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Public health vulnerability to wintertime weather: time-series regression and episode analyses of national mortality and morbidity databases to inform the National Cold Weather Plan for England

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Abstract

Objectives: To inform development of Public Health England's Cold Weather Plan (CWP) by characterising pre-existing relationships between wintertime weather and mortality and morbidity outcomes, and identification of groups most at risk.

Study design: Time-series regression analysis and episode analysis of daily mortality, emergency hospital admissions, and accident and emergency visits for each region of England.

Methods: Seasonally-adjusted Poisson regression models estimating the percent change in daily health events per 1°C fall in temperature or during individual episodes of extreme weather.

Results: Adverse cold effects were observed in all regions, with the North East, North West and London having the greatest risk of cold-related mortality. Nationally, there was a 3.44% (95% CI: 3.01, 3.87) increase in all-cause deaths and 0.78% (95% CI: 0.53, 1.04) increase in all-cause emergency admissions for every 1°C drop in temperature below identified thresholds. The very elderly and people with COPD were most at risk from low temperatures. A&E visits for fractures were elevated during heavy snowfall periods, with adults (16-64 years) being the most sensitive age-group. Since even moderately cold days are associated with adverse health effects, by far the greatest health burdens of cold weather fell outside of the alert periods currently used in the CWP.

Conclusions: Our findings indicate that levels 0 ('year round planning') and 1 ('winter preparedness and action') are crucial components of the CWP in comparison to the alerts. Those most vulnerable during winter may vary depending on the type of weather conditions being experienced. Recommendations are made for the CWP.

Keywords: Cold weather, winter, temperature, mortality, morbidity, time-series

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Introduction

Cold-related mortality and morbidity remains a significant public health problem in many parts of the world, including the UK.(1) Thousands of deaths occur in the UK from cold weather each year.(2) In addition, many people visit GPs and hospitals during winter with a range of cold weather-related health problems.(3, 4) Cold weather directly leads to increases in heart attacks, stroke, respiratory disease, influenza, falls and injuries, and hypothermia.(5-8)

Many of these impacts are predictable and largely preventable. England does not compare well with other northern European countries in this respect.(9) Countries with cooler winter climates are often better prepared for winter, with better-insulated, well-heated housing, and warm outdoor clothing.(10)

Prompted by these observations and recent harsh winters, Public Health England (PHE) introduced in 2011 a Cold Weather Plan (CWP) for England. The plan aims to avoid the adverse health effects of winter by raising public awareness and triggering actions by health and social care services and other public health agencies and professionals who are in contact with those most at risk from cold weather. The plan is underpinned by a system of cold weather alerts developed with the Met Office in order to trigger interventions when severe winter weather (either low temperatures or widespread snow and ice) is forecast. The CWP has great potential to save lives and to reduce annual pressures on health and social care systems during the busiest months of the year. However, implicit in such an assertion is that actions are implemented during the most harmful weather conditions and that those most vulnerable are correctly identified.

This paper presents findings from an epidemiologic analysis of retrospective data assessing the explicit effects of weather factors on wintertime health. The aim is to characterise the impacts of low temperatures and extreme weather events on mortality and morbidity outcomes in order to provide a baseline level of current cold-related health burdens against which any future impacts of CWP implementation can be compared. It identifies sub-groups of the population most at risk during wintertime weather, and provides new evidence on the health burdens associated with the alert thresholds used in the CWP.

Methods

Data

Health information was obtained from 3 national databases:

1. All deaths occurring in England during 1st Jan 1993 – 31st Dec 2006, obtained from the Office for National Statistics. More recent years of data were not available.
2. All emergency hospital admissions occurring in England during 1st April 1997 – 31st March 2011, obtained from the Health and Social Care Information Centre.
3. Visits to Accident & Emergency (A&E) departments in England during 1st April 2007 – 31st March 2011, obtained from the Health and Social Care Information Centre.

Each health outcome was aggregated by date and Government region to create a time-series of the daily number of events for each region of England. Based on expected risk groups, the series were stratified by the following age-bands: children (0-15 years), adults (16-64 years), and 3 elderly groups (65-74 years, 75-84 years, 85+ years). For mortality and hospital admissions data, the series were also stratified by the following disease groups: all cardiovascular (CVD) diseases [ICD10 codes: I00-I99], all respiratory diseases [J00-J99], chronic bronchitis and chronic obstructive pulmonary disease (COPD) [J40-J44] and external causes [V01-Y99]. For A&E data, the following diagnosis categories were considered: 'dislocation/fracture/joint injury or amputation', 'cardiac conditions', and 'respiratory conditions'. Data from other countries of the UK were not considered since the CWP is only operational in England.

The exposure data consisted of daily minimum, maximum and mean temperatures for the same time periods, with the mean temperature being derived from the average of the daily minimum and maximum values. These data were recorded by Met Office land surface stations obtained through the British Atmospheric Data Centre website. For each measure, one composite series was created for each region by combining data from stations recording measurements on at least 75% of days during the study period and using a previously published imputation method to deal with missing values.(11) On average, 20 stations contributed data to each regional series. Mean temperature was found to be a better predictor of cold-related health than either minimum or maximum temperature, and so is used here as the main exposure measure. Daily measures of resting snow depth for one site in each region were also obtained from the Met Office.

Statistical analysis

Assessment of the acute (i.e. day-to-day) relationships existing between weather and health events consisted of two components:

1) Time-series regression analysis to characterise the temperature-health relationships occurring throughout the winter months.
2) Episode analysis to assess the impact of individual episodes of extreme weather, in particular periods of heavy snowfall.

The time-series regression analysis was conducted on the daily mortality and emergency hospital admissions data, using previously published modelling choices.(11) Regression models assumed a Poisson distribution for each outcome, with standard errors adjusted for overdispersion. Slow-changing seasonal patterns in the health counts (unrelated to temperature) and any secular trends were controlled for using splines of time, using 7 degrees of freedom per year of data analysed. Splines functions are a series of polynomial curves (in this case cubic) joined together to flexibly model changes in the health series. This means that variations in the size of the population during the study period are inherently controlled for since such changes occur only slowly over time. Indicator terms were used to model variations by day-of-week, and influenza activity was adjusted for using weekly counts of laboratory-based influenza A notifications recorded by PHE. Since analysis was undertaken at regional level, no adjustment for air pollution was made. Following confounder control, the relationship between temperature and health indicators was assessed graphically, again using spline functions. As effects of low temperatures can be delayed, all impacts distributed up to 4 weeks following initial exposure were considered. In general, the graphical relationships indicated a gradual linear increase in the risk of a cold-related health event once mean temperatures dropped below certain threshold levels. For quantification purposes, therefore, a linear-threshold model was used, wherein there is assumed to be no risk at temperatures above the threshold value, and a linear relationship between the risk of a cold-related health event and a drop in temperature at values below the threshold. To objectively identify the cold threshold for each region, maximum likelihood estimation was used to compare models with threshold values fixed at varying temperatures. Regional estimates of risk were combined in a random-effects meta-analysis to obtain a national-level estimate.

For the episode analysis of individual periods of heavy snowfall, focus was on the daily number of A&E events as these were expected to be the most sensitive health indicator during such periods. The observed number of A&E visits during identified snowfall periods was compared to the expected number of visits, as reflected by the same time-period in surrounding years. As visitor numbers vary greatly by day-of-week, a 7-day moving average of series counts was used in comparisons. Analyses were conducted in STATA. Results are presented as Relative Risks (RR) and the percentage change in health events, which is derived as follows: (RR-1) * 100

Results

Table 1 shows summary statistics for the exposure and health data during winter months (October-March). As expected, the southern regions experience warmer winters than elsewhere. In most regions, there are approximately 3 visits to A&E departments for every 1 emergency hospital admission, and approximately 8 emergency hospital admissions for each death. Figure S1, showing the time-series of the daily number of deaths and daily mean temperature in the North East region, illustrates the greater health burdens experienced during the winter months compared with other seasons. The days with very high winter mortality are mostly due to influenza epidemics. Similar patterns are observed in the other regions. Nationally, the percentage distribution of mean daily counts of all-cause deaths by age-group was: 1.0% (0-15 years), 16.5% (16-64), 19.6% (65-74), 33.2% (75-84), 29.9% (85+); for all-cause emergency hospital admissions was: 11.7% (0-15 years), 47.1% (16-64), 13.6% (65-74), 17.0% (75-84), 10.6% (85+); and for all-cause A&E visits: 19.5% (0-15 years), 61.2% (16-64), 7.2% (65-74), 7.4% (75-84), 4.7% (85+).

Relationships between temperature and all-cause mortality and all-cause emergency hospital admissions

Figure 1 shows the seasonally-adjusted relationship between temperature (bottom axis) and the relative risk (RR) of all-cause mortality (right-hand axis) during the winter months (October-March) for each region of England. The solid middle curve represents the estimated relationship, and the dashed outer curves the 95% confidence interval. The histograms displayed behind the risk curves show the distribution of temperatures within each region, with the left-hand axis indicating the percentage of days at each of the temperature values.

An elevated risk (RR greater than 1) is observed with low temperatures in all regions, and in each case the impacts become apparent at fairly moderate values of mean temperature (4-8°C). In some regions, e.g. the North West, the threshold is well defined with little increased risk above this value, but in other regions such as the southern regions the relationship tends more towards linearity across the whole of the temperature range across winter months and so some rise in 'cold' risk is already apparent at temperatures above the identified threshold.

Table 2 quantifies these associations by displaying the percent change in mortality for every 1°C decrease in temperature below the identified threshold in each region. Although there was overlap in the confidence intervals between most regions, the North East, North West and London regions were associated with the highest effect estimates. At the national level, there was a 3.44% (95% CI:

3.01, 3.87) increase in deaths for every 1°C drop in temperature below regionally-identified thresholds.

Impacts on all-cause emergency hospital admissions (Figure S2) were also present, with thresholds observed at temperatures similar to those for mortality, however effect sizes were not as large. Nationally, there was a 0.78% (95% CI: 0.53, 1.04) increase in emergency admissions per 1°C fall below thresholds.

Modification of risk by age- and disease groups.

Adverse effects of low temperature on mortality were observed in all age groups, but risk was greatest for the very elderly: 4.34% (3.72, 4.96) for those aged 75-84 years, 4.96% (3.89, 6.04) for 85+ years. With emergency admissions, the elderly were again at highest risk, but children were at reduced risk of all-cause admission during cold days: -3.26% (-3.90, -2.62).

Cold-related deaths from respiratory diseases were particularly elevated, with a 7.61% (6.35, 8.88) rise in chronic bronchitis and COPD deaths per 1°C fall. Deaths from external causes were also sensitive to low temperature: 4.63% (1.03, 8.36), and, to a lesser extent, CVD deaths: 3.11% (2.43, 3.78). With hospital admissions, again respiratory diseases were particularly elevated, with the COPD risk being even greater than with mortality: 8.53% (7.71, 9.36).

Lagged effects of temperature

National-level estimates of the RR of all-cause mortality per 1°C drop in temperature at different lags of exposure are shown in Figure 2. The separate lag effects were estimated from a distributed lag model from 0 to 28 days, so the lag 0 risk represents the effect on mortality on the same day as exposure, lag 1 represents the effect on mortality one day later, and so on up to 28 days following exposure. This figure shows that the mortality effects of low temperatures, although not always statistically significant, do remain elevated at most lags – indicating that cold effects can be distributed over many days and weeks following initial exposure.

An increased risk in deaths is not observed on the day of exposure – indeed a cold day is associated with a reduced risk of same-day mortality. However, adverse effects become apparent from the following day onwards. Although only shown for all-cause mortality, the early peak is mostly driven by cold-related deaths from CVD and the later rise are respiratory deaths, which can be delayed by 3-3½ weeks following initial exposure. With hospital admissions, the patterns were less clear (not shown).

Attributable fractions of cold-related mortality at different temperature thresholds

Figure 3 reproduces the North East risk curve from Figure 1, but also shown underneath are the corresponding attributable fractions at different temperature thresholds to take into account the typical number of days on which the estimated RRs occur. If all days below the identified threshold of 6°C are taken to represent 100% of the cold burden in the North East, then it is observed that the more extreme cold temperature days (i.e. when alerts are issued in accordance with the thresholds used by the CWP – dashed vertical line in Figure 3) are only responsible for a small fraction of the total cold burden due to their infrequency – less than 3% of cold-related deaths in the North East occur on alert days. A similar pattern was observed in the other regions.

Episode analysis of extreme weather events

Periods of heavy snowfall, as measured by depth of resting snow, were identified during the two recent harsh winters of 2009/10 and 2010/11. Figure 4 shows the daily number of A&E visits at North East region hospitals during 2010 for the diagnosis category 'dislocation/fracture/joint injury or amputation'. Two periods of heavy snow depth in this region, 1st-10th January 2010 and 26th Nov-28th Dec 2010, were associated with an increase in visits of 23.9% (95% CI: 17.4, 30.7) and 5.5% (95% CI: 2.3, 8.7), respectively, compared to expected levels at those times of the year. Figure S3 shows impacts of the same events by age-group. Effects among the very elderly were observed to be negative or modestly increased, as were those among children where A&E numbers peaked in the summer months for this diagnosis category. It was among those of working age (16-64 years) where the highest relative increases were observed.

Increases were observed during similar snowfall periods in most other regions also during the same 2 winters (Table 3). In all cases, the second snow period was associated with a lower impact than the first snow period, even when average snow depth measurement was higher during the second event.

In general, patterns were inconsistent for A&E visits due to cardiovascular or respiratory causes, or for all-cause visits during the snowfall events. Impacts in mortality and hospital admissions outcomes were also not in evidence during these episodes (results not shown).

Discussion

Some of the main findings arising from this work and implications for the CWP are that:

- *The greatest health burdens of cold weather fall outside of the alert periods used in the CWP.* Adverse cold effects were apparent at fairly moderate values of temperature, and calculation of attributable fractions indicated that the days when a CWP alert is called (when mean temperature is forecast to be below 2°C) are responsible for only a small fraction of the cold-related mortality burden, e.g. in the North East, alert days are responsible for less than 3% of the total cold burden. This raises the question of what purpose the CWP alerts should serve. They are useful as regular reminders of the dangers of cold weather, but in terms of reducing the total health burden, it is likely that longer-term intervention strategies (e.g. improvements in housing) and the more general preparations taken throughout the winter months are more important than the acute interventions activated by the alerts. For this reason, levels 0 ('year round planning') and 1 ('winter preparedness and action') are now emphasised more in revised CWP documents.(12)

- *Cold-related health Impacts can be delayed by up to a few weeks.*
  Unlike with heat exposure, where health impacts are mostly immediate and short-lived, adverse effects of a cold day may not become immediately apparent, but the impacts may be distributed over many subsequent days following initial exposure. This indicates that *forecasts* of temperature may not be as crucial for responding to cold weather as they are for heat, but that heightened care of vulnerable individuals needs to be more prolonged.

- *Vulnerable groups differ depending on the type of winter weather conditions experienced.*
  The very elderly (75+ years) are the most vulnerable to low temperatures, but do not seem to be so during periods of heavy snowfall, where those of working age had the highest relative increases in A&E visits. The CWP now makes a clearer distinction between the different types of weather conditions, and targets advice accordingly.

Although a significant adverse cold effect was observed in all regions, the mortality risks associated with the northernmost regions of England and London were the highest. A previous study reported that populations in the east of the country may be particularly vulnerable to cold weather.(3) This may partly be due to exposure to cold winds,(13) however differences are also likely to be explained by modelling choices, such as variations in identified thresholds. This also explains why our national-level mortality cold effect estimate of 3.44% per degree decrease is smaller than estimates from studies with lower thresholds.(14) In the current study, although thresholds have been identified for each region, they only give an indication of the temperatures at which risks become most obvious. In some regions, such as those in the south (Figure 1), there is evidence that a raised risk is already apparent at temperatures above the estimated thresholds.

The apparent protective effect of cold on mortality on the day of exposure has also been observed in other populations in Europe,(15, 16) and may reflect behavioural changes taken to reduce exposure to the elements on cold days. Deaths from respiratory and external causes were most sensitive to cold weather, although CVD events occur with greater frequency. The cold-related deaths from external causes may represent cases such as hypothermia and accidents from falls. The lack of effect of snow conditions on A&E visits in the oldest age-groups is in agreement with interviews conducted among elderly individuals who stated that they tend to stay indoors during icy conditions.(17) This suggests that this group are more vulnerable to falls indoors rather than outside and associated more with low temperatures rather than slipping in snow and ice conditions.(18, 19) Low temperatures are associated with blood pressure changes in elderly people, as well as slower reaction times and bone density loss which may contribute to the risk of falls.(20)

One strength of this work is that for both the time-series regression and episode analysis, the explicit effects of weather have been quantified, separate from other seasonal factors. So the results reported are risks associated directly with exposure to weather factors rather than the 'Excess Winter Deaths' measure referred to in the CWP, which may also be reflecting increases due to circulating infections and other seasonal factors unrelated to the weather, as well as being biased in various ways.(21) Assessment of specific exposures allows for better targeting of interventions.

One limitation which may have otherwise helped to inform the discussion about differing precipitating factors for indoor and outdoor falls is that, although incident location type of A&E visit is recorded, this information was missing for most cases and so it was largely unknown whether the accident occurred at home or in a public place. Another limitation of these data is that we would not expect all components of the disease category 'dislocation/fracture/joint injury/amputation' to be sensitive to environmental factors, but this category could not be subdivided. However, this would only serve to dilute the true cold effect. Also, we did not attempt to control for air pollution, however, it has recently been argued that air pollution should not be a confounder in any temperature-health relationship.(22)

Another shortcoming is that only data up to 2006 were available for the mortality analysis. A long time-series going back to 1993 has been used here to estimate effects robustly, but the nature of the relationships and the thresholds have the potential to change over time due to socio-economic and demographic changes and adaptation measures such as improvements in housing.(23, 24) Using more recent years of data would provide the best evidence of current associations. Also, although this work was undertaken as part of a broader evaluation of the CWP, the limited number of years since the introduction of the plan provides little opportunity for epidemiologic assessment of the effectiveness of the CWP, and so to, therefore, its cost-effectiveness.(25) Nevertheless, the findings presented here establish a rigorous baseline against which any changes in the temperature-health profile as a result of CWP implementation can be determined in any future work.

In conclusion, in England there is a 3.44% (95% CI: 3.01, 3.87) increase in deaths for every 1°C drop in temperature below regionally-identified thresholds. Some impacts were also observed with morbidity indicators. This works reveals that the greatest health burdens of cold weather fall outside of the level 2 alert periods used in the CWP to trigger acute interventions. Robust quantitative evidence on the effectiveness of the CWP in reducing cold-related health impacts will only be available once the system has been in operation for a number of years, and the type of relationships described here can be re-evaluated in the years post-intervention to assess any changes.

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Reference list

1. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015; pii: S0140-6736(14)62114-0. doi: 10.1016/S0140-6736(14)62114-0.
2. Goodwin J. A deadly harvest: the effects of cold on older people in the UK. Br J Community Nurs. 2007;12(1):23-6.
3. Hajat S, Bird W, Haines A. Cold weather and GP consultations for respiratory conditions by elderly people in 16 locations in the UK. Eur J Epidemiol. 2004;19(10):959-68.
4. McGregor GR, Walters S, Wordley J. Daily hospital respiratory admissions and winter air mass types, Birmingham, UK. Int J Biometeorol. 1999;43:21-30.
5. Donaldson GC, Keatinge WR. Mortality related to cold weather in elderly people in southeast England, 1979-94. BMJ. 1997;315(7115):1055-6.
6. Keatinge WR. Winter mortality and its causes. Int J Circumpolar Health. 2002;61(4):292-9.
7. Barnett AG, Dobson AJ, McElduff P, Salomaa V, Kuulasmaa K, Sans S. Cold periods and coronary events: an analysis of populations worldwide. J Epidemiol Community Health. 2005;59(7):551-7.
8. Conlon KC, Rajkovich NB, White-Newsome JL, Larsen L, O'Neill MS. Preventing cold-related morbidity and mortality in a changing climate. Maturitas. 2011;69(3):197-202.
9. Fowler T, Soutgate RJ, Waite T, Harrell R, Kovats S, Bone A, et al. Excess Winter Deaths in Europe: A multi-country descriptive analysis. Eur J Public Health. 2014;Jun 11. pii: cku073.
10. Marmot Review Team. The health impacts of cold homes and fuel poverty. 2011. http://www.instituteofhealthequity.org/projects/the-health-impacts-of-cold-homes-and-fuel-poverty
11. Armstrong BG, Chalabi Z, Fenn B, Hajat S, Kovats S, Milojevic A, et al. Association of mortality with high temperatures in a temperate climate: England and Wales. J Epidemiol Community Health. 2011;65:340-5.
12. Public Health England. Cold weather plan for England 2015. 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468160/CWP_2015.pdf
13. Carder M, McNamee R, Beverland I, Elton R, Cohen GR, Boyd J, et al. The lagged effect of cold temperature and wind chill on cardiorespiratory mortality in Scotland. Occup Environ Med. 2005;62:702-10.

14. Hajat S, Kovats RS, Lachowycz K. Heat-related and cold-related deaths in England and Wales: who is at risk? Occup Environ Med. 2007;64(2):93-100.
15. Pattenden S, Nikiforov B, Armstrong BG. Mortality and temperature in Sofia and London. J Epidemiol Community Health. 2003;57(8):628-33.
16. Analitis A, Katsouyanni K, Biggeri A, Baccini M, Forsberg B, Bisanti L, et al. Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. Am J Epidemiol. 2008;168(12):1397-408.
17. Jones L, Mays N. The experience of potentially vulnerable people during cold weather: implications for policy and practice. Public Health. Submitted.
18. Jacobsen SJ, Sargent DJ, Atkinson EJ, O'Fallon WM, Melton LJ. Population-based study of the contribution of weather to hip fracture seasonality. Am J Epidemiol. 1995;141:79-83.
19. Mirchandani S, Aharonoff GB, Hiebert R, Capla EL, Zuckerman JD, Koval KJ. The effects of weather and seasonality on hip fracture incidence in older adults. Orthopedics. 2005;28:149-55.
20. Collins KJ. Effects of cold on old people. Br J Hosp Med. 1987;38(6):506-8, 10-2, 14.
21. Hajat S, Kovats RS. A note of caution about the excess winter deaths measure. Nature Climate Change. 2014;4:647.
22. Buckley JP, Samet JM, Richardson DB. Commentary: Does Air Pollution Confound Studies of Temperature? Epidemiology. 2014;25:242-5.
23. Carson C, Hajat S, Armstrong B, Wilkinson P. Declining vulnerability to temperature-related mortality in London over the 20th century. Am J Epidemiol. 2006;164(1):77-84.
24. Hamilton I, Milner J, Chalabi Z, Das P, Jones B, Shrubsole C, et al. Health effects of home energy efficiency interventions in England: a modelling study. BMJ Open. 2015;5:e007298.
25. Chalabi Z, Hajat S, Wilkinson P, Erens B, Jones L, Mays N. Evaluation of the Cold Weather Plan for England: Modelling of Cost-Effectiveness. Public Health. In press.