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ORIGINAL PAPER

Mortality attributable to heat and cold among the elderly in Sofia, Bulgaria

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Abstract

Although a number of epidemiological studies have examined the effects of non-optimal temperatures on mortality in Europe, evidence about the mortality risks associated with exposures to hot and cold temperatures in Bulgaria is scarce. This study provides evidence about mortality attributable to non-optimal temperatures in adults aged 65 and over in Sofia, Bulgaria, between 2000 and 2017. We quantified the relationship between the daily mean temperature and mortality in the total elderly adult population aged 65 and over, among males and females aged 65 and over, as well as individuals aged 65–84 and 85 years or older. We used a distributed lag non-linear model with a 25-day lag to fully capture the effects of both cold and hot temperatures and calculated the fractions of mortality attributable to mild and extreme hot and cold temperatures. Cold temperatures had a greater impact on mortality than hot temperatures during the studied period. Most of the temperature-attributable mortality was due to moderate cold, followed by moderate heat, extreme cold, and extreme heat. The total mortality attributable to non-optimal temperatures was greater among females compared to males and among individuals aged 85 and over compared to those aged 65 to 84. The findings of this study can serve as a foundation for future research and policy development aimed at characterizing and reducing the risks from temperature exposures among vulnerable populations in the country, climate adaptation planning and improved public health preparedness, and response to non-optimal temperatures.

Keywords Temperature · Heat · Cold · Mortality · Bulgaria

Introduction

The impacts of temperature on human mortality are of substantial public health concern globally and studies of temperature and mortality are increasingly carried out across many regions of the world. A large body of recent epidemiologic evidence has linked both hot and cold temperatures to elevated risk of mortality, with respective impacts varying substantially by country (Aboubakri et al. 2019; Curriero et al. 2002; Gasparrini et al. 2015; Keatinge et al. 2000; Ma et al. 2014; McMichael et al. 2008; Pascal et al. 2018; Rodrigues et al. 2019; Smith and Sheridan 2019; Son et al. 2016; Ye et al. 2012). Studies that have investigated mortality impacts across the full temperature spectrum have found that, in most locations, moderate hot and cold temperatures represent most of the total health burden while cold temperatures are responsible for a greater overall mortality burden than hot temperatures (Åström et al. 2018; Gasparrini et al. 2015; Pascal et al. 2018; Rodrigues et al. 2019; Son et al. 2016; Yang et al. 2016).

A number of epidemiological studies have examined the effects of non-optimal temperatures on mortality in central and eastern Europe in recent years. In Estonia, Orru and Åström (2016) reported cumulative relative risks of 1.2 (95% CI: 1.1–1.3) for heat, defined as an increase in temperature from the 75th to 99th percentile and of 1.2 (95% CI: 1–1.4) for cold, defined as a decrease from the 25th to 1st percentile. Another study that evaluated cold-related mortality in Tallinn, Estonia,

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and Riga, Latvia (Åström et al. 2019), reported cold-related attributable fraction of 7.4% (95% CI: 3.7–17.5) in Tallinn and of 8.3% (95% CI: 0.5–16.3) in Riga. Heat waves in Riga were associated with an increase of 10% to 20% in the risk of all-cause mortality, depending on the heat wave definition used, compared to days with normal temperature. The impact was more pronounced in the 65 years and over age group where heat wave–related mortality was reported to be between 12 and 22% (Pfeifer et al. 2020). An association between heat waves and elevated mortality risk was also reported in Poland, with individuals aged 65 years and over being more susceptible to heat wave–related mortality than younger individuals (Graczyk et al. 2019). In Bucharest, Romania, there was a 0.9% (95% CI: 0.4–1.3) increase in mortality for each °C decrease in temperature below 22 °C and a 3.3% (95% CI: 2.4–4.3) increase in mortality for each °C increase in temperature above 22 °C (McMichael et al. 2008).

Sofia is the capital and the largest city in Bulgaria and has a humid continental climate with cold winters and hot summers (Kottek et al. 2006). Evidence about the mortality risks associated with exposures to hot and cold temperatures in Bulgaria is scarce. Two studies have previously evaluated these risks in Sofia using data from 1996 to 1999. Pattenden et al. (2003) reported a mortality increase of 3.5% (95% CI: 2.2 to 4.8) for each °C rise above the 95th centile of the 2-day mean and mortality increase of 1.8% (95% CI: 0.59 to 3.90) for each °C below the 10th centile of the 2-week mean temperature. McMichael et al. (2008) reported a U-shaped temperature-mortality relationship with higher death rates at colder temperatures. The study reported a 2.9% (95% CI: 2.1–3.7) increase in mortality for each °C increase in temperature above 16 °C and a 0.9% (95% CI: 0.4–1.5) increase in mortality for each °C decrease in temperature below 16 °C (McMichael et al. 2008). Neither study evaluated differences by age group or sex.

A number of studies have concluded that the effects of non-optimal temperatures on mortality can be modified by age and sex, among other demographic characteristics. Older age has been consistently associated with higher risks from heat exposure while the evidence of differences in risk between age groups with regard to cold exposures has been less conclusive (Benmarhnia et al. 2015; Liu C et al. 2015; Pattenden et al. 2003; Son et al. 2019; Ye et al. 2012). Similarly, the existing evidence regarding the role of sex as an effect modifier of the temperature-mortality associations is inconclusive. Some studies report higher mortality risks associated with exposure to non-optimal temperatures for women while others report greater impacts for men or no differences between men and women (Achebak et al. 2019; Bai et al. 2014; Goggins et al. 2013; Liu C et al. 2015; Moghadamnia et al. 2017; Ng et al. 2016; Son et al. 2019).

In this paper, we apply recently developed methods (Gasparrini and Leone 2014) to evaluate mortality attributable to non-optimal temperatures in Sofia across the entire temperature range. We quantify the total mortality burden attributable to non-optimum ambient temperatures, as well as the relative contributions from mild and extreme heat and cold among adults aged 65 or older in Sofia, Bulgaria, by age groups and sex using data from 2000 to 2017. The findings of this study can inform the future development of local and international policies aimed at reducing the burden of temperature-related mortality, improving public health preparedness and climate adaptation.

Methods

We obtained daily all-cause mortality for adults aged 65 years or older and daily mean temperature data for Sofia, Bulgaria, from 2000 to 2017 from the National Statistical Institute (2020) and the National Institute of Meteorology (2020), respectively. During this period, 135,962 deaths were reported in adults aged 65–84 years of which 67,245 among males and 68,717 among females. In total, 53,800 deaths were reported among adults over 85 years of age of which 19,418 among males and 34,382 among females. The average mean, maximum, and minimum temperatures during this period were 11 °C, 16.7 °C, and 6 °C, respectively. We quantified the relationship between the daily mean temperature and mortality in the total elderly adult population aged 65 and over as well as among individuals aged 65–84 and 85 years or older using a previously established methodology (Gasparrini and Leone 2014). For this analysis, we used a distributed lag non-linear model (DLNM) with a 25-day lag to fully capture the effects of both cold and hot temperatures. The model utilizes Poisson regression allowing for overdispersion and controlling for seasonal long-term trends and day-of-week effects using a 10-df/year spline. We quantified the total attributable fraction (AF) of mortality due to non-optimal temperatures, calculating the components due to cold and hot temperatures. The AFs due to cold and hot were calculated below and above the minimum mortality temperature (MMT), respectively, as demonstrated previously for other locations (Pascal et al. 2018; Gasparrini et al. 2015; Åström et al. 2018). We also calculated mortality attributable due to mild and extreme hot and cold temperatures. The mild and extreme cold mortality AFs were calculated from the MMT to the 2.5th percentile and below the 2.5th percentile of the temperature distribution, respectively. The mild and extreme heat AFs were calculated from the MMT to the 97.5th percentile and above the 97.5th percentile of the temperature distribution, respectively. We used R version 3.6.1 and the package DLNM (Gasparrini 2020).

Results

Temperature-mortality relationships

Figure 1 a displays the temperature-mortality curves for the total elderly population aged 65 and over in Sofia, Bulgaria. The associations between temperature and mortality have a stretched U shape, with higher mortality risks at low temperatures compared to high temperatures. The temperature-mortality curves by sex presented on Fig. 1 b had a similar shape. Both men and women experienced more elevated mortality risks at low temperatures compared to high temperatures. The overall mortality risks were slightly higher for women across the temperature spectrum. Figure 1 c presents the temperature-mortality relationships by age group. The overall mortality risks were higher for older adults aged 85 or older compared to adults aged 65–84, particularly at the extreme ends of the temperature spectrum. The histograms included in each panel represent the distributions of the daily averages of mean temperatures between 2000 and 2017.

Fractions of all-cause mortality attributable to moderate and extreme hot and cold temperatures

The attributable fraction (%) of mortality due to different temperature conditions is provided in Table 1. Minimum mortality percentiles (MMPs) ranged between 76% (males over 85) and 79.5% (females aged 65–84). Overall, 12.3% (95% CI: 7.3–16.8) of the mortality in the elderly population was due to non-optimal temperatures during the studied period between 2000 and 2017. Most of the temperature-attributable mortality was from moderate cold (10.9%; 95% CI: 5.8–15.6), followed by moderate heat (1.1%; 95% CI: 0.5–1.6), extreme cold (0.6%; 95% CI: 0.4–0.7), and extreme heat (0.3%; 95% CI: 0.1–0.4). We found that females experienced a greater burden of temperature-related mortality, as evident by the calculated total, hot and cold attributable fractions, compared to males in both age groups investigated in this study. Overall, 9.8% (95% CI: 2.2–16.3) of the total deaths among males were temperature-related compared to 14.4% (95% CI: 8.1–20.5) among females. 1.2% (95% CI: 0.4–2) of the temperature-attributable mortality was due to hot temperatures in females compared to 0.9% (95% CI: 0–1.7) in males. The attributable fraction of mortality due to cold was 8.9% (95% CI: 1.6–16) among males compared to 13.4% (95% CI: 6.7–19.5) among females. We also found that both older males and females experience a greater burden of temperature-related mortality compared to their younger counterparts. Among females aged 85 years or older, 1.8% (95% CI: 0.6–3.2) and 14.1% (95% CI: 2.1–24) of the mortality was attributable to hot and cold temperatures, respectively, in contrast to the 0.9% (95% CI: 0–1.8) attributable to heat and 12.8% (95% CI: 4–20.2) attributable to cold among females aged 65 to 84. The attributable fractions of hot and cold were 1.6% (95% CI: − 0.2 to 3.1) and 12.4% (95% CI: − 2.9 to 25) among males aged 85 or older compared to 0.7% (95% CI: − 0.2 to 1.6) and 7.4% (95% CI: − 1.9 to 15.6) among males aged 65 to 84. Although most of the mortality burden was due to exposure to cold in both age groups, these results suggest that, in the 85+ age group compared to the 65–84 age group, the increase in the attributable fraction of mortality due to cold temperatures was more modest than the increase in the attributable fraction of mortality due to hot temperatures.

Discussion

To our knowledge, this is the first study to investigate the total mortality burden attributable to non-optimum ambient temperatures, as well as the relative contributions from mild and

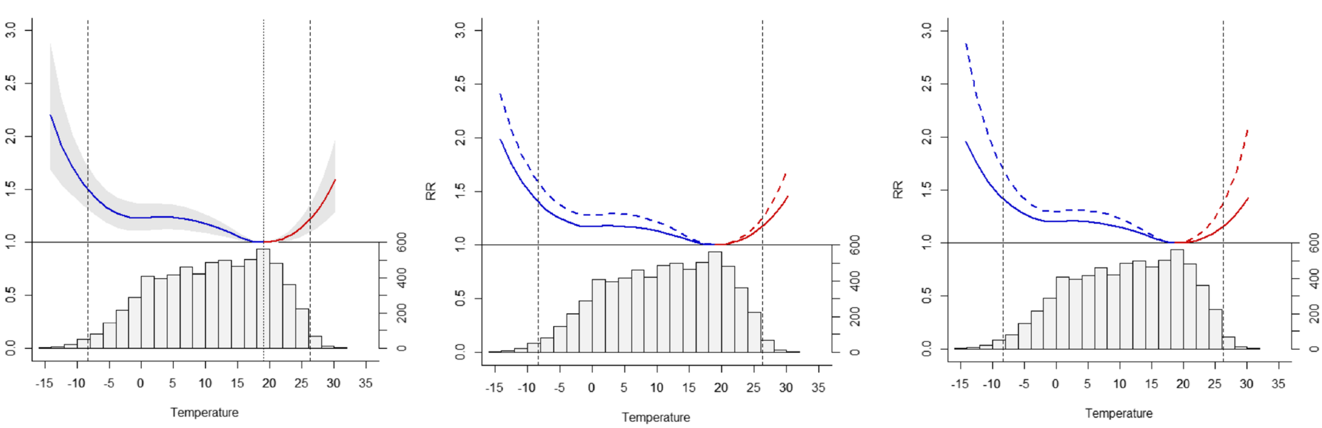

Fig. 1 Panel **a** (*left*) Overall cumulative exposure-response association, adults 65 years of age and over, Sofia, 2000–2017. MMT (centering point) displayed as a dotted vertical line and cut-off values for extreme cold and heat displayed as dashed vertical lines. Panel **b** (*center*) Overall cumulative exposure-response association, males 65 years of age and over (solid colored line) and females 65 years of age and over (dashed colored line), Sofia, 2000–2017. MMTs and 95% CIs not displayed. Panel **c** (*right*) Overall cumulative exposure-response association, adults 65–84 years (solid line) and 85 years and over (dashed line), Sofia, 2000–2017. MMTs and 95% CIs not displayed

Table 1 Attributable fractions (%) of mortality due to mild and extreme heat and mild and extreme cold with 95% empirical confidence intervals (95% CIs) in the elderly population of Sofia, Bulgaria, between 2000 and 2017 by age group and sex

Age	MMT	Total	Heat	Mild heat	Extreme heat	Cold	Mild cold	Extreme cold
Over 65 (total)	19	12.3 (7.3–16.8)	1.1 (0.5–1.6)	0.8 (0.4–1.3)	0.3 (0.1–0.4)	11.4 (6.2–16.5)	10.9 (5.8–15.6)	0.6 (0.4–0.7)
Over 65 (males)	18.9	9.8 (2.2–16.3)	0.9 (0–1.7)	0.7 (0–1.3)	0.2 (0–0.4)	8.9 (1.6–16)	8.5 (0.8–15.2)	0.5 (0.2–0.7)
Over 65 (females)	19.1	14.4 (8.1–20.5)	1.2 (0.4–2)	1 (0.4–1.6)	0.3 (0.1–0.4)	13.4 (6.7–19.5)	12.9 (6.2–19.2)	0.6 (0.4–0.9)
65 to 84	19.2	10.9 (5.3–16.8)	0.8 (0.1–1.4)	0.6 (0.1–1.1)	0.2 (0.1–0.3)	10.2 (4–15.5)	9.7 (4–15.3)	0.5 (0.3–0.7)
65 to 84 (males)	19.1	8 (−0.4 to 15.9)	0.7 (−0.2 to 1.6)	0.5 (−0.2 to 1.3)	0.2 (0–0.3)	7.4 (−1.9 to 15.6)	7.1 (−2.2 to 14.7)	0.3 (0–0.6)
65 to 84 (females)	19.4	13.6 (5.3–21.4)	0.9 (0–1.8)	0.7 (−0.1 to 1.5)	0.2 (0–0.4)	12.8 (4–20.2)	12.3 (3.4–19.7)	0.7 (0.4–1)
Over 85	18.6	15.3 (6.4–23.8)	1.7 (0.6–2.7)	1.4 (0.5–2.3)	0.4 (0.2–0.6)	13.8 (4.7–21.4)	13.1 (3.6–21)	0.7 (0.4–1.1)
Over 85 (males)	18.5	14.5 (−1.9 to 27)	1.6 (−0.2 to 3.1)	1.3 (−0.3 to 2.7)	0.3 (0–0.6)	13.2 (−2.6 to 26.1)	12.4 (−2.9 to 25)	1 (0.5–1.5)
Over 85 (females)	18.7	15.7 (4.8–25.6)	1.8 (0.6–3.2)	1.5 (0.3–2.5)	0.4 (0.1–0.7)	14.1 (2.1–24)	13.6 (2.7–23.6)	0.6 (0.1–1)

extreme heat and cold by age group and sex in Sofia, Bulgaria. We report a U-shaped temperature-mortality relationship with higher death rates at colder temperatures which is in agreement with previous research on risks associated with exposures to hot and cold temperatures in Bulgaria (McMichael et al. 2008; Pattenden et al. 2003). Studies that have investigated mortality impacts across the full temperature spectrum in other locations around the world have also reported greater mortality burden from cold temperature in most of the locations studied (Åström et al. 2018; Gasparrini et al. 2015; Pascal et al. 2018; Rodrigues et al. 2019; Son et al. 2016; Yang et al. 2016).

The results of this study indicate that the mortality risk from exposure to non-optimal temperatures is higher in older individuals, with individuals aged 85 and over experiencing a higher fraction of deaths attributable to both hot and cold temperatures compared to those aged 65 to 84. Studies that previously examined the relationship between temperature and mortality in Bulgaria have not provided a quantitative assessment of the impacts in different age groups (McMichael et al. 2008; Pattenden et al. 2003). Our findings are in agreement with the findings from most studies that have evaluated temperature-mortality associations. Some studies report a greater risk from mortality due to cold exposure among younger age groups compared to older age groups (Achebak et al. 2019; Atsumi et al. 2013; Davídkovová et al. 2014; Son et al. 2011). Occupational exposure to cold has been suggested as a possible explanation for the greater vulnerability to cold temperatures among younger age groups reported in such studies (Liu et al. 2015). However, the majority of previous studies have reported an association between older age and higher risks from both heat and cold exposure (Bai et al. 2014; Ma et al. 2014; Rocklöv et al. 2014; Son et al. 2019; Ye et al. 2012; Yu et al. 2011). For example, in a recent systematic review of studies published between 1980 and 2017, Son et al. (2019) identified age as the most consistent effect modifier of the temperate-mortality association and concluded that the elderly experience higher risks from exposure to both hot and cold temperatures.

The increased risk for temperature-related mortality among the elderly may be due in part to age-related changes in thermoregulation in response to exposure to hot and cold stress. Aging is associated with an attenuated vasoconstrictor response during cold exposure that is evident in both acral and non-acral skin (Falk et al. 1994; Kenney and Armstrong 1996; Kenney and Munce 2003). Furthermore, age-related loss of muscle mass exacerbates the impact of the attenuated vasoconstrictor response on thermal balance (Kenney and Munce 2003). During exposure to heat stress, sweating is a key human thermoregulatory response that ensures cooling of the skin and widening of the thermal gradient for heat dissipation (Yanovich et al. 2020). Aging has been associated with attenuated sweat gland outputs during heat exposure, with studies often reporting a delayed core temperature onset threshold for sweating and a reduced evaporative heat loss among older individuals (Balmain et al. 2018; Dufour and Candas 2007; Inoue and Shibasaki 1996; Sagawa et al. 1988; Shibasaki et al. 2013). Older individuals are also commonly reported to experience impaired rises in skin blood flow as well as lower time-dependent changes in skin blood flow as a result of heat exposures (Balmain et al. 2018; Kenney et al. 1997; Okazaki et al. 2002). In addition to experiencing age-related decline in thermoregulation, elderly individuals may have comorbidities, live in social isolation, and have limited access to heating, air conditioning, and social services (Bunker et al. 2016; Hajat and Kosatky 2010; Kaltsatou et al. 2018; Lane et al. 2018).

We found that women experienced a slightly higher attributable fraction of deaths for both hot and cold temperatures. Although the evidence of differences in risk between men and women has not been conclusive, a number of studies have also reported higher mortality risks associated with exposure to non-optimal temperatures for women (Achebak et al. 2019; Goggins et al. 2013; Liu C et al. 2015; Moghadamnia et al. 2017; Ng et al. 2016; Son et al. 2019). Sex differences in thermoregulation may play a role in the increased risk of temperature-related mortality we are reporting among women. Women are likely to have a lower sweating capacity compared to men for the same amount of metabolic heat generation (Gagnon and Kenny 2011; Gagnon and Kenny 2012; Gagnon et al. 2013). In addition, women have been reported to have a higher temperature threshold above which sweating mechanisms are activated (Bittel and Henane 1975). Less evidence is available regarding the physiological differences in response to cold stress. Compared to men, women have been reported to experience lower core temperatures and metabolic heat production and lesser shivering heat generation in response to cold stress (Andérson et al. 1995; Graham 1988).

This study has several limitations. First, we did not control for relative humidity and air pollution. Some previous research concluded that humidity does not change the effects of temperature on mortality (Hajat et al. 2007; Armstrong et al. 2019) while other research reported that humidity may modify the relationship between temperature and mortality (Zeng et al. 2017). Therefore, future studies should investigate the temperature-mortality associations in Bulgaria using combined indices of temperature and humidity. Frameworks for analysis such as the spatial synoptic classification (Sheridan and Kalkstein 2004; Hondula et al. 2014) that also take into consideration additional weather variables could also be utilized in future studies. Some studies have also suggested possible interactive effects between temperature and air pollution (Nawrot et al. 2007; Ren et al. 2008; Anderson and Bell 2009; Qin et al. 2017; Li et al. 2012). These effects could be further investigated with data from Bulgaria.

Another limitation of the study is that outdoor conditions may not always be an accurate indicator of personal exposure. Nguyen et al. (2014) found that indoor and outdoor temperatures are well correlated only at warmer outdoor temperatures. Although a comprehensive statistic is not available, temperature-related deaths often occur indoors. For instance, most heat-related fatalities during 2003 heat wave in France were found to occur indoors (Fouillet et al. 2006) and exposure to high indoor temperatures is often recorded as an underlying cause of death during extreme heat events (Robine et al., 2008; Semenza et al. 1996). In New York City, about 25% of the cases of cold-related illness and death occur indoors and the majority of cold-related deaths and illnesses occur outside of periods of extreme cold (Lane et al. 2018). Since most of the temperature-attributable mortality among the elderly in Sofia is due to moderate cold according to this study, further investigation of the relationships between indoor temperature and mortality as well as household use of heating systems may provide valuable evidence towards better characterizing and reducing this mortality burden.

Additional research is also needed on the impacts of temperature and morbidity of non-communicable diseases in Bulgaria, as well as the risk factors of subgroups vulnerable to non-optimal temperatures. Finally, this study did not investigate projected temperature-related mortality in Sofia. Extreme weather events such as heat waves are likely to become more frequent and/or more intense with human-induced climate change (Hoegh-Guldberg et al. 2018). Therefore, the burden of temperature-related mortality due to extreme temperatures may increase in the future. Further studies should investigate the projected temperature-related mortality in the region under various climate models and scenarios.

We hope that this study can help improve public health preparedness and reduce the burden of temperature-related mortality by informing the development of relevant local and international policies. It can also inform research and policy development aimed at climate adaptation and modeling of the future impacts of non-optimal temperatures. Initiatives addressing public health preparedness and response as well as climate adaptation in Bulgaria are already underway (WHO 2019; MEW 2019).

Conclusions

To our knowledge, this is the first study to provide a comprehensive assessment of the effects of moderate and extreme hot and cold temperatures on mortality in Sofia, Bulgaria. The findings of this study can serve as a foundation for future research that characterizes the risks from temperature exposures among vulnerable populations in the country. This work can also aid the development of local and international policies aimed at improving public health preparedness and reducing the burden of temperature-related mortality. Finally, the presented findings can be helpful in deriving projections about the future mortality impacts of non-optimal temperatures and inform climate adaptation planning.

Code availability The code used in this study can be provided along with the publication or upon request.

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Data availability The data used in this study are available from the corresponding author on reasonable request.

Compliance with ethical standards

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

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