997 – 3 days, Gasparrini et al., 2015 – 21 days.