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Geographical variation in relative risks associated with heat: Update of Spain's Heat Wave Prevention Plan

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ABSTRACT

A decade after the implementation of prevention plans designed to minimise the impact of high temperatures on health, some countries have decided to update these plans in order to improve the weakness detected in these ten years of operation.

In the case of Spain, this update has fundamentally consisted of changing the so-called "threshold" or "trigger" temperatures used to activate the plan, by switching from temperature values based on climatological criteria to others obtained by epidemiological studies conducted on a provincial scale.

This study reports the results of these "trigger" temperatures for each of Spain's 52 provincial capitals, as well as the impact of heat on mortality by reference to the relative risks (RRs) and attributable risks (ARs) calculated for natural as well as circulatory and respiratory causes.

The results obtained for threshold temperatures and RRs show a more uniform behaviour pattern than those obtained using temperature values based on climatological criteria; plus a clear decrease in RRs of heat-associated mortality due to the three causes considered, at both a provincial and regional level as well as for Spain as a whole.

The updating of prevention plans is regarded as crucial for optimising the operation of these plans in terms of reducing the effect of high temperatures on population health.

1. Introduction

The effects that extreme temperatures have on mortality are evident, and there are a numerous publications which attest to this (Basu and Samet, 2002). Consequently, prevention or action plans have been implemented in many parts of the world to deal with extremely high temperatures. Nevertheless, in addition to the many uncertainties associated with determining the health impact of extreme temperatures (Konkel, 2014), when it comes to activating the action plans intended to counter the effects of such temperatures, different problems arise, linked, in great measure, to the lack of a common definition of what is known as a "heat wave" in public health (Montero et al., 2013).

The most of the studies considered as examples for illustration studies conducted using maximum daily temperature as the environmental variable to define heat waves, and daily mortality as the health variable to measure their impact (Wu et al., 2014; Zhang et al., 2014; Benmarhnia et al., 2014). Our goal is to define precisely at which specific temperature a heat wave can be deemed to exist, i.e., the point known as the "threshold" or "trigger" temperature. Some use strictly climatological criteria for defining a heat wave, i.e., a heat wave exists when the maximum daily temperature exceeds the 95th percentile of the series of maximum daily temperatures for the summer months (Montero et al., 2010); and, others hold the view that a multitude of parameters, such as socio-economic, demographic factors and the different acclimatisation to warmer temperatures (Barret, 2015), affect the magnitude of mortality risk in response to a rise in temperatures. Specific epidemiological studies focusing on the mortality-temperature relationship would have to be undertaken to determine the dose–response curve and whether indeed a temperature exists at which heat-related mortality starts to rise sharply (Montero et al., 2012). Establishing a threshold or trigger temperature for activating a heat health warning system (HHWS) is useful (Kovats and Kristie, 2006), and such a threshold can also be used for quantifying impacts of heat waves on mortality (Kent et al., 2014).

The Spanish Heat Wave Prevention Plan was first activated in 2004, and was based on threshold temperatures selected by reference to climatological criteria, which largely used the 95th percentile of the climatological temperature series for the summer months in the period 1971–2000 to determine the trigger temperature (MSSSI, 2015). Studies undertaken recently have highlighted the fact that, in certain cases, activation of the plan was not accompanied by the desired fall in mortality (Culqui et al., 2014; Linares et al., 2015b) and, moreover,

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that increases in heat-related mortality would have been observed even if the Plan had been activated (Montero et al., 2010). If the relative risks (RRs) associated with the threshold temperatures so obtained are calculated, these display a rather inconsistent behaviour pattern (Tobías et al., 2012), i.e., a few kilometres away from provinces with very high RRs, there are others with very low RRs.

These inconsistencies have led Spain's Ministry of Health, Social Services & Equality (Ministerio de Sanidad, Servicios Sociales e Igualdad/ MSSSI) to reconsider the suitability of the plan which has been in place until now, and based on the criteria outlined above, to update the respective threshold temperatures established for the country's provincial capitals, with this serving as a basis for the 2015 National Plan for Preventive Actions against the Health Effects of Excess Temperatures (MSSSI, 2015).

The designated aim of this study was to pinpoint the maximum daily temperature above which a significant increase in heat-related mortality was observed for each of Spain's provincial capitals; and, to calculate the relative risks for an increment of each degree above the temperature threshold detected and associated attributable risks and ascertain how these were distributed geographically. This analysis extended to increases in daily heat-related mortality due not only to natural, but also to circulatory and respiratory causes.

2. Methods

2.1. Setting

Spain is the second largest country in Western Europe (504,030 km^2), with a total population of 46,507,760 (INE, 2014). Mainland Spain is bordered to the south and east by the Mediterranean Sea, to the north by France and the Bay of Biscay, and to the north–west and west by the Atlantic Ocean and Portugal. Spanish territory also includes the Balearic Islands in the Mediterranean, the Canary Islands in the Atlantic Ocean off the African coast, and two autonomous enclaves in North Africa, namely, the cities of Ceuta and Melilla. The country is divided into 17 Autonomous Regions (Comunidades Autónomas), which are in turn subdivided into one to nine provinces, each with its own respective provincial capital. Due to Spain's geographical situation and conditions, the climate is extremely diverse and can be roughly classified into the following five main zones: a Mediterranean climate extending along the southern and eastern coasts up to the Pyrenees; a semi-arid Mediterranean climate in the south-east; a continental Mediterranean climate in the inland areas of mainland Spain; an oceanic climate in the north–west and along the coastal strip bordering the Bay of Biscay; and a sub-tropical climate in the Canary Islands (Prieto et al., 2004).

2.2. Data

As the health variable, we used data on daily mortality due to natural causes (International Classification of Diseases 10th Revision (ICD-10): A00-R99), circulatory causes (ICD-10: I00-I99) and respiratory causes (ICD-10: J00-J99), in each of Spain's 52 provincial capitals and in towns and cities of over 10,000 inhabitants, across the period 1 January 2000 to 31 December 2009. The daily mortality data were obtained from microfiches containing death data broken down by cause of death and supplied under a data loan agreement by the National Statistics Institute to the Carlos III Institute of Health (Ministry of Economic Affairs & Competitiveness/Ministerio de Economía y Competitividad), for the purpose of undertaking a "Study of influenza-related mortality in Spain". This analysis is an ecological design so it was exempt of ethics panel.

The maximum daily temperature data for this period corresponded to the records kept by the respective meteorological observatories in the various provincial capitals, and were furnished by the State Meteorological Agency (Agencia Estatal de Meteorología/AEMET), except in the case of Palencia for which there were no records for the period. The meteorological observatories were located in places established by the State Meteorological Agency (www.aemet.es).

There are different international approaches in literature to determine the threshold temperatures (Basu and Samet, 2002; Tong et al., 2010; Gasparrini et al., 2015). In this analysis we follow the methodology employed for determining the threshold temperatures used to define heat waves in the following papers: Montero et al., 2010; Mirón et al., 2012, 2015; Roldán et al., 2014; Linares et al., 2015a. The advantage of working with residuals rather than daily mortality is that, after modelling, residuals display neither trend nor periodicities (both of which are inherent in daily mortality), with the result that any associations found will therefore show a genuine causal mortality-temperature relationship from a statistical standpoint ($p < 0.05$) any associations between temperature and mortality, will not be confounded by longer term time trends and seasonal patterns. We first fitted a univariate autoregressive integrated moving average (ARIMA) model (Box et al., 1994) for daily mortality in each of the 52 provincial capitals, which allowed us to obtain the residuals of the mortality series. From the ARIMA models we obtained the fit and the confidence intervals corresponding to this fit (upper and lower). The residuals of mortality are the difference between the raw mortality and the fit. Then we proceeded to plot the following on a scatter plot diagram: the mean value of the mortality series residuals on the same day (vertical axis); the maximum daily temperatures at 2 °C intervals (horizontal axis), and their corresponding 95% confidence intervals (CIs) (upper and lower limits of the CI: UL and LL respectively); and the 95% CIs of the mean of the residuals for the entire study period (shown by parallel broken lines). When these mortality residuals are showed in a scatter plot with the maximum temperature data, the deviations detected correspond to real mortality anomalies. The temperature from which the mortality residuals increased significantly vis-à-vis the mean would thus be the threshold temperature.

The impact of temperature on mortality was quantified, using generalised linear model (GLM) methodology, with the Poisson regression link. This methodology allows for calculation of the relative risks (RRs) associated with increases in the environmental variable, in this case temperature. Based on the RR, we then calculated the attributable risk (AR) associated with this increase via the following equation (Coste and Spira, 1991):

$$AR = [(RR-1)/RR] \times 100.$$

On fitting the model, we controlled the following: firstly, for seasonalities of an annual, six-monthly and quarterly nature, using the sine and cosine functions with these same periodicities; and secondly, for trend and the possible autoregressive nature of the series.

To consider the effect of a heat wave through maximum daily temperatures (Tmax), we respectively created the variables Tcal, defined on the basis of the previously calculated mortality threshold temperatures (Tthreshold) as follows:

$$Tcal = 0 \quad \text{if } Tmax < Tthreshold$$
$$Tcal = Tmax - Tthreshold \quad \text{if } Tmax \geq Tthreshold.$$

From the point of view of mortality's impacts, we have considered heat-wave any day that surpasses the threshold considered in each city analysed (Díaz et al., 2002a,b).

Given that the effect of a heat wave on mortality may not be immediate, the following lagged variables were calculated: Tcal (lag 1), which takes into account the effect of the temperature on day "d" on mortality, one day later, "d + 1"; Tcal (lag 2), which takes into account the effect of the temperature on day "d" on mortality, two days later, "d + 2"; and so on successively. The number of lags were selected on the basis of the literature, which establishes that the effect of heat is a short-term effect (Tcal: lags 1–4) (Alberdi et al., 1998). The trend was controlled through