Uncovering the Age Structure of Temperature-Related Mortality in Germany from 2000 to 2023

Carlotta Dietrich* and Roland Rau*†

University of Rostock †Max Planck Institute for Demographic Research

Background

Extreme temperatures accounted for the highest proportion of deaths from natural disasters in Europe between 1970 and 2012 [1]. Numerous studies have investigated the effects of climate change and heat waves on mortality [2–6]. This paper examines how temperature impacts mortality in Germany and the age-specific pattern of mortality risk.

Data and Methods

Estimating temperature effects on mortality requires regional daily mortality data. This paper uses German all-cause daily mortality counts for each of the 16 Federal States from the Federal Statistical Office of Germany. The data are structured into broad age groups (under 75, between ages 75 and 84, 85 years and older). Daily mean temperatures originate from the German Weather Service. The data were restricted to the observation period from January 1, 2000, to December 31, 2023.

The relationship between temperature and mortality was quantified using a two-stage framework. In the first stage, we modeled region-specific estimates using Distributed Lag Non-linear Models (DLMs). This methodology, developed by Armstrong (2006) and Gasparrini et al. (2010, 2017), is essential for this analysis as it concurrently accounts for both the non-linear exposure-response curve and the complex, delayed (lagged) effects of temperature exposure on mortality [7–9]. The method utilizes flexible smoothing functions and includes built-in model selection procedures, reducing bias from a priori model specifications. A cross-basis function defines the two dimensions of the relationship: the exposure-response and the lag structure. We specified the following parameters: the exposure-response was modeled using a penalized spline with nine degrees of freedom and the lag structure was modeled with a penalized spline with ten degrees of freedom, capturing mortality effects up to 25 days after the initial exposure [7, 9].

From the first-stage cumulative associations, we computed the attributable risk for both heat and cold. We applied the forward perspective proposed by Gasparrini and Leone (2014) [10]. In the second stage, the estimated region-specific cumulative temperature-mortality associations were pooled using a multivariate random-effects meta-analytical model [11]. This process constructed an overall exposure-response curve for the whole of Germany, comprising the mean curves of all regions weighted by the precision of their respective estimates. This approach also allows for the quantification of heterogeneity.

Results & Discussion

Finding 1: The mechanisms of temperature-related mortality are similar across age groups but differ in magnitude. The overall temperature-mortality association follows a J-shaped curve, increasing steeply at both cold and heat extremes, with heat having the stronger effect on mortality risk. This vulnerability is highly age-dependent: the older the age group, the steeper the association. The lag structures (visualisations included in the full-length article) also differ by age and temperature. For cold, the elderly show a short-term mortality displacement (a delayed risk increase). For heat, the population aged over 75 shows a harvesting effect (a brief drop in risk) within the first week.

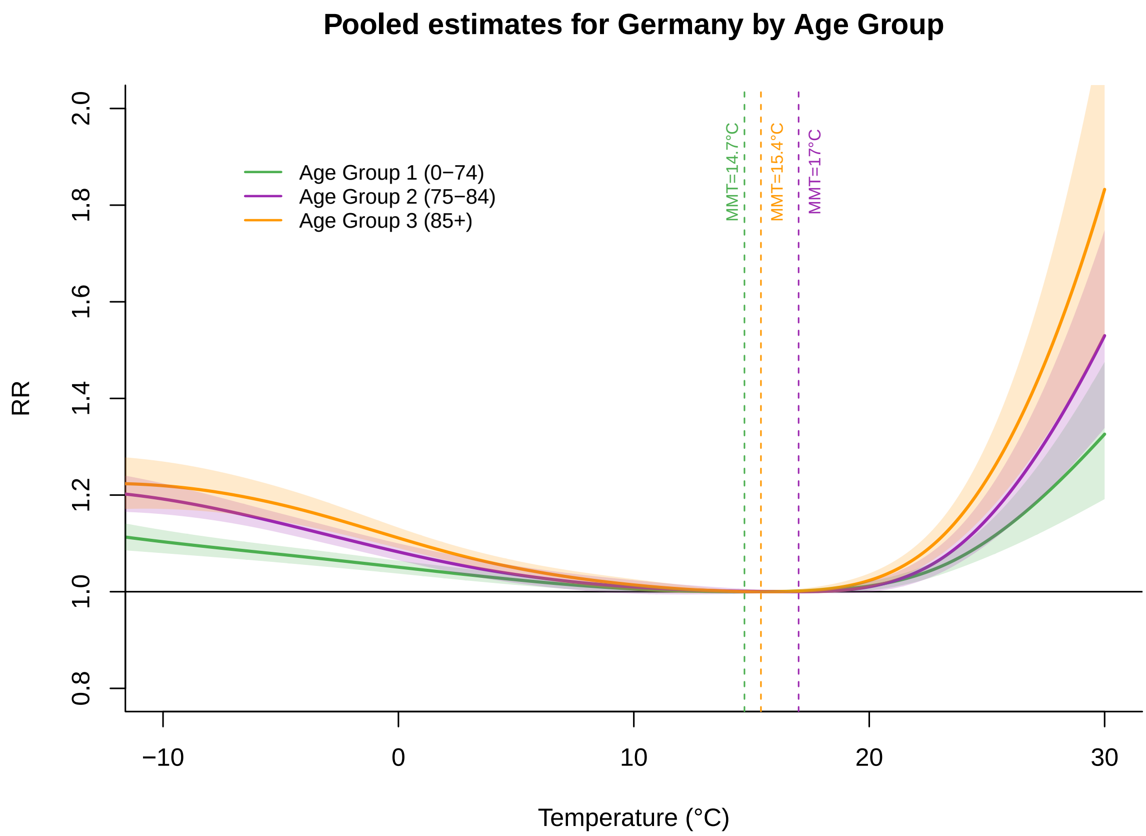

Figure 1: Pooled Temperature-Mortality Associations by Age Groups 2000-2023

Finding 2: Excess mortality due to outdoor temperature has declined across all age groups, with the strongest decline in cold mortality among the oldest age group, who nevertheless remain the most vulnerable to increasing heat risks.

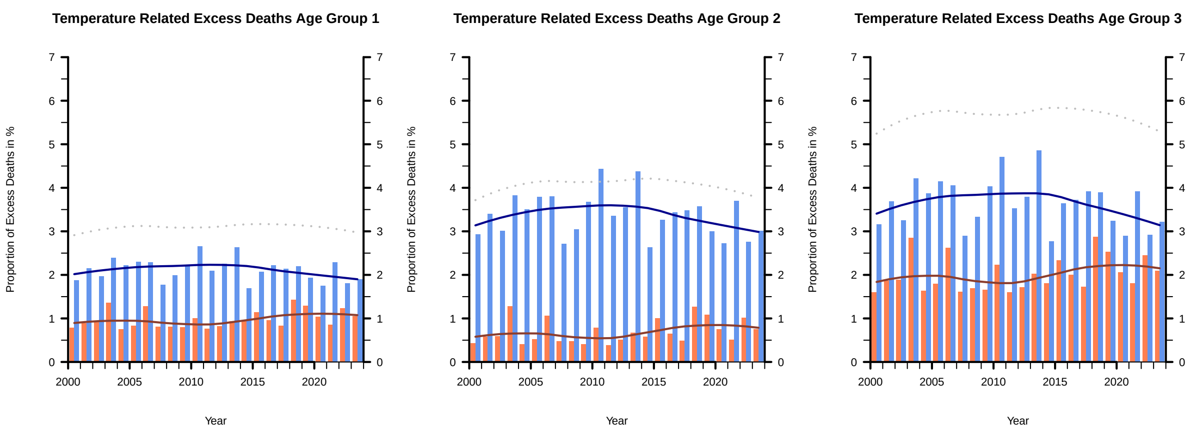

Figure 2: Proportion of Attributable Deaths to Non-Optimal Temperatures by Age Groups from 2000-2023 for Germany

Finding 3: The regional disparities follow distinct patterns for cold and heat exposure. There is a strong north-south gradient of cold excess mortality, whilst the heat clearly affects the most urban and densely populated federal states (e.g., Berlin, North Rhine-Westphalia).

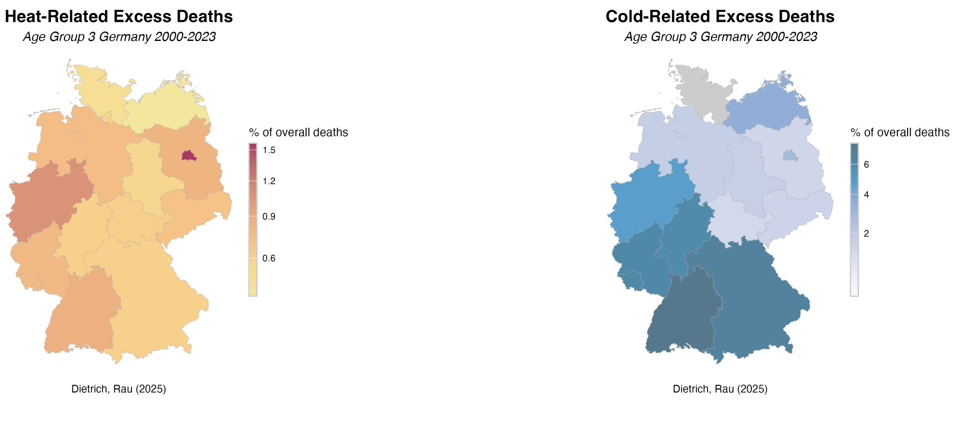

Figure 3: Attributable Deaths for Population aged 85+ (2000-2023)

Whilst this analysis uncovered valuable insights into the age structure of temperature-related excess deaths in Germany, some questions remain unanswered. Further research will explore the seemingly paradoxical heat-related mortality proportions in the 75–84 age group. Additionally, further exploration of causes of death may provide valuable context for this research.

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