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Short-term effects of air temperature on mortality and effect modification by air pollution in three cities of Bavaria, Germany: A time-series analysis

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HIGHLIGHTS

- We examined the association between daily air temperature and cause-specific mortality in Bavaria, Southern Germany.
- Emphasis was also on effect modification by age and ambient air pollution.
- Temperature-mortality relationships were non-linear for all cause-specific mortality categories showing U- or J-shaped curves.
- Results also pointed to the importance of considering effect modification by age and ozone in assessing temperature effects on mortality.

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ABSTRACT

Background: Air temperature has been shown to be associated with mortality; however, only very few studies have been conducted in Germany. This study examined the association between daily air temperature and cause-specific mortality in Bavaria, Southern Germany. Moreover, we investigated effect modification by age and ambient air pollution.
Methods: We obtained data from Munich, Nuremberg as well as Augsburg, Germany, for the period 1990 to 2006. Data included daily cause-specific death counts, mean daily meteorology and air pollution concentrations (particulate matter with a diameter < 10 μm [PM_{10}] and maximum 8-h ozone). We used Poisson regression models combined with distributed lag non-linear models adjusting for long-term trend, calendar effects, and meteorological factors. Air pollutant concentrations were categorized into three levels, and an interaction term was included to quantify potential effect modification of the air temperature effects.
Results: The temperature–mortality relationships were non-linear for all cause-specific mortality categories showing U- or J-shaped curves. An increase from the 90th (20.0 °C) to the 99th percentile (24.8 °C) of 2-day average temperature led to an increase in non-accidental mortality by 11.4% (95% CI: 7.6%–15.3%), whereas a decrease from the 10th (−1.0 °C) to the 1st percentile (−7.5 °C) in the 15-day average temperature resulted in an increase of 6.2% (95% CI: 1.8%–10.8%). The very old were found to be most susceptible to heat effects. Results also suggested some effect modification by ozone, but not for PM_{10}.
Conclusions: Results indicate that both very low and very high air temperature increase cause-specific mortality in Bavaria. Results also pointed to the importance of considering effect modification by age and ozone in assessing temperature effects on mortality.

1. Introduction

Periods of extreme hot or cold temperatures have shown adverse effects on mortality (Barnett et al., 2012; Basu, 2009; D'Ippoliti et al., 2010). As an example, the August 2003 heat wave in Europe caused at least 22,000 deaths in Western Europe (Kovats and Kristie, 2006). However, not only heat waves or cold spells, but also increases or decreases in more moderate temperatures contribute to the observed

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Abbreviations: df, Degrees of freedom; dlnm, Distributed lag non-linear models; GCV, Generalized cross validation; ICD-9, International classification of disease 9th revision; ICD-10, International classification of disease 10th revision; PM, Particulate matter; PM_{10}, Particulate matter with an aerodynamic diameter < 10 μm; 95% CI, 95% confidence interval.

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temperature-related mortality (Analitis et al., 2008; Basu, 2009; Goldberg et al., 2011). City- or region-specific exposure–response relationships for temperature and mortality are commonly described to be V-, U-, or J-shaped (Hajat and Kosatky, 2010). Moreover, the temperature–mortality relationship varies greatly by geographic, climate, and population characteristics such as social or demographic factors (Ebi et al., 2006; Liu et al., 2011). Vulnerability to temperature effects may be affected by e.g. age or gender (Hajat et al., 2007; Stafoggia et al., 2006; Xu et al., 2012; Yu et al., 2010). Also, people with underlying cardiovascular, cerebrovascular and respiratory diseases but also other disorders seem to be more susceptible (Basu, 2009; Gasparrini et al., 2012b.

Although the association between air pollution and mortality or morbidity is well established (Pope and Dockery, 2006; Rückerl et al., 2011), only a few studies on temperature effects have considered air pollution as a confounder or effect modifier. While in some studies particulate matter (PM) and ozone were found to account for a part of the increase in mortality (Baccini et al., 2008), others did not find evidence of confounding by air pollution (Basu et al., 2008). Also, only a few studies suggested that ozone and PM may interact with air temperature to affect mortality (e.g. Park et al., 2011; Pattenden et al., 2010; Qian et al., 2008; Stafoggia et al., 2008b). Both pollutants may act as an effect modifier and amplify especially the effects of high temperatures on mortality (Ren et al., 2006, 2008).

An analysis of the short-term associations between air temperature and mortality needs to account for the fact that the mortality risk depends not only on exposure to current day's temperature, but also on temperature exposures of previous days up to weeks (Anderson and Bell, 2009). Moreover, the exposure–response relationship often is non-linear and different response functions may apply at different lag periods (Goldberg et al., 2011). In addition, the use of multi-city analyses, which pool the results from different cities, has become very popular in recent years. Thereby, traditional methods rely either on a simplification of the exposure–response relationship assuming a linear association beyond a threshold or on using non-linear representations such as splines or polynomials with estimates reduced to a simple comparison between two specific temperatures (Gasparrini et al., 2012a).

In this study, we investigated the association between air temperature and different causes of mortality in three cities of Bavaria, Southern Germany. We used distributed lag non-linear models, where the city-specific estimates are then combined in the second stage using techniques based on multivariate meta-analysis. Moreover, we investigated which age and gender groups are affected the most by heat or cold as well as if ambient air pollution modifies the temperature–mortality relationship.

2. Material and methods

2.1. Study area and population

The study population comprised residents of Munich, Nuremberg, and Augsburg, Bavaria, who died in the cities between 1990 and 2006. Although all cities lie within Bavaria, there are differences between the cities regarding socio-economic and demographic factors. Munich is the largest Bavarian city with about 1.3 million inhabitants (in 2006) in an area of around 500 km^2 (Appendix Fig. 1) (Bavarian State Office for Statistics and Data Processing, https://www.statistik.bayern.de/statistik/bevoelkerungsstand/). The old-age-dependency ratio in 2005 was 26.4%, and the unemployment rate amounted to 9.8%. Nuremberg, the second-largest city in Bavaria, is located about 170 km north of Munich. The area of the city of Nuremberg had 186.5 km^2 with about 500,000 inhabitants (in 2006). In 2005, the old-age-dependency ratio in Nuremberg amounted to 32.1%, and the unemployment rate was about 14.9%. Finally, Augsburg – located about 70 km north-west of Munich – had about 260,000 inhabitants (in 2006) in an area of 145 km^2. The old-age-dependency ratio in 2005 was 32.4%, and the unemployment rate amounted to 15.0%.

All cities lie in a temperate zone. Foehn winds from the Alps can raise temperatures sharply within a few hours in Munich and Augsburg, even in the winter. A feature of all cities is that there is little air conditioning in homes but that the buildings are well-heated during cold periods (usually mid-October until mid-April, with December to February being the coldest periods of the year) (Diefenbach et al., 2010).

2.2. Mortality data

We obtained death counts for Munich, Nuremberg, and Augsburg from the Bavarian State Office for Statistics and Data Processing. Data included date of death, cause of death, and age. We chose the categories <85 years vs. ≥85 years for analysis as recent literature suggests that heat and cold risks increase with successive age groups, with the greatest risks by far occurring in those 85+ years (Hajat et al., in press; Yu et al., 2011). For the death causes, we used the International classification of disease (ICD)-9 codes for the period 1990–1997 and ICD-10 for the years 1998–2006. We obtained deaths from non-accidental causes (ICD-9 code: 1-799; ICD-10 code: A00-R99), due to cardiovascular diseases (ICD-9: 390-459; ICD-10: I00-I99), and respiratory diseases (ICD-9: 460-519; ICD-10: J00-J99).

2.3. Meteorological and air pollution data

Hourly meteorological data were obtained from the German Weather Service and the Bavarian Environment Agency and included air temperature, relative humidity and barometric pressure. For Munich, we obtained meteorological data from three locations – one monitor located at the airport Munich and two monitors located near the city center – whereas for Nuremberg and Augsburg, data from two monitors was available (Nuremberg: data were obtained from a monitor at the main train station and near the airport; Augsburg: data was available at the airport and at a site in the southern part of the Augsburg urban area). Average daily mean values were calculated with a modified “Air Pollution and Health: A European Approach” procedure (Wolf et al., 2009). We calculated 24-hour mean values if at least 75% of the hourly values were available and imputed missing 24-hour means of single days of one monitor by a weighted average of the other monitors. If these values were also not available, the average of the preceding and the following day was taken. We did not impute missing values for longer periods. We further calculated apparent temperature, a measure of individually perceived discomfort due to a combination of temperature and humidity (Kalkstein and Valimont, 1986).

We obtained data on air pollutants (particulate matter with an aerodynamic diameter less than 10 μm — PM$_{10}$ and ozone) in each city from monitoring sites of the Bavarian Air Monitoring Network. For Munich, data on PM$_{10}$ and ozone were available from five and two locations, respectively. For Augsburg and Nuremberg, PM$_{10}$ data could be obtained from two monitoring sites, whereas ozone data was only available at one location. All monitoring sites were located in the urban areas of the cities. Until 1999, total suspended particles were measured at the stationary urban monitoring sites and scaled down by a factor of 0.83 to derive PM$_{10}$. Beginning from 2000 on, PM10 was directly assessed. Ozone data were available on an hourly basis, whereas PM$_{10}$ was available on a 3-hourly basis. We calculated 8-hour maximum values for ozone and daily mean values for PM$_{10}$ if at least 75% of the observations were available. Average daily mean values were again calculated using the approach described above.

2.4. Influenza data

We obtained data on influenza epidemics from the German Influenza Working Group (http://influenza.rki.de/Default.aspx) in the form of a weekly doctor's practice index for each winter season (October through