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# A multi-country analysis on potential adaptive mechanisms to cold and heat in a changing climate

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## ABSTRACT

*Background:* Temporal variation of temperature-health associations depends on the combination of two pathways: pure adaptation to increasingly warmer temperatures due to climate change, and other attenuation mechanisms due to non-climate factors such as infrastructural changes and improved health care. Disentangling these pathways is critical for assessing climate change impacts and for planning public health and climate policies. We present evidence on this topic by assessing temporal trends in cold- and heat-attributable mortality risks in a multi-country investigation.

*Methods:* Trends in country-specific attributable mortality fractions (AFs) for cold and heat (defined as below/above minimum mortality temperature, respectively) in 305 locations within 10 countries (1985–2012) were estimated using a two-stage time-series design with time-varying distributed lag non-linear models. To separate the contribution of pure adaptation to increasing temperatures and active changes in susceptibility (non-climate driven mechanisms) to heat and cold, we compared observed yearly-AFs with those predicted in two counterfactual scenarios: trends driven by either (1) changes in exposure-response function (assuming a constant temperature distribution), (2) or changes in temperature distribution (assuming constant exposure-response relationships). This comparison provides insights about the potential mechanisms and pace of adaptation in each population.

*Results:* Heat-related AFs decreased in all countries (ranging from 0.45–1.66% to 0.15–0.93%, in the first and last 5-year periods, respectively) except in Australia, Ireland and UK. Different patterns were found for cold

*Abbreviations:* DLNMs, distributed lags non-linear models; Q-AIC, quasi-Akaike score; BLUP, best linear unbiased prediction; MMT, minimum mortality temperature; MMP, minimum mortality percentile; AF, attributable mortality fractions; CI, confidence interval; RR, relative risk

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(where AFs ranged from 5.57–15.43% to 2.16–8.91%), showing either decreasing (Brazil, Japan, Spain, Australia and Ireland), increasing (USA), or stable trends (Canada, South Korea and UK). Heat-AF trends were mostly driven by changes in exposure-response associations due to modified susceptibility to temperature, whereas no clear patterns were observed for cold.

*Conclusions:* Our findings suggest a decrease in heat-mortality impacts over the past decades, well beyond those expected from a pure adaptation to changes in temperature due to the observed warming. This indicates that there is scope for the development of public health strategies to mitigate heat-related climate change impacts. In contrast, no clear conclusions were found for cold. Further investigations should focus on identification of factors defining these changes in susceptibility.

## 1. Introduction

As global warming has become more evident, public health and other sectors have turned their attention to climate change adaptation. Recent work examining the analysis of the historical impact of temperature on mortality in different locations has provided valuable insights on whether populations have adapted or, in general terms, become more or less susceptible to non-optimal temperatures, and which potential mechanisms and factors were involved (Arbuthnott et al., 2016). All this evidence is critical to inform current public health policy and protection of vulnerable populations (Hess et al., 2014). And, at the same time, knowledge of such changes can improve projections on future temperature-related health impacts under climate change scenarios.

Still, our current understanding on this subject is limited. First, a comprehensive assessment requires evidence on potential changes in susceptibility across the whole temperature spectrum (Arbuthnott et al., 2016). Most studies assessing temporal variations have focused on heat-mortality associations, reporting a substantial attenuation in risk in several locations (Åström et al., 2013; Barreca et al., 2016; Bobb et al., 2014; Carson et al., 2006; Coates, 2014; Ekamper et al., 2009; Guo et al., 2012; Heo et al., 2016; Nordio et al., 2015; Petkova et al., 2014). However, despite cold being responsible for a relatively large proportion of the overall temperature-related health burden (Gasparrini et al., 2015b), temporal variation in cold-mortality associations have only been investigated in a limited number of studies, with conflicting results (Åström et al., 2013; Barnett, 2007; Carson et al., 2006).

Second, and more importantly, most previous studies have relied on measures of relative risk (RR), and few have reported estimates in terms of impact (i.e. attributable risks), a measure shown to be more informative for policy planning and implementation (Gasparrini and Leone, 2014). Assessment of temporal variation in RR provides information on the extent of the change in susceptibility to heat or cold, although conclusions about the potential drivers for such change cannot be directly derived. For example, a reduction in heat-mortality risk can be driven by either 'pure adaptation', referred to here as any physiological acclimatisation of the population to a changing climate, or by an attenuation in risk due to extrinsic mechanisms, such as infrastructural changes or improved health care, which can happen simultaneously but independently from the changing climate (Arbuthnott et al., 2016). In contrast, attributable impact measures depend on both susceptibility, defined in terms of RR, and the prevalence of exposure (Gasparrini and Leone, 2014), and account for both adaptation to changes in exposure and autonomous attenuation. In the context of climate change, disentangling the temporal changes in attributable mortality driven through these two pathways can provide a more comprehensive picture of the evolution of the temperature-related health burden and is important in determining the contribution of different adaptive mechanisms to this evolution, and the potential for populations to adapt to global warming.

This study aims to address this issue by providing a comprehensive assessment of the potential adaptive mechanisms to non-optimal ambient temperatures during recent decades across different locations, characterized by different climates. Specifically, we illustrate the trends in both cold- and heat-attributable mortality in ten countries, and differentiate between the potential contribution of 'pure adaptation' to changes in temperature and other non-climate driven mechanisms of attenuation in risk.

## 2. Material and methods

### 2.1. Data

Time series daily data including mortality and weather variables were collected through the Multi-Country Multi-city (MCC) Collaborative Research Network (http://mccstudy.lshtm.ac.uk/). We analysed data from 305 locations in 10 countries in largely overlapping periods ranging from 1st of January 1985 to 31st December 2012. Specifically, the data was from: Australia (3 cities,1988–2008), Brazil (18 cities, 1997–2011), Canada (25 cities, 1986–2011), Island of Ireland (All-island data, 6 regions, 4 in the Republic of Ireland, and 2 in the Northern Ireland, 1985–2007), Japan (47 prefectures, 1985–2012), South Korea (7 cities, 1992–2010), Spain (50 cities, 1990–2010), Switzerland (8 cities, 1995–2012), the United Kingdom (UK, 10 regions, 1990–2011), and the United States of America (USA, 135 cities, 1985–2006). These data have been used in previous single- or multi-country studies (Gasparrini et al., 2015b, 2015a; Vicedo-Cabrera et al., 2016). A more detailed description of the data is provided in the appendix (Table S1). Daily mean temperature was considered as the main exposure variable in the present study.

### 2.2. Estimation of yearly heat- and cold-mortality associations

We adopted a two-stage time series design to assess the temporal patterns in heat and cold impacts in each country, throughout the study period available in each location between 1985 and 2012. Methods have been illustrated in detail in previous papers (Gasparrini et al., 2015b, 2015a).

#### 2.2.1. First-stage time series analysis

We estimated the location-specific temperature-related mortality associations for each year of the series through quasi-Poisson regression and time-varying distributed lags non-linear models (DLNMs). This class of models can describe complex non-linear and lagged dependencies, through the combination of two functions into a cross-basis that define the conventional exposure-response association and the additional lag response association, respectively. We extended the methodology of the basic DLNMs, which assumes time-constant exposure-lag-response associations, to time-varying DLMNs by including a linear interaction between time and the cross-basis function defining the exposure-lag-response associations (Gasparrini et al., 2015a).

Specifically, the cross-basis function of daily mean temperature was composed of a natural cubic spline function for the temperature dimension with 3 internal knots in the 10th, 75th and 90th percentile of the location-specific temperature distributions, and a natural cubic spline with an intercept and 2 internal knots placed along equally-spaced values on the log scale, for the lag dimension. The lag period was extended to 21 days to capture the long-lagged associations and potential short-term harvesting. The chosen combination of nonlinear