**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 morality 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

**DECLARATIONS**

**Funding**

This study was partially funded by the Frontiers of Science Program at Columbia University. In addition, AG and FS were supported by the Medical Research Council-UK (Grant ID: MR/M022625/1), the Natural Environment Research Council UK (Grant ID: NE/R009384/1), and the European Union’s Horizon 2020 Project Exhaustion (Grant ID: 820655).

**Conflicts of interests/Competing interests**

The authors declare that they have no competing interests.

**Availability of data and material**

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

**Code availability**

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

**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. 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).

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. Two studies have previously evaluated these risks in the capital city Sofia using data from 1996 to 1999. Pattenden and colleagues (2003) reported a mortality increase of 3.5% (95% CI 2.2 to 4.8) for each degree Celsius rise above the 95th centile of the two-day mean and mortality increase of 4.2% (95% CI 3.4 to 5.1) for each degree below the 10th centile of the two week mean temperature. McMichael and colleagues (2008) reported a U-shaped temperature-mortality relationship with higher death rates at colder temperatures. 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)

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). 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 and the National Institute of Meteorology, respectively. During this period, 135962 deaths were reported in adults aged 65-84 of which 67245 among males and 68717 among females. 53800 deaths were reported among adults over 85 of which 19418 among makes and 34382 among females. 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.

**RESULTS**

**Temperature–mortality relationships**

Figure 1A displays the temperature–mortality curves for total elderly population aged 65 and over in Sofia, Bulgaria. The associations between temperature and mortality has a stretched U shape, with higher mortality risks at low temperatures compared to high temperatures. The temperature-mortality curves by sex presented on Figure 1B 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 1C 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.

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**Figure 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.

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

The attributable fraction (%) of mortality due to different temperature conditions are 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 morality 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: -0.2-3.1) and 12.4 % (95% CI: -2.9-25) among males aged 85 or older compared to 0.7 % (95% CI: -0.2-1.6) and 7.4 % (95% CI: -1.9-15.6) among males aged 65 to 84. Finally, although most of the mortality burden was due to exposure to cold, the attributable fraction of mortality due to hot temperatures was over twice as high in the 85 + age group compared to the 65-84 age group compared to a more modest increase in the attributable fraction of mortality due to cold temperatures.

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| **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 (-0.4-15.9) | 0.7 (-0.2-1.6) | 0.5 (-0.2-1.3) | 0.2 (0-0.3) | 7.4 (-1.9-15.6) | 7.1 (-2.2-14.7) | 0.3 (0-0.6) |
| **65 to 84 (females)** | 19.4 | 13.6 (5.3-21.4) | 0.9 (0-1.8) | 0.7 (-0.1-1.5) | 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 (-1.9-27) | 1.6 (-0.2-3.1) | 1.3 (-0.3-2.7) | 0.3 (0-0.6) | 13.2 (-2.6-26.1) | 12.4 (-2.9-25) | 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) |

**Table 1.** Attributable fractions (AFs) 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.

**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 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 attributable 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 and colleagues (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 nonacral skin (Falk Bet al. 1994; Kenney et al. 1996; Kenney et al. 2003). Furthermore, age-related loss of muscle mass exacerbates the impact of the attenuated vasoconstrictor response on thermal balance (Kenney et al. 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 Aet al. 2007; Inoue et al. 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 et al. 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 woman hasn’t 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 Cet al. 2015; Moghadamnia et al. 2017; Ng et a. 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 (44-46). In addition, women have been reported to have a higher temperature threshold above which sweating mechanisms are activated (Bittel al. 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 et al. 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 a. 2014) that also take into consideration additional weather variables could also be utilized in further studies. Some studies have 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 should 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 and colleagues (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 are often reported to occur indoors. For instance, most heat-related fatalities during 2003 heatwave 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 at al. 2018). Since most of the temperature-attributable morality among the elderly in Sofia is from moderate cold according this 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 are likely to become more frequent 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 the 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.

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