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ORIGINAL ARTICLE

Extreme temperatures and mortality in the North of Spain

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Abstract

Objective To study the relationship between mortality and temperature in Cantabria, a Spanish region that includes both rural and urban areas.

Methods Meteorological data (2003–2006) were obtained from the Spanish Meteorological Agency and daily numbers of deaths were obtained from the Spanish Institute for Statistics. A graphical approach using locally weighted regression smoothing was used to explore the relationship between mortality and temperatures and to identify temperature thresholds; we estimated the excess of mortality due to extreme temperatures in both warm and cold periods using Poisson regression models, and we simulated a situation with increased temperatures.

Results Raising maximum or minimum temperatures by 1°C was associated with a 2% excess in mortality risk in the whole population throughout the warm period, and we found no effect in mortality on the cold season; almost all changes in mortality occur in people aged 65 or more. Women are more sensitive to temperature changes in the warmer months.

Conclusions The deleterious effect of increasing temperatures in summer is more pronounced than the beneficial effect of a similar increase in winter.

Keywords Temperature · Summer · Winter · Mortality · Poisson regression · Lowess · North of Spain

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Introduction

It is believed that climate change will increase the risk of extreme meteorological conditions, such as heat waves (Pirard 2003; IPCC 2007; Vineis 2010; McGeehin and Mirabelli 2001). For instance, heat waves occurring in Europe in summer 2003 produced a rise in general mortality and alarm in both people and public health authorities (Michelozzi et al. 2005; Vandentorren et al. 2006; Martínez Navarro et al. 2004). Health services' preparedness and response require the identification of at-risk population groups, and alarm thresholds, in order to implement public health measures.

Most studies have dealt with the effect of high temperatures on health in big cities (Hoshiko et al. 2010; Semenza et al. 1996; Rooney et al. 1998; Bell et al. 2008); living conditions in these cities, however, are better prepared for extreme climate conditions (air conditioning, for instance) than in small cities or rural areas (Vandentorren et al. 2006; Mirchandani et al. 1996). Therefore, there is a lack of knowledge about how the health of inhabitants in medium- and small-sized nuclei is affected by temperature. In this paper, we report the relationship between mortality and temperature in the whole population, and in age and sex groups throughout the year, and identify the

Table 1 Number of population nuclei included in the study, according to their number of inhabitants, Cantabria, Spain, 2005

No. of inhabitants	No. of population nuclei	Total inhabitants
<100	8	368
100–199	12	1,727
200–499	14	4,312
500–999	7	5,071
1,000–1,999	15	20,068
2,000–4,999	9	27,374
5,000–9,999	4	32,202
10,000–14,999	8	94,432
15,000–24,999	1	22,247
25,000–29,999	1	28,360
30,000–150,000	1	147,256
Total		383,417 (68.19%)
Cantabria		562,309 (100%)

temperature thresholds associated with higher mortality risk. The study was performed in Cantabria, a Spanish region which includes both rural and urban areas.

Methods

Setting

The study was performed in Cantabria, which is a coastal, 562,309-inhabitant region located in the North of Spain. Its demographic composition is very similar to that of Spain, with about 108,837 inhabitants (19%) being 65 years old or over. The main urban concentrations are Santander, with about 181,802 inhabitants, and Torrelavega, with about 55,418 inhabitants. The remaining 383,417 inhabitants live in about 1,000 population nuclei (grouped in 102 municipal areas), with an average of 384 inhabitants per nucleus. Details on population nuclei are displayed in Table 1.

Source of data

Data on mortality from January 1, 2003 to December 31, 2006 were obtained from the Spanish National Institute for Statistics (Instituto Nacional de Estadística, INE); they include city of residence, age at death, day of death, gender, and cause of death. Because of Spanish laws on confidentiality of databases, the INE only provides data on municipal areas with a minimum of 10,000 inhabitants; this allows us to obtain data on a population basis of 388,000 inhabitants (68% of the total regional population).

The Spanish Meteorological Agency (Agencia Española de Meteorología, AEMET) provided data on meteorological variables on a daily basis; it included maximum, minimum and mean temperatures; maximum and minimum humidity; wind speed and direction, and other meteorological phenomena (for instance, rain, snow, storms, etc.). All data were available for a number of meteorological stations located around Cantabria; their geographical distribution is shown in Fig. 1. Then, data on mortality were associated with weather data from the nearest weather station.

Statistical analysis

We organized our statistical analysis in three steps. First, we explored the general relationship between temperature

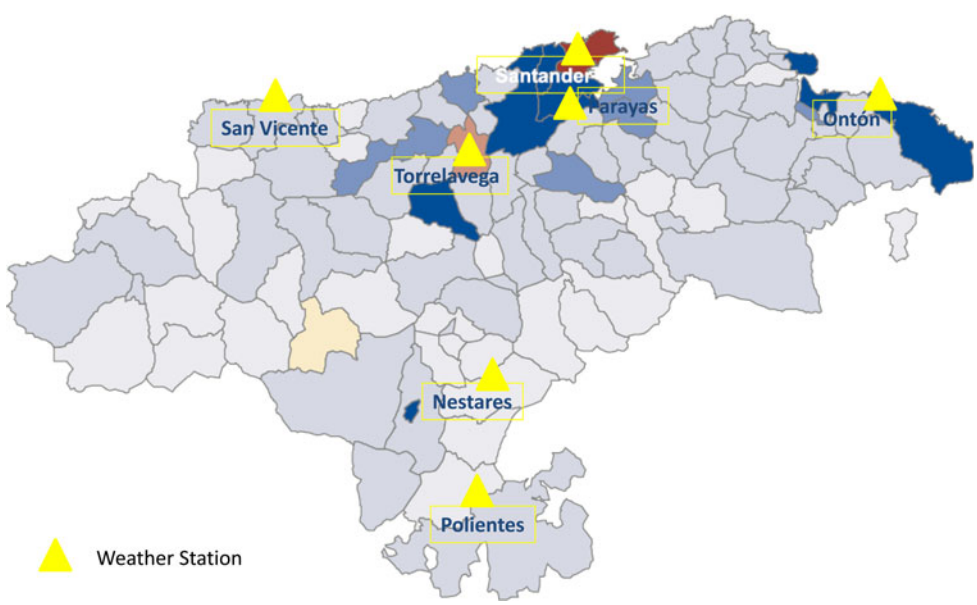


Fig. 1 Cantabria (North of Spain) Map with the locations of the meteorological stations relative to the population centers from which the mortality statistics were obtained

and mortality using locally weighted regression smoothing (lowess) curves. Second, we estimated the increase in mortality due to each degree Celsius via Poisson regression. Third, we simulated the mortality that would occur in a scenario with higher temperatures in average and with more days with extreme temperatures; such scenario is compatible with the usual predictions on climate change. Second and third steps were performed separately for warm and cold seasons.

First step: Exploring temperature-mortality relationship. Lowess (locally weighted regression smoothing) curves with 80% confidence interval bands were plotted in order to display the relationship between maximum or minimum temperatures (*X*-axis) and the number of daily deaths (*Y*-axis). The habitually used linear regression attributes the same influence to each datum; we chose locally weighted regression because it attributes higher influence to points located closer (Cleveland 1979). Lowess curves are useful in order to identify local trends and thresholds for trend change (Braga et al. 2002).

Second step: Estimating mortality due to an increase of 1°C with actual data. Having obtained a V-shaped relationship between temperature and mortality, we split our database: we used data from June to September (warm season) in order to quantify the effect of temperature on mortality in the right arm of the "V" (i.e. high temperatures). In the same way, we used data from November to March (cold season) in order to quantify the effect in the left arm of the "V" (i.e. low temperatures). To do that, we estimated Poisson regression models with the number of deaths as dependent variable, and the number of inhabitants and the temperature as regressors. Data's structure is time series and some seasonal control is needed; in order to perform it, we introduce a smooth function of time as a covariate, which was obtained via Holt–Winters seasonal smoothing (Holt 1957; Winters 1960). The general Poisson regression model we were using is displayed in Eq. 1. These models were obtained separately for warm and cold seasons, stratifying for gender and age group.

$$\log(\text{no. of deaths}) = \log(\text{no. of inhabitants}) + \beta_0 + \beta_1 \times \text{temperature} + \beta_2 \times \text{smooth function} \quad (1)$$

Usually, results in Poisson regression are displayed as rate ratios (i.e. exponential of β_1); in order to obtain a more easily interpretable result, we transformed rate ratios into percentage of increase in mortality produced by each centigrade increase in temperature via the Eq. 2.

$$\text{Excess of mortality } (\%) = (\text{rate ratio} - 1) \times 100 \quad (2)$$

Third step: Simulating climate change. Finally, we explored the modifications that would occur in mortality in warm and cold periods (June–September and November–February, respectively) if temperatures change by increasing both their average and their variability; to do that, we simulated new maximum and minimum temperatures by adding to the actual ones a random noise normally distributed with mean = 2°C and standard deviation = 2°C. Then, we applied the previously obtained Poisson models to these simulated temperatures in order to obtain new predictions of mortality.

Results

General relationship between temperatures and mortality

The maximum temperature in Cantabria in 2003–2007 ranged from 4.6 to 34.1°C, with an average of 17.8°C (Table 2), while the minimum temperature ranged from −0.3 to 22.8°C, with an average of 12.2°C. Both maximum and minimum temperatures were about 9°C higher in the warm season (June–September) than in the cold season (November–February) (Table 2).

Figure 2 displays the relationships between temperatures and mortality in the whole population, stratifying by gender. All plots show a V-shape relationship, where the lowest mortality was produced when maximum temperature was 20–22°C, and minimum temperature was 15–17°C.

When studying the mortality-temperature relationship by age groups, the right arm of the V-shape was hardly visible in people older than 90 years (maximum temperature), and not visible at all in people aged 25–64 years (Fig. 3; Table 3).

Increased risk of death in the warm season

In the warm season (June–September), the higher the temperature the higher the mortality; mortality increased by 2.0% when maximum temperature increased by 1°C, and by 2.5% when minimum temperature increased by 1°C (Table 4). This effect is more intense in women than in men, especially with respect to minimum temperature. When stratifying by age, temperatures have no effect on mortality in people younger than 65; moreover, maximum temperature has no effect in people older than 90 (Table 4).

The youngest age groups (0–14 and 15–24) were excluded from this analysis because of their lower number of deaths (57 and 79, respectively) make the results unreliable.

In November–February, however, the decrease by 1°C in temperature was not associated with an increase in the mortality (Table 5).

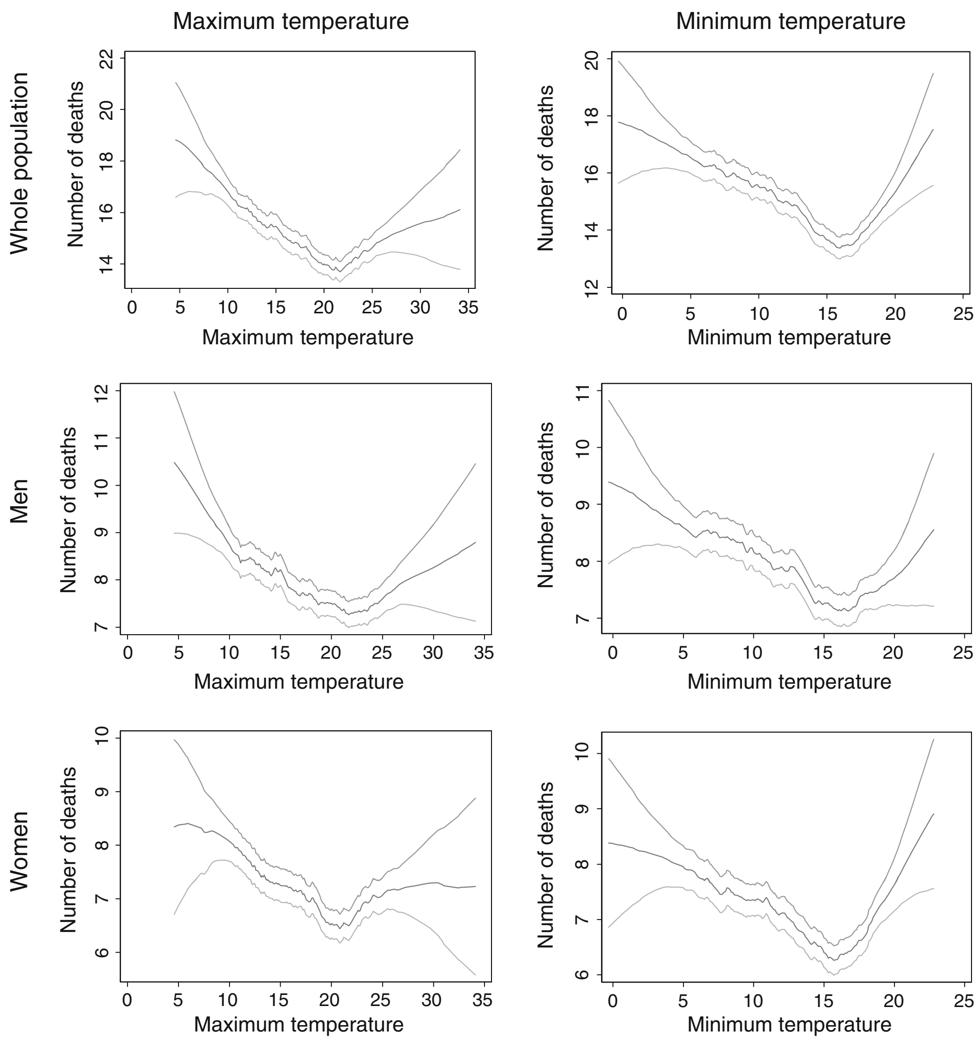
Table 2 Temperatures in Cantabria (North of Spain), 2003/2006

Period	Maximum temperature (°C)[a]		Minimum temperature (°C)[a]	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Whole year	17.8 ± 5.1	18.0 (13.6–21.7)	12.2 ± 4.7	12.2 (8.8–16.2)
June–September	22.6 ± 6.6	22.3 (20.8–23.8)	17.1 ± 1.9	17.2 (15.8–18.4)
November–February	13.3 ± 3.5	13.0 (11.0–15.6)	8.2 ± 3.1	8.4 (6.2–10.3)

IQR Interquartile range, *SD* Standard deviation

[a] The temperatures are averages from all the reporting stations

Fig. 2 Relationship between maximum and minimum temperatures (*X*-axis) and daily number of deaths (*Y*-axis) obtained via locally weighted regression: central estimate and 80% confidence bands for the whole population and by gender. Cantabria (North of Spain), 2003/2006



Changes in mortality when increasing both mean and standard deviation of temperatures

Table 6 displays the expected changes in mortality when maximum and minimum temperatures are increased in average (+2°C) and in standard deviation (+2°C). In the whole population, mortality would increase in the warm season by nearly 5% while it would decrease in the cold season by about 2%. When stratifying by age or gender, the pattern of change remains the same: the increment in mortality in June–September is higher than the decrement in November–February. In this simulation, women seem to be more sensitive to higher temperatures with estimated increases of 4.69% if taking into account maximum temperatures or 8.23% if taking into account minimum temperatures. People older than 90 would also be more susceptible to changes in minimum temperatures, while people aged 65–74 would be more easily affected by

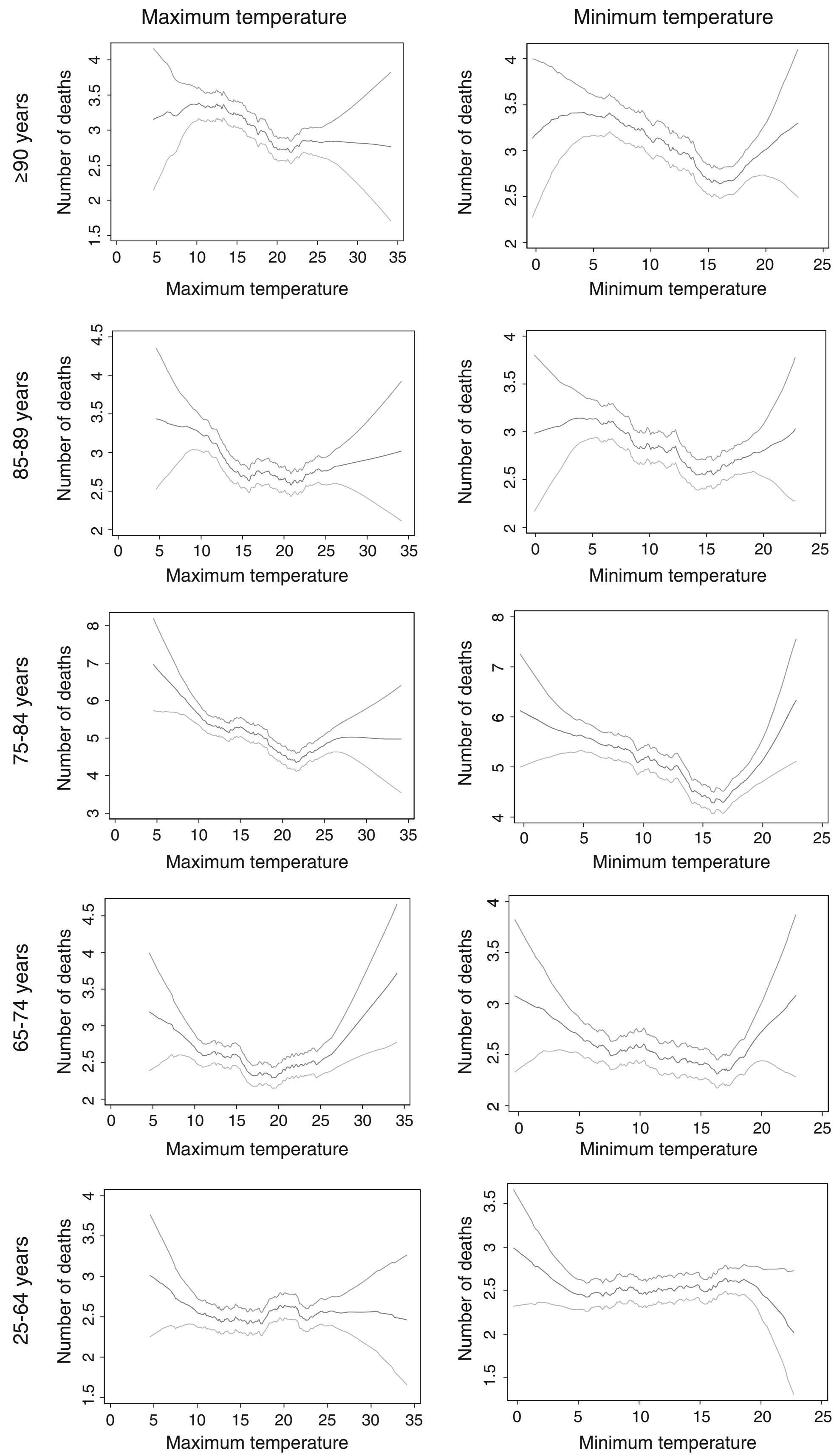


Fig. 3 Relationship between maximum and minimum temperatures (*X*-axis) and daily number of deaths (*Y*-axis) obtained via locally weighted regression: central estimate and 80% confidence bands by age group. Cantabria (North of Spain), 2003/2006

Table 3 Characteristics of mortality in Cantabria, North of Spain (2003–2006)

Total sample	*N* (%) 21,898 (100)	Age (mean ± SD) 77.30 ± 15.22
Male	11,498 (52.5)	73.52 ± 15.22
Female	10,400 (47.5)	81.48 ± 13.75
Age group		
<15 years	89 (0.4)	
15–24 years	120 (0.5)	
25–64 years	3,304 (15.1)	
65–74 years	3,323 (15.2)	
75–84 years	7,196 (32.9)	
85–89 years	3,805 (17.4)	
≥90 years	4,061 (18.5)	
	Averaged deaths/day	
Month		
January	17.53	
February	17.03	
March	16.27	
April	14.90	
May	13.91	
June	13.89	
July	13.98	
August	13.56	
September	13.90	
October	14.38	
November	14.58	
December	16.02	
Weekday		
Monday	15.61	
Tuesday	14.64	
Wednesday	14.97	
Thursday	14.77	
Friday	15.11	
Saturday	15.42	
Sunday	14.41	

SD Standard deviation

maximum temperatures. As in the precedent sections, the youngest age groups (0–14 and 15–24) were excluded from this simulation because of their lower number of deaths.

Discussion

If temperatures rise throughout the year, the effects on mortality would be conflicting as higher temperatures are associated with higher mortality in summer but with lower mortality in winter. Our main results suggest that the rise in mortality due to the increased temperature throughout the warm season would outweigh the mortality decline in the cold season.

Usually models of climate change predict that extremely hot days or even heat waves (i.e. a succession of hot days) will be more frequent due to two mechanisms: (1) the rise in temperatures itself, and (2) an increase in the temperature variability, with more days included in the right tail (higher temperatures) of the distribution. The impact of climate change on mortality, however, remains controversial: as cold temperatures in winter are associated with higher mortality, warmer winters would eventually compensate the mortality excess produced by hotter summers (IPCC 2007; The Eurowinter Group 1997; Bøkenes et al. 2000).

Our study indicates, however, that the deleterious effects of increasing temperatures in summer will not be counterbalanced by the beneficial changes in winter climate, assuming that temperatures in both seasons change in the same magnitude.

The impact of temperature change on age groups seems to be irregular, and will probably be modified by local conditions. Some authors have reported that people living in cold countries would be more sensitive to hot temperatures, probably because they have no housing conditions oriented to protecting themselves from extremely hot temperatures (Curriero et al. 2002; García-Herrera et al. 2005). As temperatures in Cantabria are quite moderate, most houses have no special features such as insulation or air conditioning. About 50% of people over 65 live in houses built before 1960, largely before Spain became an industrialized country, and building quality reached high standards; moreover, 25% of them live alone and 40% with only one person (frequently, of similar age). Therefore, old-aged people in Cantabria could be more susceptible to extreme heat not only because of the increased fragility due to age but also due to their living conditions. Impact of high temperatures on people younger than 65 seems, nevertheless, to be negligible. Other authors suggest that extreme temperatures could have greater effect on mortality in regions where those temperatures are uncommon, probably due to the lack of climatic adaptation (Flynn et al. 2005; Grundy 2006; Hajat et al. 2006; Medina-Ramón et al. 2006; Basu 2009; Stafoggia et al. 2006), this is the case in Cantabria, where temperatures are usually moderate (Table 2).

It is noteworthy that the increase in mortality associated to higher putative temperatures in the future can at least partially be prevented by adopting adaptive measures such as air conditioning or changing norms of home construction; therefore, the results of our simulation should not be seen as "predictions" in a pure sense (i.e. "what will happen") but as counterfactual forecasts (i.e. "what would happen letting all the remaining factors unchanged").

Table 4 Excess in mortality due to each increase in 1°C in June–September, Cantabria, North of Spain, 2003–2006. Results obtained via Poisson regression smoothing for season (see Eq. 1)

Age/sex group	Temperature	% Excess in mortality risk by each increase in 1°C (95% CI)	*P* value
Whole population	Maximum	2.0 (1.1, 3.0)	<0.001
	Minimum	2.5 (1.3, 3.8)	<0.001
Men	Maximum	1.9 (0.6, 3.1)	0.004
	Minimum	1.3 (−0.4, 3.1)	0.125
Women	Maximum	2.2 (0.8, 3.5)	0.002
	Minimum	4.0 (2.1, 5.9)	0.000
≥90 years	Maximum	1.0 (−1.2, 3.2)	0.370
	Minimum	3.3 (0.3, 6.3)	0.031
85–89 years	Maximum	2.5 (0.4, 4.8)	0.022
	Minimum	3.3 (0.3, 6.4)	0.034
75–84 years	Maximum	2.3 (0.7, 3.9)	0.005
	Minimum	3.2 (1.0, 5.5)	0.004
65–74 years	Maximum	2.8 (0.5, 5.1)	0.017
	Minimum	2.2 (−0.9, 5.4)	0.165
25–64 years	Maximum	−0.7 (−2.9, 1.7)	0.570
	Minimum	−0.1 (−3.1, 3.0)	0.956

CI Confidence interval

Table 5 Excess in mortality due to each decrease in 1°C in November–February; Cantabria, North of Spain, 2003–2006. Results obtained via Poisson regression smoothing for season (see Eq. 1)

Age/sex group	Temperature	% Excess in mortality risk by each decrease in 1°C (95% CI)	*P*
Whole population	Maximum	0.1 (0.8, 0.6)	0.836
	Minimum	0.1 (0.9, −0.7)	0.776
Men	Maximum	0.3 (1.3, −0.6)	0.497
	Minimum	0.4 (1.4, −0.7)	0.506
Women	Maximum	0.1 (1.1, −0.8)	0.780
	Minimum	0.2 (1.3, −0.9)	0.718
≥90 years	Maximum	0.0 (1.5, −1.4)	0.966
	Minimum	−0.1 (1.6, −1.8)	0.872
85–89 years	Maximum	1.2 (2.8, −0.4)	0.131
	Minimum	1.0 (2.8, −0.8)	0.276
75–84 years	Maximum	0.3 (1.5, −0.8)	0.565
	Minimum	0.7 (2, −0.6)	0.262
65–74 years	Maximum	1.6 (3.3, −0.1)	0.068
	Minimum	1.2 (3.2, −0.7)	0.212
25–64 years	Maximum	−0.3 (1.4, −2)	0.728
	Minimum	−0.9 (1, −2.9)	0.343

Although air pollution, influenza transmission and other variables which are associated with higher mortality can be influenced by temperature and other weather conditions, (Katsouyanni et al. 1993, 2001; Ballester et al. 2003; Samoli et al. 2006), we decided not to control for them as they can be intermediate factors in the relationship between temperature and mortality (irrespective of the fact that extreme temperature itself has a direct effect on death rate). Therefore, the results reported here indicate the general effect of temperature and associated variables. Of note, rural areas and small cities such as the populations under study are usually less polluted; in fact, high levels of air pollution have only been declared around the industrialized area of Torrelavega (approximately 55,000 inhabitants) (Llorca et al. 2005), and meteorological phenomena such as thermal inversion, which can increase pollution, are sparse because of the wind regime of the region (Gómez-Acebo et al. 2010).

This study has some limitations. First, the INE only provides data on municipal areas with a minimum of 10,000 inhabitants because of Spanish laws on confidentiality of databases; this allows us to obtain data on a population basis of 383,417 inhabitants (68.19% of the total regional population), with an average of 384

Table 6 Predicted change in mortality in Cantabria, North of Spain, when increasing both maximum and minimum temperatures with a normal noise with mean = 2°C, standard deviation = 2°C

Age/sex group	Temperature	June–September		November–February	
		Actual number of deaths	% of change	Actual number of deaths	% of change
Whole population	Maximum	6,751	4.24	7,834	−0.15
	Minimum	6,751	5.24	7,834	−0.24
Men	Maximum	3,570	3.64	4,094	−0.70
	Minimum	3,570	2.85	4,094	−0.72
Women	Maximum	3,181	4.69	3,740	−0.28
	Minimum	3,181	8.23	3,740	−0.43
≥90 years	Maximum	1,182	2.51	1,546	0.79
	Minimum	1,182	9.49	1,546	0.81
85–89 years	Maximum	1,145	8.05	1,365	−2.13
	Minimum	1,145	7.48	1,365	−1.91
75–84 years	Maximum	2,185	5.38	2,616	−0.81
	Minimum	2,185	8.17	2,616	−1.48
65–74 years	Maximum	1,075	6.46	1,157	−3.72
	Minimum	1,075	2.85	1,157	−3.87
25–64 years	Maximum	1,096	−0.10	1,082	0.42
	Minimum	1,096	0.03	1,082	1.45

inhabitants per nucleus, but no less populated rural areas. Second, when estimating the effect of temperature, we have not adjusted our models for air pollutants or other meteorological variables, such as relative humidity or wind speed. Cantabria has Atlantic climate in which precipitations are about 1,200 mm/year; it is open to the Bay of Biscay to the North, and it receives dominant winds from the North-West. Third, we have limited our analysis to the relationship between mortality and temperatures on the same day (i.e. lag 0); some studies have dealt with larger lags, which could be responsible for deaths when the physiological response works in the very short-term but becomes exhausted when exposed to, say, 3 or 4 days in a row with extreme temperatures.

In summary, a rise in summer temperature by 1°C would result in an increase in mortality of about 2%, almost all in people aged 65 or more, while the decline in winter mortality produced by a similar rise in winter temperature would be insufficient to compensate this deleterious effect; other scenarios including higher variability of temperatures led to similar conclusions.

Conflict of interest The authors declare that they have no competing interests.

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