High Summer Temperatures and Heat Stroke Mortality in Spain

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Background: Heat stroke is a significant cause of mortality in response to high summer temperatures. There is limited evidence on the pattern and magnitude of the association between temperature and heat stroke mortality. We examined this association in Spain, using data from a 27-year follow-up period.

Methods: We used a space-time-stratified case–crossover design. We analyzed data using conditional quasi-Poisson regression with distributed lag nonlinear models.

Results: Spain recorded a total of 285 heat stroke deaths between 1990 and 2016. Heat stroke deaths occurred in 6% of the days in the summer months. The mean temperature was, on average, 5 °C higher on days when a heat stroke was recorded than on days without heat stroke deaths. The overall relative risk was 1.74 (95% confidence interval = 1.54, 1.96) for a 1 °C rise in mean temperature above the threshold of 16 °C, at which a heat stroke death was first recorded. We observed lagged effects as long as 10 days.

Conclusions: Although heat stroke represents a small fraction of total heat-attributable mortality during the summer, it is strongly associated with high temperatures, providing an immediately visible warning of heat-related risk.

Keywords: case-crossover; conditional Poisson regression; heat stroke; mortality; temperature.

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The relationship between temperature and mortality has been well characterized worldwide.[1,2] Although high summer temperatures adversely affect multiple physiological processes, previous studies have only considered the major mortality causes, such as all-natural, cardiovascular, and respiratory causes. Although heat stroke could be the more responsive cause indicator of high temperatures,[3] the evidence on the pattern and magnitude of the association is limited. A recent systematic review between high temperature, heat waves, and heat-related illnesses reported that only two out of the 62 studies evaluated the association between high temperature and heat stroke mortality.[4]

Short-term effects of high summer temperatures on daily mortality have been previously established in Spain in a multicity study.[5] However, the impact on heat stroke has yet to be evaluated in the epidemiologic context. In this study, we aim to study the patterns of heat stroke mortality in Spain, using data from a 27-years follow-up period for all capital cities, and assess the temperature–mortality relationship countrywide.

METHODS

Daily counts of heat stroke mortality (International Classification of Diseases-9th revision/ICD9: 992 and 10th revision/ICD10: X30) for the 52 provincial capital cities in Spain between 1990 and 2016 was provided by the Spain National Institute of Statistics. Because mortality data are daily counts did not require the consent of ethics. Average daily temperature (in °C) for the summer months (from 1st June to 31st September) for the 52 capital cities was provided by the European Climate Assessment & Dataset.[6]

We investigated the association between summer temperature and daily heat stroke mortality using a space-time-stratified case–crossover design.[7] Control days are taken from the same city, day of the week, calendar month, and year as the case day (i.e., day of death), allowing control for long-term trend and seasonality by design. We analyzed data using conditional quasi-Poisson regression,[8] and we modeled the temperature–heat stroke mortality association using distributed lag nonlinear models.[9] We explored the shape of the exposure–response relationship from linear to nonlinear associations. We initially modeled the temperature–heat stroke association using a natural cubic spline with three internal knots placed at the 50th, 75th, and 90th percentiles of the temperature distribution, and the lag exposure up to 1 week with a natural cubic

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Mortality data analyzed in the study are not publicly available. Code for replicating the analysis is available from the corresponding author.

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spline with three internal knots equally spaced in the log scale. We made this choice after exploring the joint temperature–heat stroke mortality distribution (eFigure 1; http://links.lww.com/EDE/C57). Unlike other causes of mortality, heat strokes frequently occur from the 75th percentile of the temperature distribution in summer. We evaluated other modeling choices further in sensitivity analyses with knots at the 75th, 85th, and 95th percentiles and reduced with two knots at the 75th and 90th percentiles. Moreover, we tested departure from linearity. Comparison between model goodness of fit was made using quasi-Akaike's information criteria.[10] Death from heat stroke may not occur until days after onset[11]; therefore, we also examined the lag pattern up to 2 weeks. We conducted analyses using R, version 4.2.2 (R Development Core Team, 2022), using the "dlnm" and "gnm" packages.

RESULTS

Over the 27-year follow-up period, we recorded 285 heat stroke deaths, which is 0.03% of all summer mortality during the study period. Among these, 52% were male, and 84% were aged more than 50 years. Heat stroke deaths start occurring in June (8%), but the majority of these deaths occurred in July (41%) and August (42%). The highest number was recorded in the summer of 2003, with 71 deaths, whereas the lowest was

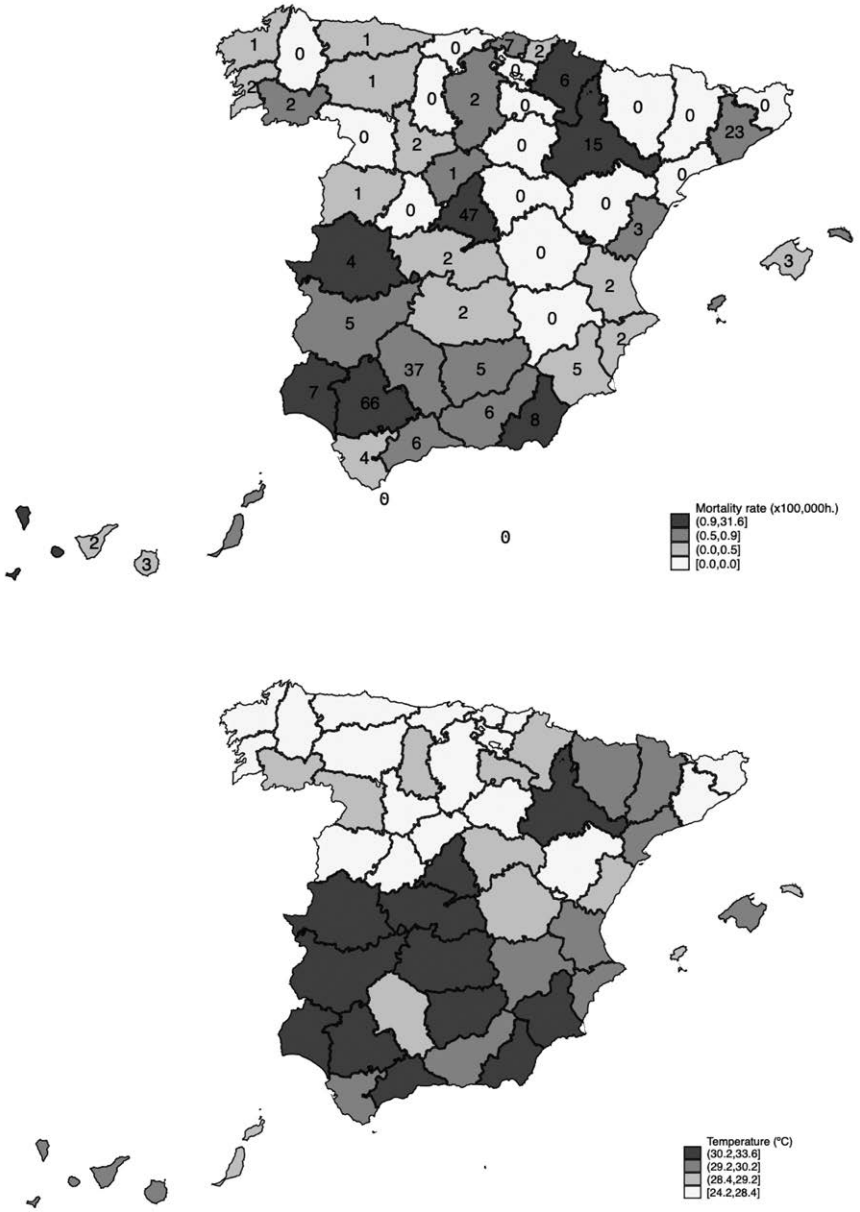

FIGURE 1. Maps of the 99th percentile distribution of summer daily mean temperatures (bottom, in °C), and heat stroke mortality rate (×100,000 inhabitants) and total number of heat stroke deaths (top), in the 52 capital cities in Spain, 1990–2016.

in 1991 and 1996, with only one death each year (eTable 1; http://links.lww.com/EDE/C57). Heat stroke deaths occurred in 6% of the days in the summer months over the study period (eTable 2; http://links.lww.com/EDE/C57).

Figure 1 shows a high correlation between the provinces recording the highest heat stroke deaths rate, per 100,000 inhabitants, with those recording high summer temperatures. These provinces are mainly located in the Southwest region. The minimum daily mean temperature where a heat stroke death was recorded was 16 °C. On average, the mean temperature was 5 °C higher on days when a heat stroke was recorded than on days without heat stroke deaths (eTable 2; http://links.lww.com/EDE/C57).

The overall association centered at 16 °C from the linear and nonlinear exposure–response associations showed a similar fit (Figure 2). However, because no deaths occur below 16 °C we also consider a linear threshold model (i.e., hockey-stick). The chosen combination of exposure–response functions provided a lower quasi-Akaike's information criteria for the linear association with lagged effects for up to 2 weeks (eTable 3; http://links.lww.com/EDE/C57). The overall relative risk across all lags was 1.74 (95% confidence interval = 1.54, 1.96) for each 1 °C rise above the threshold of 16 °C. We observed lagged effects up to more than 10 days, with an effect estimate peaking at lag 1 (Figure 3).

DISCUSSION

Using data from 52 capital cities in Spain, we found an exponential association between daily mean temperature and heat stroke mortality. Our results are similar to that reported in the meta-analysis (relative risk = 1.35; 95% confidence interval = 1.29, 1.41; I^2 = 0%) from a recent systematic review on the association between high temperature and heat stroke mortality.[4] Moreover, other studies conducted in the United States have also reported the exponential pattern for temperature–heat illness mortality,[12,13] and high risk estimates for heat-coded deaths during high temperatures compared with low temperatures.[14] Although very high temperatures are the main factor associated with clinical symptoms of heat stroke,[3] we observed that heat stroke deaths start occurring in early summer when temperatures are not excessively high, and increasing substantially in July and August. This pattern of reporting heat stroke events early in the warm season has also been described in Japan with heatstroke-related ambulance dispatches.[15]

In our study, the highest risk occurred at lag 1 day and remained for more than 10 days. Although heat stroke has a substantial case-mortality ratio and progression to death can be rapid,[16] it has a slow onset, often developing over days.[11] Previous studies conducted in Spain have also observed that heat associations with all-cause mortality persist up to 5 days.[5] It may be that the sequelae of acute heat stroke have led to death only after a few days. However, it is also possible that coding heat stroke as the underlying cause may not always have been accurate.

We found a similar distribution of heat stroke deaths in males and females and the majority in people over 50 years. This is consistent with previous evidence showing a heat effect

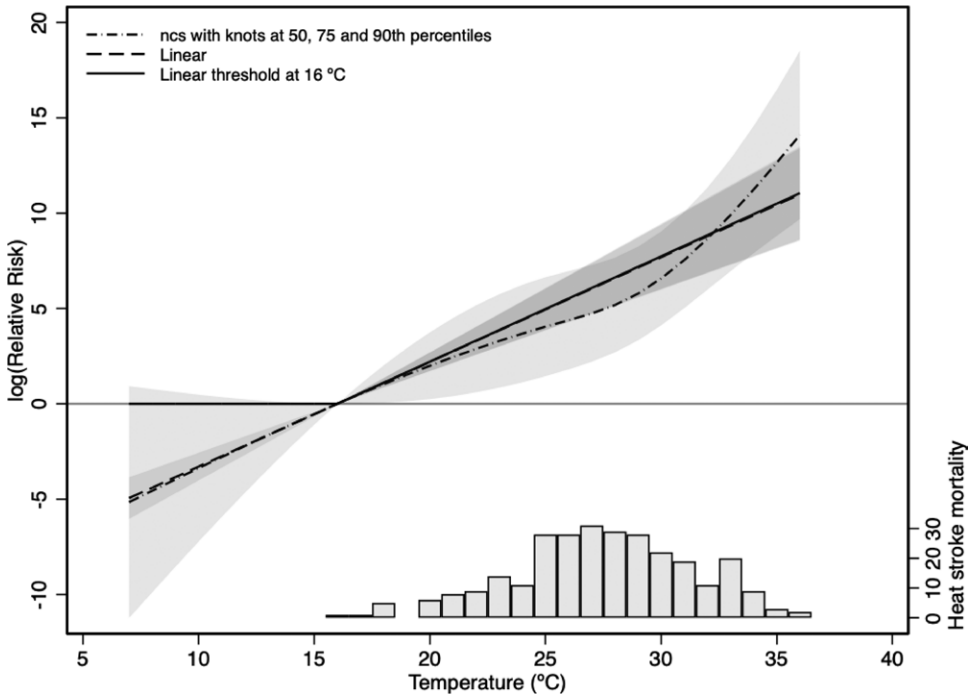

FIGURE 2. Overall association across all the lags between heat stroke deaths and mean temperature centered at 16 °C.

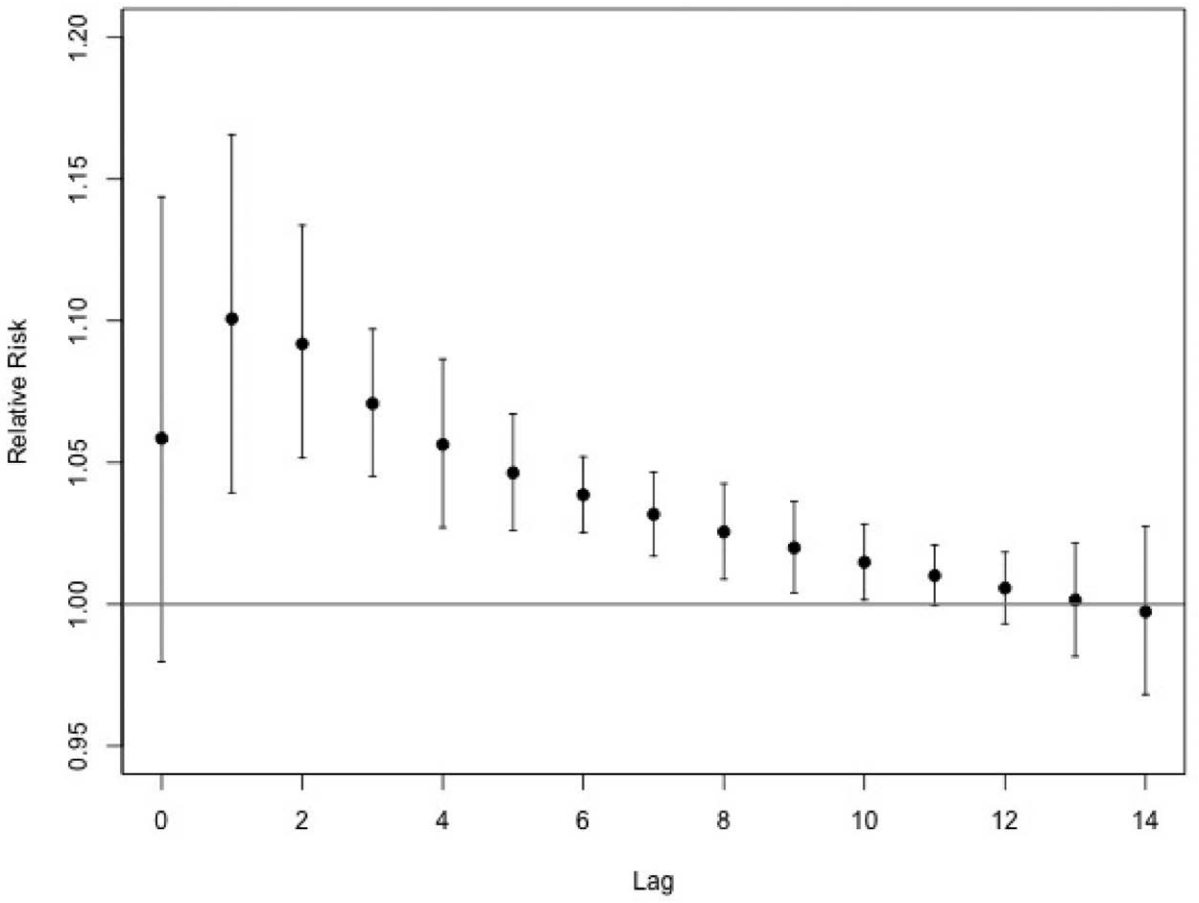

FIGURE 3. Lag distribution up to 2 weeks for the risk of heat stroke mortality for each 1 °C rise above the threshold of 16 °C.

in the elderly population, with increased mortality risk in older age groups.[11,16] However, we could not estimate vulnerability by sex and age in our analysis because we could not access individual data due to confidentiality issues.

The risk of heat stroke mortality quantified in this study is much higher than for other causes of mortality in Spain.[5,17] However, heat stroke deaths are only a small fraction of mortality attributable to heat exposure[2]; unlike other heat-related mortality causes (e.g., cardiovascular and respiratory),[4] heat stroke is directly related to heat exposure. Moreover, heat stroke mortality is likely the most sensitive outcome for society during heat episodes, providing immediate and visible evidence of the dangers of heat in the media. Thus, heat stroke could be considered in heat-health warning systems and action plans as a sentinel for the severity of heat episodes. As shown in eTable 1; http://links.lww.com/EDE/C57, the largest heat stroke mortality was reported during the summer of 2003.

A major strength of the current study was the availability of long-time series data sets from all provincial capital cities of Spain, which has enabled this countrywide assessment. As limitations, we acknowledge the lack of verification of coding of cause of death and lack of individual age and sex data. Also, we used ambient temperature from city monitoring stations as an exposure measure, which may not correctly reflect the personal susceptibility to heat.

In conclusion, high temperature in summer is strongly associated with increased heat stroke deaths, despite a small proportional contribution of heat stroke deaths to overall mortality. In addition, it provides an immediately visible warning of more general high risk. This evidence is relevant to the development of prevention strategies because if climate change leads to increased summer temperatures,[18] heat stroke mortality might be expected to increase.

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