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Time trends in the impact attributable to cold days in Spain: Incidence of local factors

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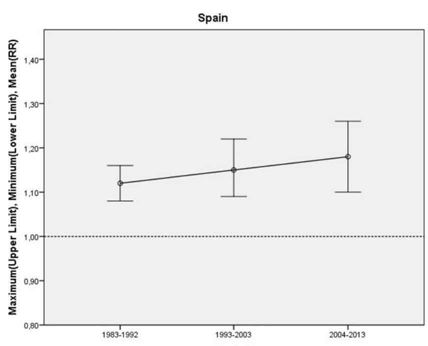
HIGHLIGHTS

- This study analyses the time trend of the impact of cold on daily mortality in Spain.
- The results obtained show a clearly different behaviour pattern to that found for heat.
- The impact of cold days has remained constant over time.
- It is necessary to implement prevention plans to reduce the impact of cold on health.

GRAPHICAL ABSTRACT



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Background: While numerous studies have shown that the impact of cold waves is decreasing as result of various processes of adaptation, far fewer have analysed the time trend shown by such impact, and still fewer have done so for the different provinces of a single country, moreover using a specific cold waves definition for each. This study thus aimed to analyse the time trend of the impact of cold days on daily mortality in Spain across the period 1983–2003.

Methods: For study purposes, we used daily mortality data for all natural causes except accidents in ten Spanish provinces. The time series was divided into three subperiods. For each period and province, the value of $T_{threshold}$ was obtained via the percentile corresponding to the cold day's definition for that province obtained in previous studies. Relative Risks (RRs) and Population Attributable Fraction (PARs) were calculated using Generalised Linear Models (GLMs) with the Poisson regression link. Seasonalities, trends and autoregressive components were controlled. Global RRs and ARs were calculated with the aid of a meta-analysis with random effects for each of the periods.

Results: The results show that the RRs for Spain as a whole were 1.12 (95% CI: 1.08 1.16) for the first period, 1.15 (95% CI: 1.09 1.22) for the second and 1.18 (95% CI: 1.10 1.26) for the third. The impact of cold days has risen slightly over time, though the differences were not statistically significant. These findings show a clearly different behaviour pattern to that previously found for heat.

Conclusion: The results obtained in this study do not show a downward trend for colds days. The complexity of the biological mechanisms involved in cold-related mortality and the lack of robust results mean that more research must be done in this particular field of public health.

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1. Introduction

In 2017 Gasparrini et al., analysed the impact of extreme temperatures under different climate change scenarios over a long time horizon, 2090–2099 (Gasparrini et al., 2017), and concluded that southern European regions were going to experience an increase in heat-related mortality and a clear decline in cold-wave-related mortality: this means in turn that the greater the increase in greenhouse-effect gas emissions, the greater the intensity of any increase in summer mortality. These conclusions are reached on the twin assumptions that there will be no population acclimatisation processes to such extreme temperatures and no changes in the population mortality rate. In contrast, other studies indicate that populations are indeed adapting to heat (Vicedo-Cabrera et al., 2018), basing their conclusions on the existence of heat-wave prevention plans (Díaz et al., 2015a), socio-economic improvements in infrastructures, homes (Vandentorren et al., 2006) and health (Ha and Kim, 2013), and in general, what has come to be called the “heat culture” (Bobb et al., 2014). This acclimatisation process is contributing to an increase in minimum mortality temperatures (Åström et al., 2016, Miron et al., 2012) and changes in heat-wave definition temperatures, with a general rising trend (Díaz et al., 2018). As a consequence of the above-mentioned adaptation factors, the impact of heat is likewise decreasing around the world (Gasparrini et al., 2017). Other studies undertaken at the level of a single country agree with these results: hence, this decrease has been reported as 85% in the case of Australia (Coates et al., 2014), 70% in the case of the USA (Barreca et al., 2016) and 93% in the case of Spain (Díaz et al., 2018).

This proven downward trend in the impact of heat has not been observed for cold, however, and there are practically no studies which have analysed the trend in the impact of cold on mortality in recent years (Wang et al., 2016; Vicedo-Cabrera et al., 2018). Despite the rise in mean temperatures across the planet (IPCC, 2013) under a climate change scenario, cold waves are not going to disappear (Kodra et al., 2011). In fact, studies conducted in Sweden show the number of cold waves recorded in Stockholm in recent decades as being slightly higher than that of those which occurred at the beginning of the 20th century (Åström et al., 2018). Moreover, the shifts in the Arctic vortex observed in recent decades may bring about an increase in cold waves in mid-latitudes (Cohen et al., 2014; Zhang et al., 2016). Added to this is the fact that the impact of cold-related mortality is greater than that of heat-related mortality (Gasparrini et al., 2015a, 2015b; Carmona et al., 2016a), so that from a public health standpoint it is essential that the impact on mortality be analysed by considering the impacts of heat and cold waves jointly. Along these same lines, a recent study conducted in the city of Vilnius (Sánchez-Martínez et al., 2018b) with the aim of comparing the impact of heat and cold waves on mortality under different climate change scenarios over various time horizons, shows that if adaptation is not taken into consideration, then heat-related mortality is going to be very much greater than that of cold, but that if acclimatisation processes are taken into account, by maintaining the trigger threshold percentile of heat- and cold-wave definition temperatures constant over time, then mortality will be very similar. In this case, the risk attributable to the impact of cold on mortality over time is assumed not to vary.

The few studies that have focused on cold-related time trends show that, far from decreasing, the impact of cold on mortality is either remaining constant (Åström et al., 2018) or actually increasing (Díaz et al., 2015b; Lee et al., 2018), and that in other cases there is no clear pattern over time (Miron et al., 2012; Vicedo-Cabrera et al., 2018).

As a rule, the time period analysed by these studies is short, without climatic representativeness, and no account is taken of the diversity of local factors that are crucial when it comes to ascertaining the impacts of extreme temperatures on health (Díaz et al., 2015a; Carmona et al., 2016b; Lee et al., 2018).

Accordingly, this study sought to analyse the time trend in the impact of cold days on daily mortality in Spain over a time period with climatic significance, namely, >30 years, and across the same study period for which heat trends had been analysed (Díaz et al., 2018), so as to maintain the social, population, health and economic characteristics constant, with the impact of cold being determined on the basis of the temperatures below which mortality increased in each place.

2. Material and methods

2.1. Data

Of a total of 52 Spanish provinces, we selected ten on the basis of geographical and population criteria representative of each of the areas in which cold behaves differently in terms of its effect on mortality (Carmona et al., 2016b). The dependent variable used was the daily mortality rate for all causes except accidents (International Classification of Diseases, 10th Revision (ICD-10) codes: A00-R99) in provincial capitals and in cities with >10,000 inhabitants, over the period 1983–2013. Both the daily mortality data and population data used to calculate the rate were provided by the National Statistics Institute (*Instituto Nacional de Estadística/INE*).

As the independent variable, minimum daily temperature (Tmin) data were obtained for each of the previously selected ten provincial capitals from their respective provincial reference observatories. Minimum daily temperature was used because other studies conducted in Spain have indicated that this displays the most reliable association with mortality in processes used to model the impact of cold on mortality (Montero et al., 2010; Carmona et al., 2016b). The meteorological data were obtained from observatories located in each provincial capital and were provided by the State Meteorological Agency (*Agencia Estatal de Meteorología/AEMET*). The analysis also controlled for average relative daily humidity.

2.2. Methodology

The dependent and independent variable series for the period 1983–2013 were divided into the following three subperiods: 1983–1992; 1993–2003; and 2004–2013. We controlled: firstly for seasonalities, using the sine and cosine functions with these same periodicities; and secondly, for trend and the possible autoregressive nature of the series. To control for trend, a variable called n1 was introduced. This variable was defined as n1 = 1 for 1 January 1983, n1 = 2 for 2 January 1983, and so on for the rest of the period. To control for annual (365 days), six-monthly (180 days), and three-monthly (90 days), and bi-monthly (60 days) seasonality, the functions sine and cosine were included in these periodicities in the following way: $\mathrm{Sin365} = \sin(2\pi n1/365)$ and $\mathrm{Cos365} = \cos(2\pi n1/365)$. Days of the week are included as *dummy* variables.

Generally in different places the studies in which the impact of cold waves on mortality is evaluated, arbitrary percentiles are used to define a cold wave; i.e.: Percentile 10th (Vicedo-Cabrera et al., 2018; Weinberger et al., 2017) Percentile 2.5th (Åström et al., 2018) or even several percentiles at the same time 5th, 3rd or 1st (Lee et al., 2018). It is clear that in the impact of cold waves on mortality, other factors as socio-economic, demographic and health conditions influence in the impact, in addition to the climatic conditions. These last are determined by the different percentiles selected (Carmona et al., 2016b). In this paper, it is known from previous studies the specific percentiles in each province, which defines cold days. These ones have been used for the determination of the threshold temperatures in each period. Since the temperature series vary from one period to another, so will the threshold temperatures of cold day's definition for each period and each province.

Previous studies (Carmona et al., 2016b) have calculated the mortality trigger threshold temperature for cold days in Spain for each province analysed, and the percentile in respect of the minimum daily temperature series for the winter months to which this percentile corresponds during the period 2000–2009. This was based on the assumption that this percentile was not going to vary throughout the study period (1983–2013). As minimum daily temperatures vary in each subperiod, the minimum temperatures corresponding to a given percentile will be different for each province and period, thus allowing for cold days mortality threshold temperature ($T_{threshold}$) to be obtained for each such province and period.

Based on the $T_{threshold}$ values for each province and period, we calculated the variable Tcold, defined as follows (Montero et al., 2010; Carmona et al., 2016b; Sánchez-Martínez et al., 2018b):

$$\begin{aligned} \text{Tcold} &= T_{threshold} - \text{Tmin} \quad \text{if Tmin} < T_{threshold} \\ \text{Tcold} &= 0 \quad \text{if Tmin} > T_{threshold} \end{aligned}$$

Some heat- or cold-wave definitions require that the threshold temperature be exceeded on two or more days (Guo et al., 2017). From a health impact standpoint, however, when the value is exceeded on just one day, this means that there is already an impact on mortality. Generally in the previous published studies a cold wave is defined when the threshold temperature is 2 or more days below the threshold temperature. In this study, a cold wave is defined with a single day being below the threshold temperature. For this reason the term "cold days" instead "cold wave" will be used throughout the text.

This finding has been published by a considerable number of papers which analyse the impact of heat and cold on mortality (Díaz et al., 2005; Linares et al., 2016; Díaz et al., 2015a; Carmona et al., 2016b; Sánchez-Martínez et al., 2018a, 2018b; Gasparrini et al., 2017; Wang et al., 2016). Hence, rather than being immediate, the effects of cold days on mortality may be lagged until up to 13 days after a fall in temperature (Alberdi et al., 1998; Montero et al., 2010; Linares et al., 2016; Carmona et al., 2016b). This made it necessary to calculate the relevant lags, selected on the basis of the current literature, which establishes that cold can have both short- and medium-term effects (Tcold: lags 1–13). Similarly, relative humidity was also included as a control variable, on a linear basis, until lag 13 (Montero et al., 2010; Carmona et al., 2016b; Sánchez-Martínez et al., 2018b).

To determine the values of the relative risks (RR) attributable to cold days, we used generalised linear model (GLM) methodology with the Poisson regression link; and to pinpoint the significant variables to be used in the modelling process for calculating such RRs, we employed the backward stepwise procedure. This meant including all the lags (1−13) for Tcold and relative humidity, as well as the first-order autoregressive component of the mortality variable, beginning with the model that included all the explanatory variables, and gradually eliminating those that individually displayed least statistical significance, with the process being reiterated until all the variables included were significant at $p < 0.05$. We calculated the increases in RR corresponding to each degree of Tcold, i.e., for every °C that the minimum daily temperature fell below the cold days definition temperature.

Based on the RRs, the population attributable fraction (PAF) associated with these increases was then calculated by means of the following equation (Coste and Spira, 1991):

$$\text{PAF} = (\text{RR} - 1/\text{RR}.) * 100$$

Based on the RR for each province, a meta-analysis was performed with random effects for each of the periods considered, in order to obtain an overall picture of cold behaviour patterns for all the provinces considered.

All analyses were performed using the IBM SPSS Statistics 22 and STATA v 11.2 statistical software programmes.

3. Results

Table 1 shows the descriptive statistics corresponding to the dependent and independent variables for each of the periods analysed. As regards the dependent variables shown in Table 1, in general the mortality rate per 100,000 population registered a significant increase in all the provinces analysed, decreasing only in the most densely populated ones (Madrid, Barcelona, Seville and Valencia), if the first and third subperiods are compared; however, comparison of these same subperiod also shows a significant rise in the population aged over 65 years. With respect to the mean minimum daily temperature, this was observed to increase at all the observatories covered, though this increase only proved statistically significant in the cities of Barcelona, Seville, Valencia and Bilbao.

Shown in Table 2 are the minimum threshold temperatures for cold-related mortality in the provinces analysed corresponding to the respective provincial percentiles, which ranged from 11.8 for Badajoz to 1.5 for Bilbao and Valencia. Also shown in Table 2 are the lags at which statistically significant associations between mortality and Tcold were obtained. As a general rule, for the immense majority of provinces and periods these were obtained from lag 3 onwards, occasionally as late as lag 13.

With regard to the PAF time trend in Table 2, comparison of the first and third periods shows a statistically significantly increase in four of the provinces analysed (Barcelona, Madrid, Seville and Valencia), with a statistically significant decrease being in evidence in the province of Badajoz alone. In the remaining provinces analysed, the variations observed were not statistically significant. At a provincial level, note should be taken of the high AR values in Valencia in the last two periods, with PAF values of 46.31% and 41.76% respectively. In contrast, the lowest value was found for Zaragoza in the period 1993–2003, in which the relevant PAF was only significant at $p < 0.10$, with a value of 1.31%.

The meta-analysis corresponding to each period is shown in Fig. 1. The RR for every degree that the minimum daily temperature fell below each province's threshold temperature was 1.12 (95% CI: 1.08, 1.16) for the first period, rising to 1.15 (95% CI: 1.09, 1.22) for the second period, and 1.18 (95% CI: 1.10, 1.26) for the third period, with none of these increases being statistically significant between any of the periods considered. The respective PAF values for each period were 10.7% (95% CI: 7.4, 13.8) for 1983–1992, 13.0% (95% CI: 8.3, 18.0) for 1993–2003, and 15.3% (95% CI: 9.1, 20.6) for 2004–2013. Fig. 2 shows a graph depicting the overall time trend in relative risk corresponding to the three subperiods for all provinces.

4. Discussion

According to the State Meteorology Agency (*Agencia Estatal de Meteorología Española/AEMET*), between 1980 and 2010 Spain experienced an increase of 1 °C in mean temperatures (Aemet, 2012), and in minimum temperatures in particular, as a consequence of the heat-island effect of large cities (Fernandez and Rasilla, 2008). The results shown in Table 1 are in line with these *AEMET* data, in that the only towns in which this increase in the minimum daily temperature proved statistically significant were the country's major cities, with the single exception of Madrid, possibly due in this specific case to the location of the Madrid-Retiro reference observatory (Fernandez and Rasilla, 2008).

This increase in the minimum daily temperature might lead one to think that, instead of increasing, the effect of cold days on mortality should have decreased across the study period, albeit without statistical significance, as obtained in this study. A number of studies which have recently examined cold-related mortality trends display a diversity of views when reporting this pattern (Vicedo-Cabrera et al., 2018). Hence, while Japan, Korea, Switzerland and Canada record a rising trend in recent years (from approximately 2005 onwards), the UK and USA report observing this growth in cold-related mortality throughout the period analysed (1985–2006 for the USA; 1990–2011 for the UK), and other places, such as Australia, Brazil, Ireland and Spain, register a downward trend in cold-related mortality. In contrast, specific studies undertaken in different countries and cities go to confirm the constant

Table 1
Descriptive statistics of the dependent variable (daily mortality rate due to all causes except accidents, ICD-10: A00-R99, per 100,000 population (mortality rate)) and the independent variable (minimum daily temperature (Tmin)) in °C per period.

Province (capital)	1983–1992				1993–2003				2004–2013			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Asturias (Oviedo)												
Mortality rate (×100,000)*	0.00	1.60	0.39	0.20	0.00	1.32	0.48	0.22	0.00	1.60	0.54	0.23
Tmin (°C)	−6.00	22.00	8.95	4.73	−3.80	20.20	9.34	4.46	−4.00	20.80	9.15	4.74
Population over 65 years (%)*	13.28	17.65	15.23	1.33	17.65	22.03	20.30	1.40	21.72	23.54	22.18	0.50
Badajoz												
Mortality rate (×100,000)*	0.00	1.85	0.38	0.26	0.00	1.53	0.39	0.26	0.00	1.64	0.41	0.25
Tmin (°C)	−4.80	26.00	10.15	5.87	−6.00	24.00	10.56	5.72	−7.20	25.80	10.40	6.24
Population over 65 years (%)*	13.00	15.17	13.90	0.70	15.17	18.13	16.83	0.96	17.53	18.38	17.83	0.18
Barcelona												
Mortality rate (×100,000)*	0.34	2.00	0.94	0.19	0.45	2.11	0.92	0.19	0.31	1.92	0.78	0.17
Tmin (°C)*	−7.20	24.20	10.89	6.02	−3.60	25.80	12.31	5.83	−3.50	26.80	12.74	6.61
Population over 65 years (%)*	10.92	14.29	12.50	1.03	14.29	16.93	15.94	0.82	16.17	18.18	16.69	0.56
Madrid												
Mortality rate (×100,000)*	0.65	2.84	1.31	0.24	0.69	2.63	1.30	0.22	0.65	2.16	1.14	0.19
Tmin (°C)	−7.40	25.30	9.95	6.57	−5.50	25.40	10.32	6.35	−6.10	25.70	10.34	6.69
Population over 65 years (%)*	9.59	12.30	10.86	0.84	12.30	14.49	13.69	0.68	14.06	16.50	14.76	0.69
Ourense												
Mortality rate (×100,000)*	0.00	2.75	0.55	0.40	0.00	3.16	0.73	0.48	0.00	3.60	0.89	0.53
Tmin (°C)	−7.00	22.60	8.26	5.40	−8.60	22.20	8.71	5.25	−6.80	22.10	8.54	5.60
Population over 65 years (%)*	16.99	23.07	20.00	1.90	23.07	28.14	25.86	1.64	28.09	30.01	28.79	0.57
Seville												
Mortality rate (×100,000)*	0.06	2.15	0.88	0.27	0.23	2.10	0.91	0.27	0.15	2.13	0.85	0.25
Tmin (°C)*	−4.00	27.00	12.27	5.79	−2.50	27.00	13.38	5.65	−3.50	29.30	13.64	6.16
Population over 65 years (%)*	9.53	11.46	10.42	0.61	11.46	13.70	12.79	0.73	13.65	15.15	14.09	0.45
Valencia												
Mortality rate (×100,000)*	0.09	1.87	0.83	0.23	0.14	2.15	0.86	0.23	0.24	1.77	0.77	0.21
Tmin (°C)*	−2.60	25.60	13.49	5.81	−0.50	26.40	14.03	5.69	−1.60	25.90	14.21	6.01
Population over 65 years (%)*	11.27	14.06	12.54	0.89	14.06	16.28	15.44	0.70	15.69	17.64	16.22	0.53
Valladolid												
Mortality rate (×100,000)*	0.00	3.64	1.08	0.50	0.00	3.63	1.32	0.54	0.00	3.72	1.40	0.54
Tmin (°C)	−12.00	21.80	5.03	5.94	−11.80	22.50	5.48	5.66	−10.50	20.50	5.33	5.96
Population over 65 years (%)*	10.73	13.95	12.17	1.00	13.96	17.31	15.91	1.06	17.28	20.58	18.44	0.98
Vizcaya (Bilbao)												
Mortality rate (×100,000)*	0.00	1.76	0.71	0.26	0.09	2.57	0.82	0.28	0.09	2.17	0.83	0.29
Tmin (°C)*	−6.60	25.00	9.47	5.08	−6.00	23.50	10.06	4.94	−3.90	23.30	10.37	5.15
Population over 65 years (%)*	9.59	13.79	11.38	1.26	13.79	18.81	16.74	1.58	18.77	21.45	19.64	0.77
Zaragoza												
Mortality rate (×100,000)*	0.00	4.05	1.48	0.47	0.35	4.03	1.71	0.49	0.31	4.33	1.68	0.48
Tmin (°C)*	−7.60	24.00	9.79	6.50	−9.50	24.30	10.08	6.29	−6.50	24.70	10.21	6.69
Population over 65 years (%)*	13.39	17.10	15.11	1.16	17.10	19.89	18.86	0.87	18.49	19.91	19.02	0.36

* Statistically significant differences at $p < 0.05$ between the first and last periods.

or growing impact of cold-related mortality. Accordingly, the study by Lee et al. (2018) reports this same rising trend in Korea and Japan, as do Åström et al., for Stockholm (Åström et al., 2018).

In the case of Spain, studies conducted for the city of Madrid by age group showed heat-related mortality to be decreasing across all age groups, while cold-related mortality was increasing, particularly in the over-65 age bracket (Díaz et al., 2015b). With respect to Vicedo-Cabrera et al.'s study, the trend observed in Spain for the period 1990–2010 displayed a downward trend in the impact of cold on daily mortality. These results in no way contradict those obtained in the above study, since the cold-wave definition used by Vicedo-Cabrera et al., is based on daily mean temperatures below the 1st percentile, whereas those used by Díaz et al. (2015b) in all cases correspond to minimum daily temperatures above this 1st percentile. In a study conducted for Spain as a whole over the period 2000–2010 (Carmona et al., 2016b), the mortality trigger threshold temperature was calculated for each Spanish provincial capital. This cold-wave threshold temperature was below the 1st percentile in only 3 cases; not only was it above this 1st percentile in the remaining 49 cases, but in 6 of these it went above the 10th percentile. This is why, rather than corresponding to an analysis of the impact of cold days in Spain, the cold-wave definition used by Vicedo-Cabrera corresponds instead to an extreme temperature that is highly improbable in a Spanish setting. Furthermore, the effect of cold is known to be greater in places with mild climates than in those with cold climates, which are more accustomed to low temperatures (Lim et al., 2013; Wang et al., 2012; Carmona et al., 2016b). Hence, there can be little justification in using the same percentile to define cold days in Spain as that used in Canada.

It is noteworthy that, in contrast to what happens in the case of cold, this differing behaviour pattern is not observed in the case of heat; indeed the pattern found in places in which the heat-related time trend has been analysed is identical, i.e., a clear reduction in its effects on daily mortality (Díaz et al., 2018; Vicedo-Cabrera et al., 2018; Åström et al., 2018; Lee et al., 2018). Given that the studies relating to heat and cold were undertaken on the same population over the same time period, this differentiated behaviour pattern between the impacts of

Table 2
Cold-related mortality threshold temperature ($T_{threshold}$) in °C; percentile to which this $T_{threshold}$ corresponds; relative risk (RR) with 95%CI; population attributable fraction (PAF) in % with its 95%CI; and lags at which the associations between cold (Tcold) and the daily mortality rate are established.

Province		Period		
		1983–1992	1993–2003	2004–2013
Asturias	$T_{threshold}$ (percentile)	0 °C (p7)	1 °C (p7)	0.2 °C (p7)
	RR (95%CI)	1.05 (1.00–1.10)	1.05 (1.01–1.09)	1.07 (1.02–1.13)
	PAF (95%CI)	4.93 (0.36–9.30)	4.76 (1.05–8.33)	6.50 (1.57–11.17)
	Tcold (signif. lags)	3	7	8
Badajoz	$T_{threshold}$ (percentile)	−0.2 °C (p11.8)	0.4 °C (p11.8)	−0.4 °C (p11.8)
	RR (95%CI)	1.28 (1.22–1.35)	1.03 (1.00–1.07)	1.13 (1.08–1.17)
	PAF (95%CI)**	21.95 (18.06–25.66)	3.18 (−0.17–6.42)	11.15 (7.30–14.84)
	Tcold (signif. lags)	5, 10, 13	3*	4, 7
Barcelona	$T_{threshold}$ (percentile)	−0.8 °C (p2.4)	0.6 °C (p2.4)	−0.5 °C (p2.4)
	RR (95%CI)	1.10 (1.07–1.12)	1.07 (1.03–1.11)	1.17 (1.12–1.23)
	PAF (95%CI)**	8.71 (6.72–10.66)	6.28 (2.93–9.51)	14.77 (10.99–18.39)
	Tcold (signif. lags)	2, 6	5	5, 10, 12
Madrid	$T_{threshold}$ (percentile)	−2.1 °C (p2.3)	−1.9 °C (p2.3)	−2.1 °C (p2.3)
	RR (95%CI)	1.06 (1.04–1.08)	1.20 (1.16–1.25)	1.16 (1.13–1.19)
	PAF (95%CI)**	5.69 (3.71–7.62)	16.74 (13.49–19.86)	13.75 (11.18–16.25)
	Tcold (signif. lags)	1, 11	4, 7, 10, 13	0, 2, 5, 8
Ourense	$T_{threshold}$ (percentile)	−2 °C (p8.1)	−0.8 °C (p8.1)	−2 °C (p8.1)
	RR (95%CI)	1.09 (1.02–1.15)	1.09 (1.05–1.12)	1.08 (1.02–1.14)
	PAF (95%CI)	7.84 (2.03–13.30)	7.84 (4.45–11.11)	7.31 (2.27–12.09)
	Tcold (signif. lags)	12	9	3
Seville	$T_{threshold}$ (percentile)	0.6 °C (p4.4)	1.9 °C (p4.4)	1.7 °C (p4.4)
	RR (95%CI)	1.16 (1.11–1.22)	1.12 (1.08–1.15)	1.29 (1.25–1.33)
	PAF (95%CI)**	14.04 (10.20–17.71)	10.35 (7.32–13.28)	22.3 (19.70–24.82)
	Tcold (signif. lags)	5, 6, 13	4, 9	1, 4, 7, 10, 13
Valencia	$T_{threshold}$ (percentile)	1.4 °C (p1.5)	2.2 °C (p1.5)	1.4 °C (p1.5)
	RR (95%CI)	1.11 (1.06–1.17)	1.86 (1.70–2.04)	1.72 (1.61–1.83)
	PAF (95%CI)**	10.18 (5.60–14.54)	46.31 (41.16–51.00)	41.76 (37.92–45.37)
	Tcold (signif. lags)	4, 7	4, 6, 7, 9, 11	1, 3, 6, 8, 10, 13
Valladolid	$T_{threshold}$ (percentile)	−5.6 °C (p5.8)	−4.8 °C (p5.8)	−5.6 °C (p5.8)
	RR (95%CI)	1.16 (1.12–1.21)	1.07 (1.03–1.10)	1.13 (1.09–1.17)
	PAF (95%CI)	14.14 (10.90–17.26)	6.33 (3.30–9.27)	11.19 (7.94–14.31)
	Tcold (signif. lags)	3, 11, 13	7, 11	4, 12
Vizcaya	$T_{threshold}$ (percentile)	−2.8 °C (p1.5)	−2.2 °C (p1.5)	−1.2 °C (p1.5)
	RR (95%CI)	1.17 (1.09–1.25)	1.36 (1.25–1.47)	1.10 (1.01–1.21)
	PAF (95%CI)	14.43 (8.12–20.31)	26.36 (20.32–31.94)	9.31 (0.84–17.06)
	Tcold (signif. lags)	3, 7	3, 7, 10	2
Zaragoza	$T_{threshold}$ (percentile)	−2.7 °C (p6.1)	−1.3 °C (p6.1)	−2 °C (p6.1)
	RR (95%CI)	1.04 (1.01–1.08)	1.01 (0.99–1.03)	1.05 (1.02–1.07)
	PAF (95%CI)	4.20 (1.07–7.23)	1.31 (−0.66–3.24)	4.36 (1.87–6.79)
	Tcold (signif.l)	10	5*	6

* Significance $p < 0.1$.
** Significance $p < 0.05$.

heat and cold cannot be explained by demographic factors, since the target population for both heat and cold is the over-65 age group (Alberdi et al., 1998; Díaz et al., 2015b; Urban et al., 2014; Medina-Ramon et al., 2006; Ryti et al., 2015). Similarly, the explanation for this difference cannot be sought in factors linked to the health system (Linares et al., 2016). Rather, it must be related to the lack of adaptation mechanisms designed to cope with cold, which in the case of heat are indeed in place at a health level (Mayrhuber et al., 2018), and to the fact that infrastructures and homes are properly equipped to handle heat but not cold (Vardoulakis et al., 2014).

In the first place, here in Spain daily cold-related mortality is higher than heat-related mortality (3.5 deaths/day versus 3.0 deaths/day) (Carmona et al., 2016a). Despite this, however, there are no cold-wave prevention plans of the type which exist for heat (MSSSI, 2018) and which, as in other countries (Mayrhuber et al., 2018), are demonstrating their effectiveness in terms of reducing mortality (Díaz et al., 2018). Secondly, cold-related mortality includes viral and infectious processes (Kysely et al., 2009) which result in its effects being much more lagged and diffuse in time than those of heat (Alberdi et al., 1998; Díaz et al., 2005; Montero et al., 2010; Ryti et al., 2015), a finding in line with the wide range of statistically significant lags shown in Table 2, something which in turn hinders the implementation of prevention plans and an effective health-measure response. The type of biological mechanisms involved in cold-related mortality are in great measure unknown (Ebi and Mills, 2013) and probably differ from those that influence heat-related mortality, so that their behaviour vis-à-vis acclimatisation would not necessarily be the same.

Furthermore, one of the aspects that clearly have an influence on the decrease in heat-related mortality relates to home infrastructures, the existence or absence of air conditioning, and the type of construction that minimises the impact of heat on mortality (Vandentorren et al., 2006). In this respect, in 1991 Boardman (Boardman, 1991) coined the term "energy poverty", which refers to households that have to use 10% of their income to maintain their homes in adequate climatic conditions. In the European Union, a comparative study conducted by Healey and Clinch (2002) concluded that Greece, Spain and Portugal were the countries with the highest energy poverty rates. In the case of Spain, over 10% of homes can be assumed to be in a situation of energy poverty, with this effect being especially important in large cities (Tirado et al., 2016). Although this aspect is very important in the case of heat, it is even more so in the case of cold. One study recently undertaken in the city of Madrid shows that heat-related mortality in Madrid across the period 2001–2009 accounted for 344 deaths, whereas cold-related mortality accounted for a total of 1473 deaths, i.e., fourfold

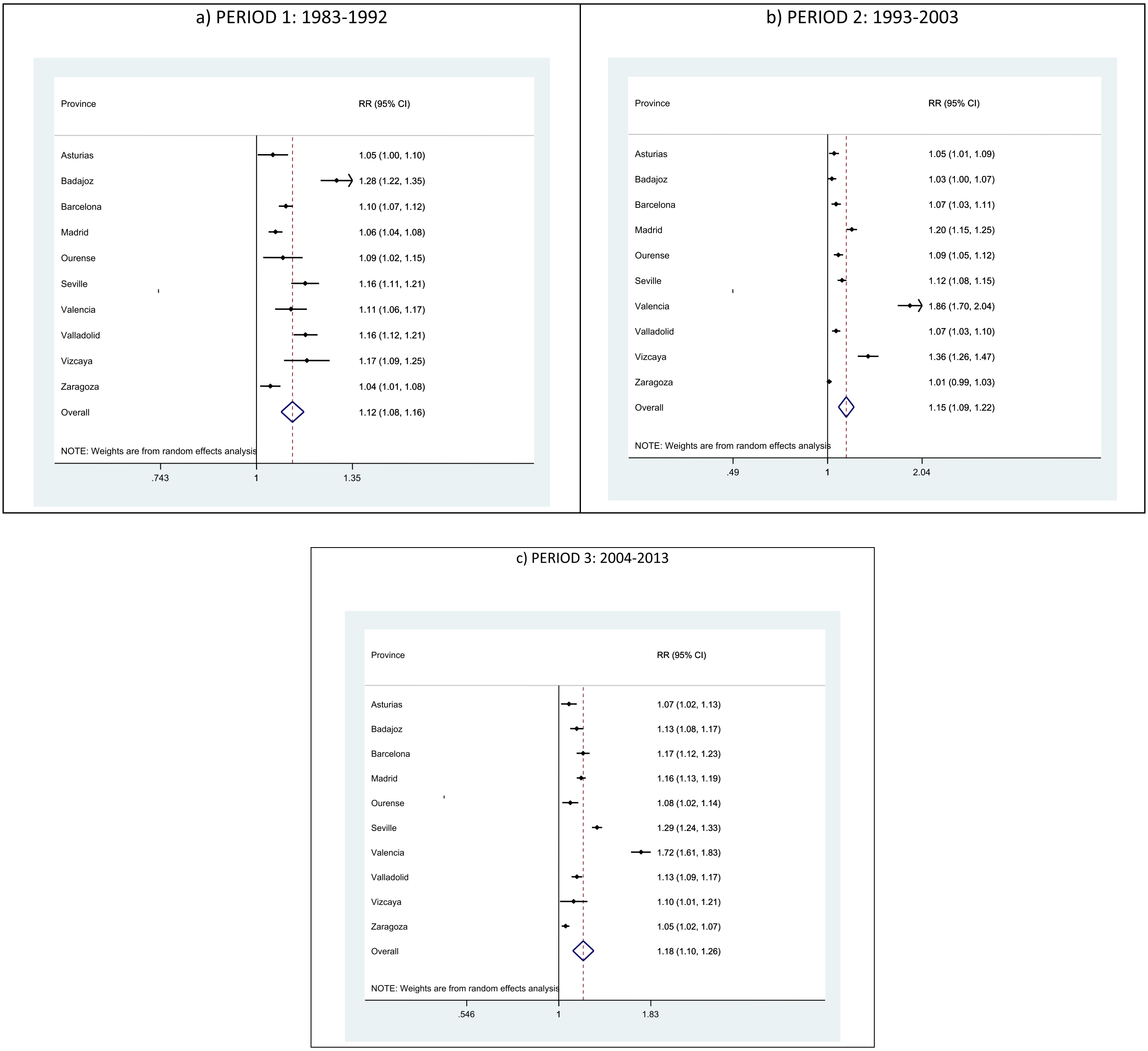

Fig. 1. Meta-analysis of the RRs for cold-related mortality for each of the provinces analysed by period: a) 1983–1992; b) 1993–2003; c) 2004–2013.

that of heat, which means that the lack of home weatherproofing is going to have a greater impact on cold- than on heat-related mortality (Sanz et al., 2016). Energy poverty has been increasing in Spain in recent years (Sanz et al., 2016). This lack of weatherproofing to maintain minimum conditions of thermal comfort in the home could account for the increase in cold-related mortality seen in this study. This finding is reinforced by the fact that statistically significant increases in cold-related mortality correspond to the cities of Madrid, Barcelona, Seville and Valencia. The common denominator shared by these four is that they are the largest and most densely populated cities in Spain (INE, 2018), in which energy poverty is especially relevant (Tirado et al., 2016).

The sum total of these factors, which is reflected in the lack of prevention plans, despite the fact that cold has a greater impact on mortality than does heat, the different biological behaviour of cold-related mortality, taken together with the increase in energy poverty may account for the time trend in cold-related mortality in Spain over the last 30 years.

From a quantitative standpoint, the impact of cold-related mortality observed for Spain as a whole, with PAF values ranging from 10.7% in the first period to 15.3% in the third period for every degree below the cold days definition temperature in each province analysed, are similar to those reported by previous studies conducted for all Spanish provinces across the period 2000–2009 (Carmona et al., 2016a, 2016b). According to this study, the PAF for Spain as a whole is 11.3%, which goes to corroborate that the cities on which this study focused are representative of Spain as a whole. Furthermore, these PAF values for cold are higher than those found by Åström et al. (2018) for the city of Stockholm, whose PAF values, depending on the period, range from 2.8% to 7.9%. They are also higher than those recently obtained for the city of Vilna for the period 2009–2015 (Sánchez-Martínez et al., 2018b), which put this PAF value at 1.6%. In contrast, these PAF values are lower than those obtained in more temperate places with values of the attributable fraction due to cold ranging from 22% to 18% according to period. The above goes to indicate that there is better

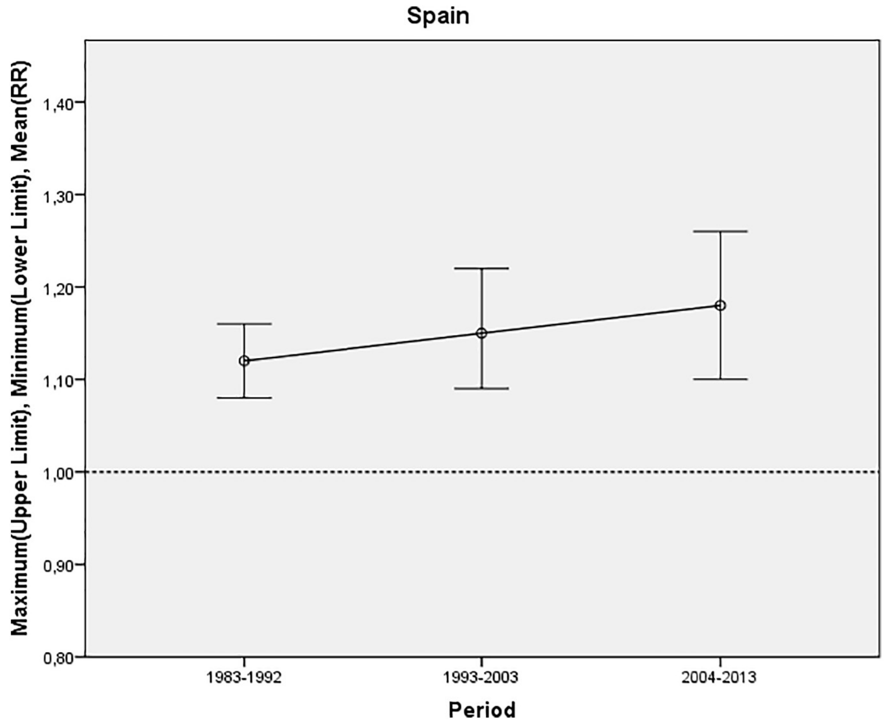

Fig. 2. Time trend in cold-related RRs for all provinces analysed by period.

acclimatisation to cold in places with cold climates than in those with warmer climates (Lim et al., 2013; Wang et al., 2012; Carmona et al., 2016b).

From the point of view of study limitations, mention must be made of those inherent in the use in each province of a percentile previously calculated in other studies (Carmona et al., 2016b). While assuming that this percentile remains constant over time for each province and period has its advantages, it nevertheless also involves certain biases. On the one hand, it has the advantage of being able to compare the different results obtained for each province in each period without these being affected by possible biases in the PAF due to the different values of the threshold temperature. It is known that in the case of cold, temperatures which correspond to low percentiles are associated with higher PAFs than are those which correspond to higher percentiles (Carmona et al., 2016a, 2016b; Lee et al., 2018). However, the drawback of this percentile-based method is that the number of cold days which occur in any given period cannot be ascertained, since they will always be the same due to their definition as a specific percentile of a series.

Owing to the unavailability of validated data in the first period of analysis, this study failed to take into account air pollution levels or influenza epidemics, but as stated above, the PAF values obtained in this study are very similar to those obtained for Spain overall by previous studies (Carmona et al., 2016b) in which both of these confounding factors were indeed considered. This finding is in line with those of other studies which report that whether air pollution is or is not is taken into account in temperature-mortality models is something that does not change the trend in the results obtained (Bobb et al., 2014; Carson et al., 2006). However, the use of the minimum daily temperature obtained at a single observatory as the indicator of exposure for an entire province entails a bias which will have to be considered in future studies (Carmona et al., 2017). Mortality data for specific causes and age-groups are not available at the provincial level for the whole series of data. For this reason, the analysis cannot be carried out at this level of disaggregation. Working only with mortality from natural causes and for all age groups is common in ecological time series studies that analyse the impact of heat/cold waves in a great amount of places (Lee et al., 2018; Weinberger et al., 2017; Vicedo-Cabrera et al., 2018).

4.1. Considerations in public health measures: prevention plans

The results obtained in this study indicate the need for the implementation of cold-wave prevention plans, particularly in more temperate countries. The fact that cold waves are not going to disappear under a climate change scenario (Cohen et al., 2014; Zhang et al., 2016), that exposure to energy poverty in some countries is on the rise (Tirado et al., 2016), that the impact of cold on daily mortality is greater than that of heat (Gasparrini et al., 2015b; Carmona et al., 2016a), and that its impact, far from decreasing, is in fact increasing in some places, calls for the implementation of the above type of cold-wave prevention plans, which are yielding such good results in terms of reducing heat-related mortality (Mayrhuber et al., 2018). These prevention plans should be activated when the minimum daily temperatures are below the threshold temperature in each province. This fact will include the activation of social and health services, the opening of overnight places for the homeless, and the implementation of measures to combat energy poverty.

5. Conclusion

The results obtained in this study do not show a downward trend for colds days. Even so, the complexity of the biological mechanisms involved in cold-related mortality, which are still not well known (Ebi and Mills, 2013), and the lack of robust results as regards its time trend in different places around the world (Vicedo-Cabrera et al., 2018) mean that more research must be done in this particular field of public health. Under a climate change scenario, cold days are not going to disappear. Their impact has remained constant over time and seems to be higher than heat impact (deaths/day). To minimise this impact on health is necessary to improve public health measurements.

Disclaimer

This paper reports independent results and research. The views expressed are those of the authors and not necessarily those of the Carlos III Institute of Health.

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